Engagement in Motion: How the Body Mediates Social and Emotional Engagement With Science Learning

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Abstract: This paper investigates sociocultural perspectives on what it means for students to be engaged with learning, paying special attention to the ways that an embodied cognition perspective shifts how we conceptualize the relationship between engagement and learning. The analysis focuses on the Science through Technology Enhanced Play (STEP) project, where young children use their bodies to model the motion of water particles in a mixed-reality system. Video data was coded for cognitive engagement with various scientific ideas about states of matter, and interaction analysis (IA) was used to explore the socioemotional dynamics of classroom interactions that supported and/or hindered this cognitive engagement. The analysis highlights key aspects of young learners' social and emotional engagement that can inform how designers of embodied learning environments leverage the body as a representational tool.

Keywords: student engagement, embodiment, emotion, science learning, mixed-reality

Introduction and background

As learning scientists, we explore the mechanisms through which learners productively (and unproductively) interact to learn concepts and practices. For sociocultural theories of learning, this means understanding the rich contexts that dynamically both influence and are influenced by the socioemotional processes between learners. Despite their importance, emotional aspects of learning remain understudied, leading to research that explores links between behavior and cognition without addressing the socioemotional processes inherent to the learning process (Baker, Andriessen, & Järvelä, 2013). One way to emphasize the socioemotional complexity of learning is to use the lens of student engagement to characterize learners' interactions. Because the literature is rife with contradictions regarding how to define and measure engagement (Appleton, Christenson, & Furlong, 2008), I draw on a sociocultural lens to define engagement as the dynamic process through which students participate in learning activities, which unfolds over time via dialectic interactions between learners and environments. Unpacking these interactions is necessary because deeper levels of engagement can support increased conceptual change in science learning (Sinatra, Heddy, & Lombardi, 2015). We can characterize engagement with learning by exploring multiple dimensions (e.g., cognitive, behavioral, emotional, and social; Fredricks, Blumenfeld, & Paris, 2004) to see how learners' multi-faceted experiences dynamically produce learning.

In particular, this paper focuses on engagement with embodied learning, which can be defined as the mapping of abstract concepts onto concrete experiences (e.g., body movements) to support understanding (Alibali & Nathan, 2012). This approach positions the body as a representational tool that can support learners in grounding abstract ideas in movement to make them more concrete and accessible for inquiry (Lindgren & Johnson-Glenberg, 2013). In other words, behavioral engagement that leverages body movement for sensemaking can support students' cognitive engagement with abstract concepts. Students also experience social and emotional reactions to learning that are grounded in their bodies, which may influence the impact of embodiment on cognitive engagement. Much of current embodied cognition research focuses on how individual students use their bodies to understand conceptual ideas (e.g., Alibali & Nathan, 2012; Flood, Neff, & Abrahamson, 2015). However, our research team has recently proposed a Learning in Embodied Activity Framework (LEAF) that emphasizes how individual students' embodied movements dynamically influence collective movement, and vice versa (Danish et al., 2020). A review of embodiment literature also reveals that learners' emotional reactions to both individual and collective forms of embodiment have been studied only rarely (cf. Lindgren et al., 2016); thus, while this paper discusses all four dimensions of engagement (behavioral, cognitive, emotional, and social), particular emphasis will be placed on understanding how emotional and social engagement support learning with and through the body. To explore these gaps in our understanding, I address the following research questions: (1) *How does the use of the body as a representational tool influence the dynamic unfolding of young learners' social, emotional, behavioral, and cognitive engagement during scientific inquiry?* (2) *How do positive and negative moments of social and emotional engagement in particular support and/or interrupt opportunities for collaborative, conceptual engagement with scientific ideas?*

Sinatra et al. (2015) proposed a continuum of perspectives on engagement, with "person-oriented" approaches viewing engagement as individually driven, "context-oriented" analyses focusing on systemic school and community factors that promote engagement, and "person-in-context" approaches emphasizing the dialectic production of engagement via interactions between individuals and their environments. The following sections highlight how this paper takes up a sociocultural, person-in-context approach to define and measure engagement across cognitive, behavioral, emotional, and social dimensions. The first three dimensions were chosen because they are most commonly discussed in the engagement literature (Fredricks, Blumenfeld, & Paris, 2004), and recent learning sciences studies have highlighted social engagement as an essential fourth dimension (Sinha et al., 2015).

