“Can’t Nobody Floss Like This!”: Exploring Embodied Science Learning in the Third Space

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Abstract: I present an out-of-school science study situated in a performing arts center. The design brings together a mixed-reality science learning environment with ensemble dance in a series of embodied learning activities exploring the states of matter. Building on the theoretical framework of the third space, I analyze hybrid embodied movements that highlight the diverse role the body can play in learning science. Additionally, I report on pre- and post-measures indicating participants learned targeted science concepts and hybrid embodiments supported learning one particularly unintuitive concept. Finally, I make a case for the design of embodied learning activities that extend beyond considerations of analogous movements to include local and diverse movements that, if recognized as legitimate, expand possibilities for learning and doing science.

Keywords: science, performing arts, technology, elementary education

Introduction

Educational research has increasingly recognized ways in which the body can play an important role in learning and engaging with disciplined practices (Alibali & Nathan, 2012; Azevedo & Mann, 2018; Goodwin, 2000). More recently, our natural tendency to use the body as a learning resource has been paired with motion-tracking technologies (e.g., mixed-reality environments) in the design of individual and collective instructional contexts that leverage embodiment (Danish et al., 2015; Lindgren & Johnson-Glenberg, 2013). Often these designs focus on some degree of congruency between body movements and the content to be learned, for example pushing arms forward to represent applying force to an object in a Newtonian simulation (Enyedy, Danish, & DeLiema, 2015). However, a focus on cleanly mapping bodily movement to content potentially ignores a diversity and potential hybridity of embodiment and how more informal ways of moving can support learning.

Notions of diversity and hybridity in learning build on the theoretical construct of the third space (Gutiérrez, 2008). The third space highlights the transformative power of hybridity—how informal and formal discourses (e.g., home and school) can become interconnected to productively challenge what counts as knowledge and how knowledge is produced. Hybridity in language practices has been well explored through the lens of the third space (Gutiérrez, Baquedano-López, & Tejeda, 1999; Gutiérrez, Rymes, & Larson, 1995). I aim to extend the exploration of hybridity to consider how embodiment can bring together informal and formal ways of moving and knowing (Ma, 2016). In this case, I view hybrid embodiments as those that merge dance-based ways of moving with science. Specifically, I explore how one fun and familiar embodied action (known as “flossing”) can represent a scientific phenomenon to act as a shared resource for participation and sense-making in collective science learning activities. To unpack the role of hybridity and embodiment in learning, I describe the design of a 10-lesson science activity sequence that integrated mixed-reality science learning with ensemble dance. I report on the results of the activity sequence and discuss how hybrid forms of embodiment supported learning by connecting dance movements throughout the intervention to performances on pre- and post-measures. I highlight how the unintuitive scientific concept that solid particles vibrate (i.e., they have high energy but are stationary) is explored that through a variety of ways of moving. I aim to answer the following research questions:

1. How do participants use familiar dance movements to represent and build upon scientific understandings of states of matter?
2. How do these movements support performance on pre- and post-measures?

Background, design, and community

To illustrate the role of hybridity in embodied learning, I describe the design of a science learning research study that took place in a performing arts center. In contrast to science classrooms, all activity surrounding science learning focuses on local music and dance practices in which the adults and children participate. Hybridity, therefore, is made possible in the ways in which participants make sense of the conceptual practices of science in relation to the local, everyday ways of knowing and doing in dance. The intervention design explicitly connects two thematically and conceptually related ensemble learning activities: mixed-reality science models and dance (Figure 1). Within ensemble settings, individuals learn to take on a role within a system (e.g., a collective dance), but much of their understanding and performing requires moving and thinking relatively to one another (Ma & Hall, 2018). In science, I explore ensemble learning through what I call collective embodied models. I build on the successful Science Through Technology Enhanced Play (STEP) mixed-reality learning environment that combines motion-tracking technology with a computational simulation (Danish et al., 2015; Danish et al., 2017; Enyedy et al., 2017). STEP allows participants to move across the room pretending to be water particles. The technology tracks their respective movements in real-time to generate a virtual representation of what state of matter those particles would collectively create. Through engaging with and analyzing the simulation, participants learn to coordinate their movement in certain ways to build, test, and refine models that predict and explain the rules behind the particulate nature of matter (Schwarz et al., 2009).

