Science Through Technology Enhanced Play: Designing to Support Reflection Through Play and Embodiment

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Abstract: We describe the design of the Science through Technology Enhanced Play (STEP) project. In STEP, we explore the potential for dramatic play, a form of activity that is familiar to early elementary students, in promoting meaningful reflection about scientific content. We report on the first round of design experiments conducted with 18 second-grade students who explored states of matter within the STEP environment. Pre-post analyses indicate that the majority of students learned the content and demonstrate how the design promotes distinct forms of reflection. In particular, it appears that students attended to the projected simulation at key moments in play and then reflected on the underlying rules of the content.

Keywords: science education, technology, embodiment, elementary school, reflection

Introduction

In recent years, growing recognition of the role of embodiment in cognition coupled with the increasing availability of technologies that track bodily movement has led to a proliferation of instructional designs intended to support learning through embodiment (Lindgren & Johnson-Glenberg, 2013). These designs frequently rely on the mapping between specific bodily motions and related content, such as using a swinging arm gesture to reflect a pendulum (Segall, 2011 as cited in Lindgren & Johnson-Glenberg, 2013) or looking at data of one's own motion for mathematical trends (Lee & DuMont, 2010). However, focusing narrowly upon the alignment between an individuals' embodied activity and a concept in this way obscures how groups of students might interact to collectively embody more complex phenomena, and how the organization of activity may influence student learning. To address these contexts, we build upon sociocultural theories of learning (John-Steiner & Mahn, 1996) which highlight the importance of the sociocultural context in individual learning and cognition, and thus suggest that there is value in moving beyond embodied actions to examine how the organization of activity impacts the value that students glean from their actions. To demonstrate the value of this approach, we describe the design of the Science through Technology Enhanced Play (STEP) project, which builds on our previous work with the Learning Physics through Play (LPP) environment. STEP explores the potential for dramatic play, a form of activity that is familiar to early elementary students, in promoting meaningful reflection about scientific content. To illustrate this process, we also report on the first round of design experiments conducted with 18 second-graders using STEP to explore states of matter.

Background and design approach

Our design work is premised on sociocultural theory which suggests that all new knowledge is encountered first in social interaction before being "appropriated" by an individual (John-Steiner & Mahn, 1996). The notion of appropriation encapsulates the idea that learners' understanding of new concepts is shaped by their perception of how the new concept is used within a rich social context in addition to their prior experiences with similar concepts. While all social contexts can lead to learning, play is a particularly powerful space for early elementary students (Vygotsky, 1978). From a sociocultural perspective, the defining characteristic of play is that it always includes an imaginary situation and a set of rules (Vygotsky, 1978). The imaginary situation creates a context in which children can explore the rules in ways that were not previously accessible to them, allowing play to function as informal inquiry (Youngquist & Pataray-Ching, 2004). In fact, children often spend more time articulating and negotiating the rules of a play situation than actually "playing" their parts (Cooper, 2009). In this way, play is a social and collaborative activity that supports and encourages reflection.

Dewey (1933) defined reflection as "active, persistent, and careful consideration of any belief or supposed form of knowledge in the light of the grounds that support it and the further conclusions to which it extends" (p. 91). More recently, Davis (2003) suggested that reflection can focus on several general subjects: on students' specific actions, on the activities or tasks in which they are engaged, on the content being studied, or on students' knowledge in general. In other words, reflection is an opportunity for multiple kinds of sense making within activity. Our design work within the STEP environment is premised on the assumption that these multiple forms of reflection, which are promoted through play and can be seen both in students' interactions and teacher-led discussions, are central to the process through which students can explore new concepts. In our previous work with the Learning Physics through Play (LPP) environment (Enyedy, Danish, Delacruz, & Kumar, 2012; Enyedy, Danish, & DeLiema, in press), we demonstrated that play-based mixed reality environments are able to support early elementary students in reflecting on the rules of Newtonian physics, affording them an opportunity to explore concepts that are typically considered too challenging.