Applying this theoretical approach to embodied learning in a mixed-reality context helps us explore the domain-specific nature of engagement, because what counts as behavioral, cognitive, emotional, and social engagement in one context (and the mechanisms of interaction between them) won't necessarily generalize to all domains (Sinatra et al., 2015). While we are always learning with and through our bodies, the design of learning activities that explicitly leverage the body as a representational tool complicates the question of what counts as engagement by inviting new forms of participation. Thus, when designing for technology-augmented embodiment, we need to understand how the body mediates both the unfolding interactions between dimensions of engagement and the ways that these processes support (or disrupt) learning.

Cognitive, behavioral, emotional, and social engagement

Cognitive engagement can be conceptualized as containing two common subtypes: cognitive engagement with strategies for learning (i.e., metacognitive monitoring and self-regulation; Greene, 2015) and cognitive engagement with the content of learning (i.e., reflection on conceptual ideas, questions, and problems; Sinha et al., 2015). I refer to these subtypes moving forward as cognitive-strategic and cognitive-conceptual engagement and focus on the latter in this analysis. Through a sociocultural lens, instead of framing cognitive engagement as an internally driven choice, we look at how interactions in context support or constrain opportunities for students to engage with disciplinary ideas. How students build ideas about science together is influenced by the social dynamics and cultural processes mediating their interactions. From this perspective, cognitive engagement involves collaborative, productive argumentation that helps groups of learners negotiate topics before coming to a consensus. In an embodied learning context, this negotiation of collective understanding is mediated by the ways that learners use their bodies both as individual sensemaking tools and as public representations of conceptual ideas (Danish et al., 2020). Seeing cognitive engagement in our data requires measurement of this collective embodied understanding, made visible through processes such as discussing embodied performances, carrying out embodied experiments to build consensus, and negotiating connections between concepts.

Behavioral engagement represents the specific practices and methods of participation that students use to engage (or disengage) with the activity that surrounds them. It is generally defined in terms of desirable classroom-related behaviors such as asking questions, contributing to discussion, and an absence of disruptive behavior (Fredricks, Blumenfeld, & Paris, 2004; Fredricks & McColskey, 2012). Cognitive studies of engagement will often approach behavioral engagement by collecting self-report data, seeking to measure the amount of effort and participation that individuals invest in learning. However, a sociocultural approach attends to how the production of particular behaviors is situated in social, cultural, and historical contexts. The way that a student does or does not participate is not viewed as a reflection of their internal level of effort, but instead is seen as a product of the interactional opportunities that are available to the student. This shift is especially central for the study of engagement in embodied learning, because embodiment provides unique opportunities for behavioral engagement that are not available in a typical classroom. When physical movement around the classroom becomes valuable way to participate in a learning activity, it changes the rules for what it means to be engaged or disruptive. Thus, a child who embodies a water particle by running around the classroom, who may have been labeled as disruptive in a more traditional activity, is now classified as highly engaged in the embodied learning activity. Expanding what counts as desirable behaviors to include physical motion as well as verbal contributions changes both how individual students behave as well as how their behaviors influence the unfolding collective activity.