In dance, ensemble learning takes the form of learning and performing choreography. As part of a performing arts program, participants learned, rehearsed, and refined an ensemble dance based on the music and themes of the Disney production *Frozen*. The choreography and materials (e.g., props and costumes) integrate science concepts related to why and how particles move in solid, liquid, and gas. The dance was iteratively rehearsed and refined as participants learned more about the particulate nature of matter and as they practiced an increasingly more complex dance routine. Like the STEP environment, ensemble dance requires working collectively toward representing an idea, feeling, or experience. Since the dance was tied to communicating scientific understanding, it made visible important concepts and supported additional discussion and reflection about what was learned. Yet, the dance was not "scientific." Though it conveyed aspects of science, the *Frozen* dance was held accountable to dance criteria (e.g., timing, rhythm, presentation, etc.).

Figure 1. Representing ice in STEP (left) and dance (right).

Methods

Participants and data sources

Over the course of a summer performing arts program, two groups of participants (n=35, ages 6-8, 34 black or African-American and 1 white) participated in the activity sequence summarized in Table 1. Of these, 18 assented and received parent consent to participate in the study. Participants were divided into two groups. Each group participated in a 45-minute STEP activity, which was immediately followed by *Frozen* dance practice and rehearsal. Each activity had a science learning goal related to rules governing the states of matter, which progressed from macroscopic to microscopic. The STEP activities were facilitated by the research team with support from local staff. The "Frozen Dance" was choreographed a camp instructor. The dance was design to support the ideas from STEP, but maintained the ultimate goal of performing in front of loved ones at the end of camp during a large community event.

Throughout the planning process, the research team met regularly with the dance instructor to discuss the science content, locate overlaps and synergies, and build bridges between the two activity strands. During collaborative planning sessions, the research team and local instructor aimed to connect the science and dance in content, but also thematically through the narrative, characters, and settings from *Frozen.* Connections and similarities between the activities were explicitly communicated to students during activity introductions and debriefs, as well as emergently during key instructional moments. All activities from STEP and dance were video recorded provided consent.

Table 1: Integrated Activity Sequence

Activity Sequence	STEP Activity	Dance Activity	Learning Goal
Activity 1-2	Participants embodied energy sources and explored how energy and temperature drive observable changes in state and particle movement.	Participants learned the first phase of their dance focused on representing particle speed and distance during ice to liquid state changes.	Macro-level: Water exists in different states of matter: solid, liquid, and gas. Water can change states.
Activity 3-4	Participants took on roles as "energy wands" to explore how energy causes state changes in a snowman, Olaf from *Frozen*.	The dance introduced "magic wands" for participants to hold, accenting the dance and representing energy sources in the *Frozen* dance.	Marco-level: Energy and temperature produce state changes, i.e., giving energy causes melting and taking away energy causes freezing.
Activity 5-6	Participants build and test models to explore the relationship between particle distance and speed during state changes.	The dance introduced "Elsa gloves" for participants to wear, including discussion of how Elsa [the main character in *Frozen*] took away energy to make ice in things she touched. Participants learned the second phase of their dance representing liquid to gas state changes.	Micro-level: Develop rules for particle speed and distance in different states (e.g., identify different distances and speeds and associate them with states of matter).
Activity 7-8	Participants build and test models to explore the relationship between particle attraction during state changes.	The dance introduced sticks with streamers on the end for students to hold and represent the chaotic movement of particles in gas.	Micro-level: Particles in different states of matter are arranged differently. Particles in a solid are patterned, "stuck," and vibrating. Particles in liquid have no regular arrangement and move closely together. Particles in gas move freely at high speeds.
Activity 9-10	Participants took on roles as water particles inside of containers in the mixed-reality simulation to explore particle behavior.	Rehearsal for end of camp showcase performance.	Micro-level to macro-level: Particles in solids always keep their patterned shape, Particles in liquids keep their shape but can move around, and particles in gas move freely and can escape if a container is opened.
Wrap-up	Post-measures conducted.	Rehearsal for end of camp showcase performance.	N/A
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Methods: Interaction analysis to investigate hybridity