The STEP environment also uses mixed reality tools to combine students' embodied play activities with the power of computer simulations and thus support them in reflecting on scientific content. Mixed reality environments use software to combine elements of the real world with virtual objects and capabilities. In the STEP environment, students move around in the classroom space, play-acting how they believe water would behave in a range of circumstances such as a freezing cold day. They can see their activity projected into a computer simulation where an avatar of a water particle is displayed over the video display (see Figure 1). This avatar not only supports playful activity as a costume might, but also includes a representation of important information necessary for the students' inquiry such as the temperature in the imagined space or the energy level of the individual particles. The information represented is intended to direct students' attention towards key aspects of the content being studied. As the students role-play in the STEP environment, they make choices about how real particles might behave, and those choices are reflected within the projected simulation.

Figure 1. The STEP classroom environment

Thus, STEP helps to create a participatory simulation (Colella, 2000; Wilensky & Stroup, 1999) or participatory model (Danish & Saleh, 2011; Enyedy et al., 2012), where students work with peers to explore how their individual behaviors as particles of water influence the current state of the simulated matter. As the students collectively reflect through talk upon the nature of their shared model, they refine their understanding of the content. The STEP environment moves beyond our prior work by capitalizing on advances in computer vision to track multiple students without the need for physical markers, exploring a new content area (states of matter rather than Newtonian physics), and by more explicitly examining the role of play and embodiment in supporting students' reflection. In order to research the relationship between students' collective embodied play within the STEP environment and the kinds of reflection that it afforded, we designed a short 3-activity sequence intended to support students in learning about states of matter while engaging with the environment in several distinct ways. In particular, our goal was to help students to understand that matter is made of particles, and to begin exploring the relationship between energy, the motion of particles, and state change. We also wanted to target misconceptions such as the belief that the properties of particles are the same as the properties of the matter at a macroscopic level (Talanquer, 2009), and to overcome assumptions about particles changing or ceasing to exist at key points in state transitions such as when water boils.(Treagust et al., 2010).

Activity designs

We designed three sequential activities to begin exploring the potential of the STEP environment: 1) macro-level costume play, 2) particle-embodiment play and 3) energy-embodiment play (see Table 1). While all activity is in some sense "embodied", our design focuses on promoting opportunities for groups of students to move throughout the classroom, using their positions and motions to shape the activity. We also aimed to promote dramatic play by encouraging students to take on a role within an imaginary situation and to explore their role somewhat freely. In costume play, students were first introduced to state change at the macroscopic level via the costumes that they selected. This activity was intended to introduce the technology, help students see dramatic play as a science activity, and to help them reflect on the relationship between temperature and changes in states of matter (e.g., heat causes ice to melt). In the particle-embodiment play, students play-acted as particles and explored how the space between each particle and its movement impacted the state of matter that was displayed on the screen (figure 2). In the energy-embodiment activity, students took on the role of energy sources (represented as small glowing balls), observing how energy impacted the behavior of simulated particle on the screen. In addition to allowing students to explore the role of energy in state change, we wanted to see how shifting from the perspective of being the object under study (the particle) to influencing that object would impact students' play and reflection. All of the activities required the students to discuss and coordinate their actions, and in the final two activities the teacher explicitly worked with the students to reflect on the "rules" that characterized their movement by recording these rules and revising them through their activity.