Emotional engagement can be defined using three interconnected aspects: a physiological response (e.g., increased heart rate), a subjective sensation (e.g., internal feelings of joy), and a behavioral manifestation (e.g., crying) (Baker et al., 2013). This study focuses on the behavioral manifestation of emotion—the multiple verbal and nonverbal modes that students use to make their emotions visible to one another during activity. We can then define emotional engagement as students' visible positive and negative reactions to learning activities, including laughing, shouting, and sulking in the corner (Fredricks & McColskey, 2012). Emotional displays can be further categorized into positive and negative affect, both of which can contain activating (e.g., excitement, anger), neutral (e.g., happy, sad), or deactivating (e.g., relaxed, tired) valances (Sinatra et al., 2015; Linnenbrink-Garcia, Rogat, & Koskey, 2011). Assigning emotions labels of positive and negative is not meant to offer a value judgment about whether these emotions are good or bad for learning, but rather to categorize the responses of others (e.g., participants react to displays of joy as something to be encouraged but react to anger as an unwanted response). The reactions of others to an emotional display is central for a sociocultural analysis of emotion, because emotional responses are viewed as collectively produced through socially and culturally situated interactions (Baker et al., 2013). How an emotion is expressed in collaborative activity is mediated by the way in which an interaction unfolds in context, including what emotions are culturally appropriate and socially acceptable, and how the collective might pick up certain emotions and magnify them back to the individuals. A sociocultural perspective argues that "emotion is both experienced through and written on the body, not as a snapshot but unfolding in place and time" (Sakr, Jewitt, & Price, 2016, p. 84). Thus, a smile or a laugh is not simply a representation of an internal emotional state, but a socially and culturally situated production that is both created by and influencing the way the surrounding interaction unfolds. This approach requires emotion to be analyzed through observation of real-time interactions, because the snapshot provided by a questionnaire does not provide an account of how emotions are produced, sustained, and interrupted.

Social engagement looks at how the behaviors of individual students interact to impact collaborative group functioning, with a specific eye towards joint participation and group cohesion. A sociocultural perspective asserts that an individual's participation in social interaction is unintelligible without an understanding of the specific interactional context in which it was produced, because social relationships influence individual engagement and individual engagement shapes the unfolding social context in return (Ryu & Lombardi, 2015). Isohätälä et al. (2018) define the social processes that happen in collaborative groups as "learners' abilities and efforts to sustain cohesive, mutually respectful social interaction...including developing trust and fostering safety for collaboration, and building a sense of community with a shared goal" (p. 2). They operationalize positive social engagement by looking for active participation in a goal-oriented task with others, mutual engagement in joint discussion, the encouragement of one another's ideas, soliciting opinions, responding to contributions, the use of "we" to signal group cohesion, and the ability to disagree without risking one's socioemotional safety. The opposite, negative social engagement, can be seen via exclusion, ignoring others' contributions, insulting others, overruling ideas, and discouraging participation, as well as reducing effort through social loafing (Isohätälä et al., 2018; Linnenbrink-Garcia et al., 2011). Embodied activities might also contain unique evidence of social engagement, such as mimicking the movements of peers, following an agreed-upon plan for how to move, and coordinating the motion of others in a respectful way to invite joint participation. These sociocultural definitions of cognitive, behavioral, emotional, and social engagement guide our analysis in the following sections to uncover how the use of the body mediates the unfolding process of engagement with scientific inquiry.

Design

The STEP environment uses an embodied, mixed-reality simulation of water particles to help first- and second-grade students learn about states of matter (Danish et al., 2015). As students move around the classroom, they can leverage their sense of individual and collective motion to reflect on how particles behave. The STEP environment further enhances this process by presenting students with a blend of the real and the digital – as students engage in embodied play, they see themselves in a projected simulation as water particles that mirror their real-world movements (Figure 1). If they move slowly, they are depicted as ice (white lines), and if they gradually speed up, their avatar becomes first a liquid (blue lines), then a gas (red lines). The blend of digital and physical experiences augments students' exploration to make complex scientific ideas more tangible.

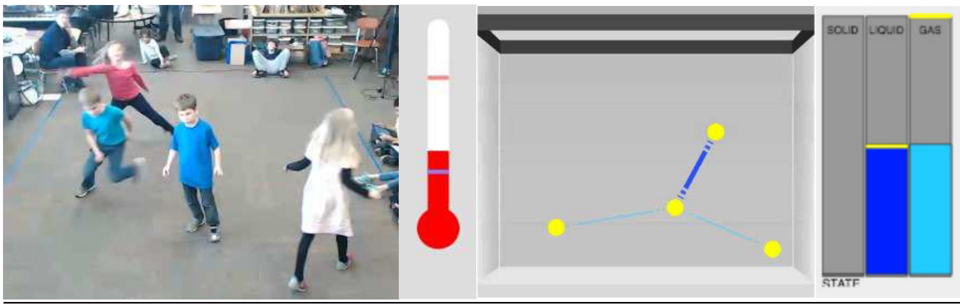

Figure 1. Students play as water particles (left) and see their particle avatars mirror their movements on a shared screen (center), which includes a state meter that tracks their collective state of matter (right).