To understand the role hybrid embodied practices played in learning science content, I used interaction analysis to better understand ways in which participants used dance movements to navigate science concepts and vice versa (Jordan & Henderson, 1995). Due to the focus on the role of hybridity in embodied learning science, I focused video analysis on interactions during STEP activities. Nonetheless, I viewed and content logged the entire dance video corpus to better understand how embodied actions were taken up and used across these activity spaces. Within STEP, I identified constructions of the third space by observing embodiment as it related to the science (e.g., moving like water particles in the simulation) or dance (e.g., moving gracefully like water particles in dance), focusing on tensions and synergies between these two types of movements. Within these sequences of embodied activity, I transcribed the video verbatim with key attention to formal, informal, and hybrid embodiments. I then categorized and compared these sequences to others to see if any patterns emerged. From there, I flagged moments where the science content was made visible in talk or embodied action to reference with the ways participants performed on pre- and post-measures.

Methods: Science content knowledge measures

To measure content knowledge, all participants completed a multiple choice pre- and post-test. Additionally, individual pre- and post-interviews were conducted with 18 participants. Interview questions focused on supporting participants in articulating how particles (on the microscopic level) resulted in how matter behaved (on the macroscopic level). I conducted paired t-tests to determine whether students learned about the particulate nature of matter over the course of the activity sequence.

Based on the work of Paik, Kim, Cho, and Park (2004), I coded interviews for reasoning levels about state change mechanisms from circular reasoning (Level 0) or observable macroscopic features (e.g., melting) (Level 1) to unobservable microscopic relationships between kinetic energy and structures of particle movement (Level 4) (Table 2). Coding was not exclusive; any utterance may have more than one code or no codes at all, with the highest level of marking the final code. I transcribed each interview and segments of talk were labeled when participants articulated their reasoning about state changes. For each interview question, codes were applied to each participant utterance, including gestures and embodied actions. I conducted a paired t-test to examine if students' average reasoning level increased from their pre- to post-interview responses. Given my focus on hybridity in movement based on one specific concept, I report on the analysis of one interview question ("How do you think the particles in the ice are behaving?") that specifically addressed participants' experience of hybrid embodiment as it relates to science.

Table 2: State Change Coding Scheme

Interview Prompt *You might know this already, but things around us, like ice cubes and water, are made up of super tiny pieces called particles. I'm going to ask you some questions about the particles in ice (show student a large ice cube).* 1. How do you think the particles in the ice are behaving? 2. What makes you think so? *(If they mention the ice cube slide or moved around, tell them to imagine the ice is completely still.)*	
Code	Example Response
Level 0 - Circular Reasoning: any explanation for why behaviors happen without providing additional information, i.e., things happen because they are just "the way they are."	"Ice doesn't change shape because it is ice."
Level 1 - Macroscopic explanation (superficial properties): Any explanation that uses observable properties of matter.	"Ice doesn't change shape because it is hard."
Level 2 - Macroscopic explanation (energy/temperature): Any explanation that uses energy or temperature.	"Ice doesn't change shape because it is frozen."
Level 3 - Microscopic explanation (single factor): Any explanation that uses the behavior of particles in articulated reasoning, but only gives a single factor in their explanation (e.g., distance, speed, or energy).	"Ice doesn't change shape because the particles have high attraction."
Level 4 - Microscopic explanation (complex interactions): Any explanation that uses the behavior of particles in articulated reasoning with multiple connected factors in the explanation (e.g., distance and energy).	"Ice doesn't change shape because the particles have low energy so the bonds can be strong."

Findings

Overall, the integration of STEP and dance afforded participants the opportunity to explore hybrid movements that bridged fun and familiar dance embodiments with scientific ones. This hybridity also appeared to support reasoning across contexts, from dance and science activities to content knowledge post-measures. Throughout the activity sequence, participants moved their bodies in a variety of ways to support reasoning about the science. A key pattern that emerged was the role of the body in reasoning about vibration. To represent ice particles, participants used a ranged of embodied intuitions from more normative scientific embodiments (e.g., standing still and shaking or jumping) to dance-based representations (e.g., doing the "wiggle worm" or "slow-mo" dance). In this paper, I focus on "flossing" as an illustrative example of how participants used dance to reason around movement and to accent their scientific understanding in new ways.