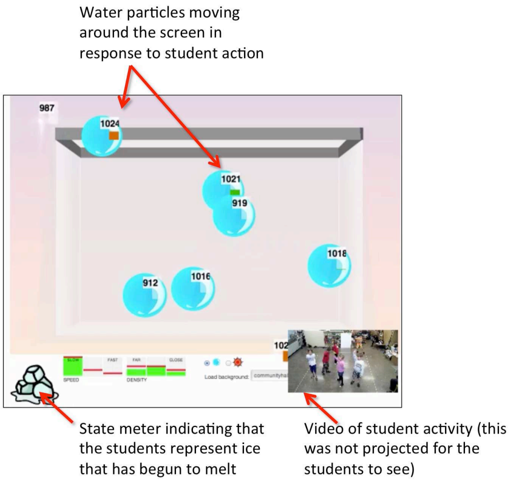

Figure 2. STEP software environment

Table 1: The three play activities

Play Activity Name and Description	Learning goals
Macro-level costume play: Students selected characters and play-acted how they would move past an ice wall.	• Introduction to macroscopic state changes. • Introduction to causal relationship between temperature and state change.
Particle-embodiment play: Students acted out how they felt particles of water might behave.	• Matter is made up of tiny particles, which are too small to see. • Particles are always in motion. • Motion and arrangement of particles affect state of matter.
Energy-embodiment play: The students acted out being sources of energy and attempted to change the state of matter.	• Temperature is related to heat energy which affects the motion of particles (e.g., higher temperature = higher energy) • A change in energy is required for state changes to occur.

Methods

Participants and data sources

This study was implemented with 18 second-grade students (ages 7-8, 12 male, 6 female) at a public school in a small mid-western town. Students were divided into four groups. Each of the two participating teachers worked with a group of three students and a group of six students in a separate classroom where STEP was installed to explore the impact of group size upon our design. All groups participated in 3 activity sessions averaging 30 minutes per session.

Examining student learning

To examine student learning, we developed a pre-post structured interview, which included a range of questions about the nature of matter and how it changes state. We coded student responses using a scheme based on Paik, Kim, Cho, and Park (2004) to reveal the depth of student content understanding. Two sets of ordered codes (i.e., superficial to deep understanding) of matter (MT) and change of matter (CT) were established (see table 2).

Table 2: Summary of the matter-type and change-type codes

Codes	Illustrative examples
MT1: Observable characteristics of matter	It's just stacked up, ice is hard, water can just sinks down to the bottom but ice has to stack.
MT2: Understand that matter is conserved	Really it's the same amount as this picture from that picture, cause it melts.
MT3: Initial discussion of particles (includes incorrect articulations)	The particles are frozen... on a hot day it melts the particles can't handle that much coldness.
MT4: Accurate discussion of particles (no incorrect articulations)	They [water] move a lot, medium fast, not like (makes whizzing-like noise), that would be gas.
CT1: Superficial description of state change	Water changes into ice.
CT2: Some mechanism involved	It [The glass shaking] sorta rocks me around.
CT3: Energy or temperature as mechanism	Energy made me [particle] move faster.
CT4: Particle behavior as mechanism	Gas [particles] coming together a little bit more [to make liquid].
CT5: Relates energy to particle behavior and state change	Well, there has to be snow or something like that to get it cooler, and get the energy not flowing as much, so they [particles] move a little.

We conducted a chi-squared analysis to determine if there were a higher proportion of content codes from the pre interviews to the post interviews. To facilitate this analysis, each question was coded for either state changes (CT) or matter (MT), with the exception of one question, where both codes can occur. We then collapsed several codes into macro (MT1, MT2, CT1, CT2, CT3) and micro descriptions (MT3, MT4, CT4, CT5). The former represents students' observable properties and simple causal mechanisms of change of states, whereas the latter includes students' characterizations of particle behavior of matter and the relationship between energy, particles and state changes. We expected that students would articulate more micro-level descriptions than macro after the implementation.

Analyzing the design in action

In our analysis of the video data, we first sought to sub-divide students' activity into interactive sequences which manifest distinct normative structures and rules (Carspecken, 1996). We identified two general sequences in our data: classroom sequences and embodiment sequences. A classroom sequence is defined by teacher-directed activity, where instructions or discussions occur. An embodiment sequence differs from the classroom sequence in that it is predominantly characterized by play, 1) an imaginary situation and 2) rules that govern actions. These rules are instantiated when students take on different roles such as being a fire fairy, particles or energy and play-acting within that role. The software was also embedded with some rules regarding particle behavior, which shaped how students approached their roles. Embodiment sequences sometimes begin with a planning phase, where students discuss what they intend to do as part of their play, and may also narrate their actions as their play unfolds. Unlike a classroom sequence, both students and teacher are equally likely to begin or direct the sequence, observations made can be spontaneous, and students interact with each other and the screen, rather than with the teacher. All the videos were watched and categorized according to the two interactive sequences. These sequences were re-watched to identify specific sub-episodes within the sequences and to determine if there were patterns that emerged, particularly with reference to the type of reflection evident in students' talk and the accuracy of content talk that accompanied each sub-episode within a sequence. Episodes were coded in terms of the kinds of reflection that they included. To identify reflection, we modified the sub-categories suggested by Davis (2003) to better reflect our data and identified three types: 1) on actions (discussions of what students just did or what they will do next); 2) activities (broader activities that are defined by the design, such as being particles, being energy), and 3) reflection on content knowledge.