The STEP environment consists of Microsoft Kinect cameras that track student movement as they pretend to be water particles. The tracking data is then transferred to a computer that produces a simulation of water particles moving around a tank. Each student has a particle avatar that is controlled via their movements around the classroom, allowing students to use embodiment to experience being a particle in a solid, liquid, and gas. They could also embody energy sources, allowing them to heat up and cool down computer-controlled particles. Students rotated between embodied and scientist-observer roles, with observers using iPad-based annotation tools to create drawings and graphs of their peers' movements and explore how the speed, distance, and energy of particles impacts their state of matter. Each of the nine days of STEP activities followed a similar cycle of two-to-five minutes of embodied activity followed by short teacher-led debriefs before the next group of particles entered the space. Sessions began and ended with discussions of what students had learned, which often involved writing draft rules of particle behavior on a shared wall chart that could be revised in future sessions.

Methods

This study took place in a Midwestern public school in the United States, in a mixed-age classroom of first and second graders (*n*=46). Lessons were co-taught by two teachers, with occasional researcher facilitation. Students were split into two mixed-age groups of 23 students for eight days of video-recorded activities and came together for a final wrap-up discussion on day nine. Thus, the entire corpus of classroom video data contains 17 videos of 40-60 minutes each. To measure learning gains, students took a 10-question pre-post multiple choice assessment.

To understand how student engagement and learning are intertwined in classroom interactions, I looked first for evidence of learning outcomes (i.e., cognitive-conceptual engagement with scientific ideas) in classroom videos, and then analyzed the surrounding interactions to understand how moments of learning were mediated by the body and by the social and emotional engagement that was collaboratively produced. Classroom video data was first coded for the presence of key scientific ideas in students' discussions. Videos were split into 30-second segments and a previously developed coding scheme (Humburg et al., 2020) was applied that covered macroscopic characteristics of solids, liquids, and gases, as well as microscopic behaviors of water particles in different states of matter (particle speed, distance between particles, and strength of attraction between particles).

After videos were coded for cognitive-conceptual engagement, a second round of video viewing was undertaken to mark visible moments of heightened emotional and/or social engagement (both positive and negative), to highlight both overlaps between these three dimensions of engagement and moments where one or more dimension was absent. Following Linnenbrink-Garcia et al. (2011)'s approach to analyzing emotion in video data, I searched for facial expressions, body language, tone, and statements and vocalizations in the data that demonstrated or discussed affect. Extra attention was given in analysis to those emotional behaviors that were taken up and responded to by other participants in the space, especially when such emotional displays appeared to be mediated by how students learned with and through their bodies. Particularly striking episodes of overlap and absence were chosen for further interaction analysis (Jordan & Henderson, 1995) to understand how behavioral, emotional, and social engagement interacted to help produce and/or interrupt moments of cognitive engagement. Such interruptions occurred when the potential for deep cognitive engagement was cut short, such as when a student's question or critique was shut down, a scientific observation was ignored, or discussions otherwise ended with little to no connections to key scientific ideas.

Renninger and Bachrach (2015) argue that using observational methods to study engagement in real world practice can be a good first step to producing an understanding of engagement that is valuable for practitioners. In the following analysis, I seek to do just that - to understand the fluid and interconnected nature of engagement in motion. To demonstrate the value of such an approach, I unpack key examples of productive and unproductive overlap between engagement dimensions, revealing the complex interactions between the body, emotion, and social interaction that influence how students engage with scientific concepts in the classroom.