Hybridity in embodied science learning

Because children's everyday observations of matter tend to lead their assumptions about particle behavior, it can be challenging to support learning about the observable properties of matter as they relate to particulate behavior (Talanquer, 2009). For example, children assume that particles in ice are frozen and therefore do not have energy and cannot move. In fact, solid particles do have energy and vibrate in a rigid lattice structure. While the STEP simulation is useful for supporting understandings about particle distance and movement over space, it is a challenge for young learners to understand that solid particles move but remain stationary. A number of dance-based movements provided a useful resource in exploring ideas related to vibration. The findings of this paper are focused on a specific hybrid embodiment that is taken up by participants that supported robust performances on post-measures related the particles in ice. The following excerpts illustrate one form of hybrid movement that appears to have supported learning about how particles in a solid behave. To illustrate the role of hybrid embodiment in learning about the behavior of particles in ice, Excerpt 1 details a moment when a fun and familiar dance move "the floss" is taken up to represent vibration (Table 3).

Table 3: Excerpt 1

1	Facilitator:	Let's look on the screen. How are these particles moving?
2	Peyton:	Glitchin' out.
3	Facilitator:	Glitchin' out. Right. Another way we can say that is vibrating. So, solid particles stay in place and they vibrate *((shaking arms and shoulders))*. Everybody stand up and vibrate like a solid particle would. *((Students all stand up and start to shake their bodies))*
4	PJ:	Can't nobody floss like this *((moving arms in front and behind of their body)).*
5	All:	*((Other students around PJ begin to laugh and floss))*
6	Facilitator:	Yeah, PJ! That is a good way to vibrate.

During the second week of the activity sequence, students took on roles as energy sources and observe how energy effects particles in different states. Excerpt 1 took place while participants were making observations about how solid particles are moving in the STEP simulation. One participant, Peyton described the particles as "glitchin' out" (Line 2). This bid was taken up by the facilitator as an opportunity to introduce the concept of vibration and a more normative embodied representation of standing still and shaking arms and shoulders. This embodied movement is transformed by another participant, PJ, who responded by performing the well know dance "the floss" (Line 4). Flossing is a dance move performed by standing in place still while swinging arms, with hands in fists, from the back of the body to the front and moving hips in the opposite direction (Figure 2).

Flossing was made popular on social media and exploded due to its performance in music videos and video games. While flossing was not an explicit aspect of the final choreography in the *Frozen* dance, it was an "insider" movement in the context of this performing arts center, and children could be seen flossing throughout the day (e.g., during free time and lunch). Flossing also often occurred informally during STEP activities that promoted the exploratory use of the body. However, in this instance PJ spontaneously introduced flossing to move like a solid particle in science (i.e., standing in place and vibrating). While not scientifically normative, the move to represent particles with locally recognized dance blended the scientific notion of vibration with a well-known dance. Moreover, it anchored students' embodiment in a way that legitimately maps to the verbal descriptions of vibrating particles as staying stationary but moving.

Figure 2. Choreographic movements of "the floss."

After this moment, flossing was taken up as a legitimate way to represent the trajectory of particles in ice during later activities. Beyond the overlaps in embodiment, the "unofficial" movement of "the floss" became central to how students understand particulate behavior. Hybridity both leveraged the prior knowledge and experiences of the participants as well as expanded the possible ways of knowing and moving related to science. For example, Excerpt 2 occurs toward the end the activity sequence. This activity focused on how particles in different states behave given the macroscopic conditions of an environment (e.g., a container with a lid) (Table 4). After engaging with the mixed-reality simulation as particles, the students re-represented their understanding from STEP with an embodied model. During the activity, the participants pretended the classroom was a container and the door was the lid. Beginning as ice particles, the facilitator gave the particles energy until they ran around the room as gas. Once the door was opened, all the participants ran out of the room like gas particles escaping a container.