Results

Learning gains

After engaging with the STEP activity, students were able to articulate accurate descriptions of particle behavior in different states of matter, as well as the relationship between energy, particle behavior and state changes (see

Table 4). This included a significantly higher proportion of micro-level descriptions than macro-level descriptions after the implementation, X2 (3, N =524) = 142.18, p <.001 indicating that students generally provided more robust and normative accounts for how matter changes after engaging in the STEP activities.

Table 4: Proportion of codes from pre and post interviews

	Macro	Micro	Other	Don't Know
Pre	191 (73%)	20 (8%)	21 (8%)	29 (11%)
Post	90 (34%)	148 (56%)	10 (4%)	15 (6%)

The role of the STEP activities in supporting reflection

General patterns in reflection

Across all of the 4 groups and all 3 days of activities, students' patterns of reflection were relatively consistent. Each group began with a classroom sequence before alternating between embodied sequences where students played with the STEP software and paused to debrief their experience in a new classroom sequence. The initial classroom sequence consisted primarily of reflecting on students' prior knowledge of the concept being studied that day in response to teacher prompts. In all of the embodiment sequences, students' reflections were focused primarily on their physical actions. Content-oriented reflections in this sequence typically occurred only when prompted by the teacher and included a shift in orientation in their play from rather fluid and chaotic to more structured and deliberate. Once prompted, students' replies did mirror the kinds of depth displayed during the classroom sequences. It is also during this phase that some of the students' non-normative beliefs about how particles behave were indicated as they called out predictions regarding how they expected their behavior to impact the simulation. In general, it appears that the students did notice interesting patterns of relations during the embodied play sequence, but required teacher support to articulate many of them.

During the debriefing classroom sequences, which occurred immediately after their embodied play, the students' shifted to focus on reflection of the actions they just completed in their play, and how those related to their prior knowledge. In these cases, the students' reflections on their prior knowledge also became more specific, such as moving from discussing energy rather abstractly to discussing specific sources of energy and how they impacted the particles in motion and thus transformed the state of matter being displayed

Reflection during costume play

Students' reflection during the costume play activity largely focused on the stories that they were constructing with the costumes. They appeared confident in the fact that temperature leads to state change, and assumed that heat led ice to melt to water, and eventually led water to evaporate. The students were quite comfortable with the idea that an avatar would follow them around the screen and quickly focused on creating narratives together. Therefore, we will not describe this sequence in detail, as it seemed to primarily serve the role of introducing the students to the STEP software. However, one accidental event is worthy of note. In 3 of the 4 sessions, the teacher asked the students to create a play about how they would get through an ice wall. The students immediately focused on the avatars that represented the ice, or a heat source such as a fire sprite. However, one teacher inadvertently suggested they find a way "over" the ice wall. Those students shifted their attention to the animal sprites that would live in the frozen wasteland that was displayed (e.g., bears and deer) and explored how they might build a bridge over the ice wall rather than trying to go through it. Those students did not discuss heat and melting until it was re-introduced by the teacher. This unintentional contrast and its resulting shift in focus helps to underscore the relationship between rules and students' engagement with the content.

Reflection during particle play

During the particle play activity, each student was represented on-screen by a particle. The students could also see a "state meter" which depicted the overall state of matter based on their movement and relative positioning. For example, if the students all stood close to each other and relatively still, the state meter displayed a block of ice. In contrast, if the students were running rapidly around the space, the state meter displayed a gas. Once the students began to notice how their behavior influenced the state meter, the teacher asked them to embody a specific state. At these times the students would begin moving around, adjusting their movement as they noticed changes in the state meter (or the absence of expected changes). Students were quite playful and would often focus on their movement without looking at the screen. For example, when becoming a "gas" the students began running around as quickly as they could, some even beginning to play tag and try to catch each other.