Results

Cognitive engagement with scientific ideas

Students improved their performance on a multiple choice test of content knowledge from pre (M=4.46, SD=1.38) to post (M=7.15, SD=1.61); $t(45) = -9.585$, $p<.001$. Classroom discussion coding revealed that this cognitive-conceptual engagement was sustained across the unit—students discussed mostly macroscopic behaviors early in the unit, then began synthesizing across key ideas about speed, distance, and attraction later in the unit (Table 1).

Table 1: Number of coded segments across both groups where students talked about key science concepts

Concept Code	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9
Macro Behaviors	11	33	11	1	6	0	1	23	0
Particle Speed	0	5	23	22	20	7	31	36	14
Particle Distance	0	6	5	8	12	7	31	29	13
Particle Attraction	0	0	1	0	18	8	19	38	14

While the pattern of cognitive engagement across the data set suggests that embodying particle movement was a powerful form of behavioral engagement for supporting students' scientific discussions, the second pass through the data revealed that moments of heightened emotional and social engagement did not always overlap with the segments that contained the most cognitive engagement codes. In the following sections, I analyze several examples of overlaps and disconnects to uncover how social and emotional engagement might function in embodied activity to influence how cognitive engagement unfolds.

Positive social and emotional engagement as boosters for cognitive engagement

When exploring moments of overlap between emotional, social, and cognitive engagement, one key pattern that emerged was how the teachers would use excited outbursts by students as jumping off points for conceptual discussion. Even when students were not engaging in embodied play, they would display emotional reactions to events occurring on screen as they waited for new activities to begin. On day six, after students had embodied red-colored energy sources to heat up computer-controlled particles, the students noticed some changes in the color of their on-screen energy avatars as the teachers transitioned to a new activity (Table 2).

Table 2: Positive displays of emotion boosting the group's collective engagement with scientific observation

Line	Speaker	
1	Ella	Wait how come they're blue?
2	Quentin	The blue energies make it go up!
3	Ella	Guys the thermometer is way up now!
4	Unknown student	Look they get blue!
5	Unknown student	The energy is blue!
6	Percy	WHOA
7	Multiple students	The energy is blue! The energy is blue!
8	Teacher 1	Oh my gosh
9	Unknown student	And the thermometer is up!
10	Unknown student	It went up!
11	Multiple students	((many students yell out and talk over one another))
12	Teacher 1	Oh my gosh! So I'm hearing that the energy looked a little different (.) look at the state meter in the corner too

Rather than treating students' noisy excitement as misbehavior, the teacher in this segment matches her comments to the excitement displayed by the students, reacting to their loud exclamations with an "Oh my gosh!" of her own (line 8, 12). She harnesses the positive emotion displayed by the students by re-voicing their most common observation—that the energy sources had changed from red heat sources to blue heat sinks (meaning that students playing as energy would be taking away energy from particles instead of giving it). These excited observations were not coded with cognitive engagement codes, since the students had not yet connected the color change to specific scientific ideas, but this moment demonstrates how even when emotional engagement did not directly overlap with moments of cognitive engagement, it could still function to support behaviors that are beneficial for learning. The teacher's excited responses to students' observations orients them towards the scientific importance of what they have noticed. Noticing that the "thermometer is way up" (line 3) leads the class to later discuss how the ambient temperature of the simulation has caused the computer-controlled particles to form gas. Another student, Kenny, notices that the particles forming gas now have thinner lines connecting them, which is an essential observation to link state change to changes in particle attraction. Kenny's observation elicits positive social engagement from his teacher, who tells him, "Oh my gosh, Kenny, what a good observation!" One of Kenny's peers then mirrors this social engagement by calling out, "Way to go, Kenny!" Though this initial discussion does not involve direct use of the body, the important scientific observations encouraged by positive social and emotional engagement helped students orient to their new role as removers of energy in subsequent embodied activities, encouraging cognitive-conceptual engagement as they began to freeze the digital particles.

Negative social and emotional engagement as an obstacle for cognitive engagement

While socially reinforced moments of positive emotion engaged students in scientific observation and discussion, social and emotional dynamics could also become obstacles for engaging with science. Table 3 demonstrates one such moment, when students playing as hot energy sources rejected an opportunity to work towards a shared goal.