Table 4: Excerpt 2

1	Facilitator:	If we were particles, what state of matter would we be in right now?
2	All:	Solid!
3	Facilitator:	Solid, right. Do solid particles stay totally still?
4	All:	No.
5	Lauren:	No, they vibrate! *((Participants start to shake arms and floss))*

Excerpt 2 begins with a typical instructional move of opening instruction with a content question (Line 1). At once, the participants respond with the correct answer that particles in this formation would create a solid (Line 2; Figure 3). Further probing the participants, the instructor calls for more detailed information about particles, which is returned with another collective response. Immediately after, another participant, Lauren, calls out the answer, which is next embodied by Lauren and her peers with flossing. This moment demonstrates that the original embodied connection persisted over the course of multiple activities, as many of the participants took up flossing to represent vibration in solid particles.

Figure 3. Embodied re-representation of solid particles.

Learning gains

Paired t-test results of the 10-question multiple choice measure indicate that individual participants significantly improved their general understanding about particle behavior ($t\,(17)=-7.071$, $p < 0.001$) from pre-test (mean=3.11, SD=1.9) to post-test (mean=6.44, SD=0.85).

Given the specific focus on how hybrid embodied movements supported learning, the analysis of pre- and post-interviews focused on the first question of the interview protocol: How do you think the particles in ice are moving? Paired t-test results of the highest level code applied to student responses to this question indicate that individual participants significantly advanced their reasoning ($t(17)=-8.416$, $p < 0.001$) from pre-test responses (predominately circular reasoning or superficial observations) (mean=0.944, SD=0.53) to post-test responses (single and multifactor micro-level particle behaviors) (mean=2.61, SD=0.77). Generally, in pre-interviews participants focused on macro-level properties of ice to reason around how particles in ice behaved. For example, most students gave the expected response that particles in a solid were frozen together and could not move. In post-interviews, most participants (14/18) said that solid particles vibrate (see Table 5). This result is in marked contrast to previous classroom implementations of the STEP activity sequence focused on modeling and embodied play where only half the students in post-interviews could accurately describe or demonstrate how particles in ice behave (Danish et al., 2015). While these previous implementations supported robust learning gains, participants' beliefs about ice particles persisted despite experiences in the mixed-reality science simulation. Given that pre-interviews in this and similar STEP studies showed that the groups were comparable on their prior knowledge of science, it seems that the dance context contributed to participants' ability to engage with the conceptual knowledge and practices of science. That is, the dance context that supported hybrid embodied movements appears to have supported students in moving beyond descriptions of solid particles based on a surface-level characteristic.

Table 5. Interview Responses

How do you think the particles in the ice are behaving?	Particles are frozen or don't move	Particles are vibrating	Circular reasoning
Pre-interview	13	0	5
Post-interview	4	14	0

Summary and significance

The integrated sequence of STEP and dance activities resulted in both learning gains and opportunities for participants to explore diverse forms of embodiment. By focusing on moments of hybridity, analysis traced specific movements from their spontaneous enactment to their use as a shared resource for sense-making in collective activities and individual assessments. In particular, flossing appears to have supported understanding an unintuitive concept that historically challenged young learners (i.e., that solid particles do in fact move). These outcomes suggest that scientific embodiments can incorporates local ways of knowing and moving and become a powerful resource in meaning-making. These results have implications for researchers and practitioners. First, work should further recognize embodiment as a diverse and hybrid practice. Second, scholars should continue to encourage the co-construction of hybrid learning spaces in a variety of modalities. Third, this study helps to articulate how future designs for embodied activity can benefit from moving beyond considerations of analogous movement (although that is still important) to include a focus on a diversity of movements that, if properly supported, can blend personally-meaningful movements with scientifically normative ones.

Overall, the goal of this paper is to highlight the need to understand the diversity of potential body movements in designing and implementing classroom-based and out-of-school science learning contexts. I argue that these results further support the central role the body plays in learning and exploring concepts. At the same time, it expands notions of embodied cognition from the ways a deliberately cued and technologically-enhanced body might directly interface with science content to include spontaneous new forms of movement that support learning (Lindgren, 2014). Moreover, this work offers new perspectives on hybridity and the third space—that is, how an *embodied* third space can produce and invite new forms of body-based participation for both individual participants and collectives. In sum, these outcomes can continue to advance computer-supported collaborative learning contexts, and in doing so expand possibilities for young learners' future scientific experiences and identification (Bell, Tzou, Bricker, & Baines, 2012).

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