However, students would sporadically notice their state either because one student would look up, or the teacher would draw their attention to it. At that point, they would attempt to adapt their movement, sometimes with one student taking on a "director" role and shouting instructions. These comments often focus on their actions and rarely included conceptual explanations unless the teacher prompted for them. For example, one group noticed that even though they were moving quickly the state meter still depicted a liquid. A student then suggested that they were too close together and needed to spread out. At this direction, the students stopped to spread out as far as the space would allow and then began running all in the same direction to attempt to create a gas. Thus, while students' talk during the activity appeared primarily focused on their specific actions, it appears likely that at least some of the students were reflecting upon the reason behind those actions. These details then became more explicit when the teacher asked the students to articulate their rules while debriefing.

While the rules were also articulated during debriefing sessions that occurred after the embodied play, one of our design goals was to help the students see their embodied play as a form of modeling where they could explore the content in greater detail, and notice concepts that were not previously apparent. This can best be illustrated with an example of students' exploring the question of whether molecules move when in a solid form. Students typically begin with the idea that particles only move in either liquid or gaseous states, but otherwise remain still in solid form. This is an example of an inheritance view (Talanquer, 2009), where students assume that properties of particles are equal to the observable properties of matter. This conceptualization of particles in solid state is a particularly challenging idea for students; only half of the students in the post interviews were able to articulate this accurately when asked demonstrate how the particles in solid ice behave.

The excerpt below demonstrates how the software and embodiment offers an effective way for students to better address their current conceptions. Prior to this, the facilitator had shown students a brief video about particles which depicted the particles in a solid as vibrating. Nonetheless, the students still suggested that particles within solid ice do not move. Excerpt 1 shows how the students worked with the teacher and the STEP environment to continue exploring this issue. First, we see that the students moved from their prior idea of modeling ice by hugging each other as closely as possible to recognize that a pattern (lattice) is necessary. On line 8, Adam shows the importance of the embodiment for articulating his idea by asking if he can physically demonstrate along with his peers. Initially, the students do not take note of the fact that they are still moving and in-fact they appear to be trying to hold as still as possible. However, the facilitator is then able to point (lines 12-16) how a little movement doesn't change the state meter from ice to water. The students then note, with the teacher's help, that a little movement is possible, an idea that they later re-articulate when drafting their rules about how particles behave when in solid form. One aspect of this example which is particularly compelling for us is that the students have previously watched a video of particles in solid form as a way of summarizing their earlier activity. Despite its clarity, the students persisted in their belief about ice particles remaining stationary. Fortunately, with the help of their teacher and the STEP environment, this group of students noticed that they could be stationary and yet exhibit movement.

<u>Excerpt 1: Students embodying ice</u>

1	Facilitator 1:	Do you remember the video when they showed us how the solids were arranged? Can anybody remember that in the video?
2	Adam:	They were like in a pattern.
3	Facilitator 1:	In a pattern. So when you guys were huddled together, was there a pattern when you ...
4	Students:	No...
5	Facilitator 1:	No? So how do you think we should arrange ourselves?
6	Fred:	Oh I think we should arrange ourselves into a rectangle, or square.
7	Facilitator 1:	Do we want to try it out?
8	Adam:	Uh, how many people. There could be a line of three and like, another… Can I demonstrate?
9	Teacher:	Sure.
10	Adam:	Can we stand up? Ian you can stay here. Stand in line with Ian, Mary. That's good ... [*Students arrange themselves according to Adam's instructions*].
11	Teacher:	What do we see on the screen? [*Students form ice on the interface*]
12	Facilitator 2:	So wiggle your fingers a little bit, and your toes. Are you still solid ice?
13	Students:	Yeah.
14	Teacher:	Well, that's movement.
15	Mary:	It's ba::rely movement.
16	Teacher:	Oh! Oh! Ba::rely movement