Table 3: Negative social engagement interrupting opportunities for embodied experiments

Line	Speaker	
1	Riley	°Everybody stand still (.) stand still°
2		((students continue to run around the space while Riley stands still in the center))
3	Riley	((leaning towards Alex)) °Stand still!°
4	Alex	You're not the boss of us Riley
5	Teacher 2	Uh hey (.) work together

After his idea is shut down by Alex (line 4), Riley spends the rest of the embodied activity staying quiet. He stands in the middle of the space for a minute, but eventually rejoins his peers by walking around the space. This brief interaction represents a missed opportunity for an embodied experiment that could have helped the students make sense of how removing energy from particles impacts their state of matter. Riley's suggestion hints at a larger problem that students often had when embodying energy, which was that students spent most of their time running quickly around the space, making it harder to observe the impact of energy location on groups of particles. The teachers frequently encouraged the students to slow down and focus on what happens when their energy source touches or move away from certain particles, an observation that Riley's "stand still" experiment would have also encouraged. However, in this instance both negative social engagement and an abundance of positive emotional engagement prevents students from engaging in this potentially useful experiment. Along the social engagement dimension, Alex's refusal to acknowledge Riley's authority over his movements (line 4) creates an instance of negative social engagement, where Riley's idea is shut down and classified as being bossy. The teacher's comment also marks this interaction as visible negative engagement, because the teacher reacts to Alex's comment with a stern voice and a command to "work together" (line 5), implicitly asserting that Alex's behavior towards Riley is not positive group collaboration. At the same time, there are emotional forces in the interaction that make it doubly difficult for Riley's suggestion to get traction, because the students display markers of positive emotion as they run around the classroom. Some students jump around and dance, while others smile as they run past each other. When asked about their favorite parts of the activity after class, many students cited "running around" as one of their most enjoyable experiences. Thus, the positive emotional engagement that results from getting to move one's body in ways that are not typically acceptable in a classroom space makes it even less likely that students will engage with Riley's scientifically productive suggestion to experiment with stillness.

The social and emotional dynamics involved in embodied learning also appeared during discussions, especially when students' movements with their bodies were the subject of reflection and critique. Table 4 shows a discussion in which the teacher asks Alex to evaluate his peer's embodiment in terms of whether it successfully demonstrated liquid, and the ripple effect of negative social and emotional engagement that followed.

Table 4: Negative social and emotional engagement during critique of a student's embodied performance

Line	Speaker	
1	Teacher 2	Was Jasper being successful? ((Alex shakes head no in response))
2	Teacher 2	What- Jasper had a couple of challenges what (.5) what were his challenges? What happened?
3	Jasper	((stares at Alex while Teacher 2 speaks, open mouthed, throws arms back)) ((turns away from Alex, crosses arms, ducks head, hunches shoulders))
4	Alex	Well he was going far apart from them- everybody and °he was running really fast=°
5	Teacher 2	=Now not all the time-
6	Jasper	I was NOT running ((faces Alex, thrusts head forward, arms still crossed))
7	Alex	I meant like [°a lot of the time- some of the time°]
8	Teacher 2	[Jasper it's okay it's okay really] (.) you were demo- you were demonstrating something very important (.) so what was happening when Jasper was not (.) in that liq(.)uid mode?
9	Alex	So he was um (.) like running into people
10	Jasper	°°I was NOT running [into people°°]
11	Teacher 2	[So his speed] was what?
12	Alex	°His speed was really fast°
13	Teacher 2	How about distance? You're right (.) speed was a little fast

14	Alex	His distance went (.) as far as gas would like (.) sometimes-
15	Jasper	((rolls his eyes as Alex speaks))
16	Teacher 2	But [MOST OF THE] TIME he was successful [being] liquid correct (.) [okay]
17	Jasper	[°°Not true°°] [°°Not true°°]