Reflection during energy play

During the energy play activity the students were represented on-screen as small suns that moved amongst a larger number of particles. If they stayed away from the particles, the particles eventually drew close together and slowed their movement, and then the state meter indicated that they had formed into ice. However, if they moved closer to the particles, the particles would slowly begin moving further and faster away, transitioning first into water and then into gas. This activity helped to highlight both the power of embodiment in our design, and the potential pitfalls to be avoided. Some students initially found the shift from particles to energy to be confusing, moving much as they had before; running around to be a gas and slowing to be a solid. However, they soon realized with the help of their teacher than they were in fact influencing the particles and thus played a different role in the environment. For example, see excerpt 2 below, which depicts the students in one group coming to understand this relationship after initially running around the space.

Excerpt 2: Students as energy

1	Facilitator 1:	Can you all line up on the back? I think that might help...
2	Students:	Yeah. [*Students move towards the back of space.*]
3	Facilitator 1:	Alright, so now you can see the energy is moving out of the way. Now let's watch what happens to the particles.
4	Carl:	The sun is moving away
5	Facilitator 1:	So they're moving real fast right now, what do you think they are?
6	Regan:	Liquid
7	Carl:	Gas. [*Students are far from the particles which slow and transition from gas to solid.*]
8	Neal:	Oh look, solid!
9	Regan:	Solid!
10	Facilitator 1:	There we go. Can someone describe, how do you know that's solid?
11	Students:	Cause it's all together!
12	Facilitator:	Ok, so now if we move the energy in so that you're starting to touch them, what do you think will happen? Step forward a little bit? [*Students step forward.*] Oh, so what's happening now?
13	Neal:	They're coming apart.

Some of the students in this group continued to find it difficult to reflect on the energy as separate from the movement of the particles. For example, when asked to "write down a note about energy" Neal suggested that "when energy moves freely, it usually means it's gas" whereas Regan noted that "whenever energy moves around, and it does not get in the way, of the gas or particles, then it ... then it can come in and turn into solid". While the facilitator re-voiced Regan's idea, stating that "I think, what you're saying is that, if you stay out of the way so that there's no energy, the particles started to slow down and stay together and become a solid," it is clear from this that the students were attending quite intensely to their own embodied role within the activity, and that some found this confusing when their embodiment played an indirect role in modeling the system (e.g., as opposed to directly acting out the movement of the particles).

One of the more successful groups appears to have resolved this tension by electing an "observer" who directed the students-as-energy in their movement while attending to the state meter. This observer helped the students to recognize their role in influencing the simulated particles more clearly, and as a result they were able to articulate the role of energy in causing particles to move, and then tying that movement to the state of matter. Thus we can see that their embodied role within the simulation was important for both the students who were able to make this connection, and for those who struggled. Given how challenging students find this concept, we view this as a promising start and will incorporate the observer role into future design iterations in order to help students to transition between perspectives as they explore the simulated system through embodied play.

Summary and significance

The initial STEP implementation was quite successful, resulting in learning gains over the course of the three technologically enhanced play scenarios. By exploring students' reflections, we are able to focus on how the STEP activities and environment support their learning effectively, as well as moments where we can continue to refine our design. From our analysis, it is clear that embodied play was central to students' sense-making activity, and yet embodiment alone was not enough. Rather, the STEP environment supported this embodiment by providing key feedback to the students as they modeled the target system, helping them to see how their movement, and the movement of their peers influenced the simulation. Furthermore, while the students appeared to notice many key principles through their embodied play, they didn't initially articulate all of these, and may not have even recognized them. Fortunately, with the help of the teacher and facilitator, the students were able to more clearly connect their observations and articulate the rules of the system. In sum, we believe the STEP environment helps to articulate how designs for embodied activity can benefit from moving beyond considerations of analogous movement (though that is still important) to include a focus on how play engaged students in reflecting on their movement, how software tools can help make the patterns in this movement more visible and relevant, and how teachers can help students to reflect more deeply upon the patterns they notice, and articulate the reasons for those patterns.

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