As Alex and the teacher have an evaluative discussion of whether or not Jasper successfully embodied a particle in liquid, Jasper first reacts to his peer's critique with silent surprise and frustration (line 3), which seems to transform into sadness as he ducks his head and physically disengages with the discussion. While we do not know for sure that these visible signs of distress mirror some internal emotional state, these public displays of emotion have the social function of signaling to Alex and the teacher that Jasper disapproves of their evaluation. Furthermore, we do not need to know Jasper's internal emotional state to see that interactionally speaking, the negative social engagement that is unfolding is disrupting Jasper's ability to engage with the conceptual discussion that the rest of the class is engaging in. When his physical signals of distress go unrecognized, Jasper begins to vehemently and repeatedly deny Alex's assertions about the ways that Jasper moved his body in the previous embodied activity (lines 6, 10, & 17). Jasper's reaction suggests that his embodied performance is emotionally charged and thus is a socially risky topic for critique, in part because the structure of the teacher's debrief categorizes students' movements as either right or wrong. Discussion about particle behaviors is derailed by the teacher's need to manage Jasper's anger (lines 8 & 16), and Alex's critique gets progressively quieter and more hesitant as he reacts to Jasper's emotional displays (lines 7, 9, & 12). Though Alex's observations about particle speed are accurate, the social and emotional dynamics involved in critiquing embodied representations create a stumbling block, preventing the class from fully engaging with the question of how particles in liquid behave.

Discussion and conclusions

Though questions remain about the complex ways that social and emotional engagement influence embodied learning, this analysis offers some initial design considerations for embodied learning environments. The emotional and social interactions between students in STEP often provided boosts to cognitive-conceptual engagement, sparking opportunities for students to collaboratively build observations about states of matter. However, there were other times when socioemotional intensity derailed students from potentially productive avenues of inquiry. The use of body movements as scientific representations may have strengthened students' emotional reactions to critique, because a critique of one's body may be experienced as more personal than the critique of an external representation. Future research should consider the ways that using the body for learning can trigger intense emotions when students' movements are also objects of inquiry, particularly for young learners. Designing for embodied activity also requires particular attention to how social dynamics can be structured to support experimentation, especially for young students who may react negatively to the perception of being bossed around by their peers. We attempted to ameliorate some of this negative social engagement in later STEP implementations by having students alternate between particle actor and director-observer roles, so that each student had opportunities to both embody the scientific phenomena and direct the movements of peers. This social re-structuring gave students more opportunities to share ideas for embodied experiments with their peers without needing to jockey for power and status. This analysis also challenges the commonly held belief that science must be serious (i.e., emotionally neutral) in order to be productive for learning, a belief which often emerges in the ways that teachers introduce the STEP activities to their students. When facilitating STEP activities, our research team collaborates with classroom teachers to encourage playfulness and heightened emotion as part of scientific inquiry process rather than obstacles to this process. Based on the above results, such an approach can leverage the interactional power of positive emotions to orient students towards important scientific observations.

A key future direction for the study of engagement in embodied learning is to understand the dynamic interactions between social and emotional engagement more deeply. Though this paper offers support for a few potential mechanisms of emotional engagement, a seemingly negative emotional reaction might in other contexts lead to powerful cognitive engagement, such as when frustration with failure drives learners to approach problems in new ways. Similarly, just because students are engaging in positive social interactions does not mean they are always engaging with the content. Furthermore, though this paper privileges the cognitive dimension of engagement to highlight how socioemotional processes can benefit learning, it is important to consider that social and emotional engagement are not lesser forms of engagement that exist only to serve cognitive engagement. Socioemotional processes may influence students' lives in ways far beyond content learning, which studies of embodied learning should take into account. While the importance of both emotion and embodiment for learning have been well documented in their respective literatures, much research on embodied learning fails to account for the role of students' emotions in the mind-body connections we investigate. If we want to more deeply understand how movement and gesture influence learners' unfolding ideas, then we need to adopt an analytic lens that views learners in all their complexity—not just how they move their bodies, but how they *feel* in their bodies, *who else* is moving with them, and how these experiences weave together to create opportunities for learning.

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