Constructing and Deconstructing Materially-Anchored Conceptual Blends in an Augmented Reality Collaborative Learning Environment

Noel Enyedy, UCLA, 2027 Moore Hall, Box 951521, Los Angeles, CA 90095 USA, enyedy@gseis.ucla.edu
Joshua A. Danish, Indiana University, 201 North Rose Ave, Bloomington, IN 47405, jdanish@indiana.edu
David DeLiema, UCLA, 2027 Moore Hall, Box 951521, Los Angeles, CA 90095 USA, david.deliema@gmail.com

Abstract: Science and math school activities around modeling often involve students stepping into a simulation to play the first-person roles of (often inanimate) components. In this case study, we examine how a student maps her own experience onto a ball to simulate the physics of force and friction. We study this mapping from a conceptual blending perspective, tracking how the narrative structure of a board game, the physical floor materials (e.g. linoleum), the student's first-person embodied experiences, the third-person live camera feed, and the augmented reality symbols become integrated in the modeling activity. The student's concepts of force and friction, in turn, are rooted in the blend between the narrative, the body, and the physical materials.

Introduction

There is a new class of computer-supported tools to aid learning referred to as mixed reality or augmented reality (henceforth AR). In AR environments, the physical world is digitally enhanced by viewing *reality* through a video feed or device that augments the display with a graphical or informational overlay. Studies have shown AR to be successful at promoting learning across the grade levels and across subject domains (Enyedy et al., 2012; Klopfer, 2008). While designing new technologies that effectively promote learning is a laudable goal in and of itself, as learning scientists, our primary goal should be to discover *why* these new technologies work. Further, as learning scientists, we want to turn the question on its head and ask what these new technologies can reveal about the basic processes of learning and instruction. In this paper we suggested that AR is uniquely positioned to support learning through its ability to support students in developing conceptual blends (Fauconnier & Turner, 1998)—cognitive spaces developed through the layering of multiple prior ideas in a way that allows students to draw new inferences.

An example Augmented Reality system

In the Learning Physics through Play (LPP) project, we designed an augmented reality system that uses socio-dramatic play as a form of scientific modeling and helps young students learn the core concepts of force and motion (Enyedy et al., 2012). There are two key components to the LPP system: 1) an augmented reality system that uses computer vision to record and display the students' physical actions and locations, and 2) software that translates this motion into a physics engine and generates a visual display based on the sensing data. We tracked students' physical motion in a 12' x 12' carpet area at the front of the classroom to create a *modeling space*. In this space, young children make predictions by pretending to be objects in motion and they see (simultaneously) their physical motion projected onto a large screen behind them in the form of an animated ball. For example, a student might act out the motion of a ball given a large force by walking quickly over tile and then slowly over an imagined sand pit.

After making predictions by directly modeling motion with their bodies, students in the LPP project seamlessly transition into a physics microworld, comparing their predictions to what happens in the ideal Newtonian simulation. Like other microworlds, LPP allows students to see and manipulate a situation in ways impossible in the real world (e.g., turning off friction). We call students' initial activities in the AR system *play-as-modeling* because students are oriented toward using multiple experiences and resources to model motion as a set of rules. Much like in pretend play, one's activity is governed by and oriented toward articulating the rules of the imaginary situation (Sidnell, 2011). During these play-as-modeling activities, students wear geometric figures mounted on cards or hats. The computer can track the motion of several figures at once, and the scene is displayed on a shared interactive whiteboard. Instead of seeing themselves walk around the rug, students see a ball moving across the floor, propelled by forces and slowed down by friction.

An important part of our pedagogical design was that the students developed all the images of objects, invisible forces, and the background art used in the LPP system during earlier lessons. Inventing these representations increased understanding of the target concepts and helped students create a personally meaningful context for the activities. Moreover, as students refined their symbols collectively, they were also determining which aspects of the phenomenon were important to capture in its representative symbol. In this way the activities slowly transitioned students from play-as-modeling to reasoning from symbols and concepts in a way that more closely resembles what is commonly recognized as scientific modeling.

In this project, the vast majority of second-grade students significantly improved their understanding of physics (see Enyedy et al., 2012 for full details). To date we have been able to illustrate what learning looked like in this environment focusing on our two design principles of the role of play and the role of progressive symbolization. However, what is needed is a microgenetic account of learning that allows us to pinpoint the details of how the affordances of AR relate to cognition and learning. Our prime candidate is conceptual blends. Conceptual blending describes a type of reasoning where selective inputs from two separate spaces are projected into a new space together to form an emergent structure (Fauconnier, 1994; Fauconnier & Turner, 1998). The blending framework helps us account for how the AR environment laminates virtual semiotic resources onto material structures.

Our goal in this paper extends beyond applying the conceptual blending framework to our data. We wish to extend the blending framework in three ways. First, we wish to argue that there is a special case of conceptual blends where one of the source domains is the student herself. The first-person, subjective perspective as a source domain may create a powerful type of blend that is particularly useful when learning or problem solving. This is consistent with some of the hypotheses of the power of agent based reasoning (Wilensky & Resnick, 1999) and 'liminal worlds' (Ochs, Gonzalez, Jacoby, 1996). Second, conceptual blending has primarily been used to explain stable forms of reasoning. We are particularly interested in learning. We will extend the blending framework by examining learning as the process of construction and partial deconstruction of blends. Third, although the blending framework was developed as a cognitive theory that makes rather large assumptions about the amount of computation that occurs within the head, we follow Hutchins' lead (2005) and examine the material circumstances of blending, attempting to remain agnostic about the degree to which blending happens inside the head. These physical objects in material (Hutchins, 2005) or real (Dudis, 2004) space—including the body, visual symbols, and physical objects—become components in the microworld that structure students' inferences.

In summary, this research project is oriented toward the following research question: How does the conceptual blending framework account for students and teachers' interactions with multiple resources (e.g. bodies, symbols, physical materials, narratives) during a microworld learning environment? What can the blending framework reveal about foundational processes of learning and instruction? Using the conceptual blending framework, we track how the verbal discourse, augmented-reality technology, physical objects, abstract symbols, and students' own bodies selectively fuse together to create a blend through which students reason about physics.

Conceptual Framework

Conceptual blending, an extension of mental spaces theory (Fauconnier, 1985), is a general model for the integration of concepts and the creative construction of meaning. In theory, a conceptual blend is created by coordinating multiple, distinct conceptual spaces, or source domains, and projecting them into a hybrid conceptual space that has emergent properties not found in the source domains (Fauconnier & Turner, 1998). For example, Fauconnier and Turner (1998) offer the hypothetical example of a professor who is lecturing and begins to have an argument with Kant. In this case, one source domain is the modern day professor. A second source domain is Kant himself, dead now for hundreds of years. Projected together into a blend, one can imagine how Kant might comment on the writings of Hegel or Wittgenstein or argue with the modern-day professor he never could have know would exist. That is, the blend has emergent properties that afford the production of new inferences.

The process of conceptual blending is hypothesized to involve three operations. The first operation is composition, where the different source domains are evoked and elements from one source domain are explicitly mapped to another. The second phase is completion, where an inference or a computation is made from the emergent properties of the blend. Often, completion is thought to involve filling in the blend by matching it to memories or frames stored in long-term memory (Coulson & Oakley, 2000). However, we argue that the important aspect of completion is putting the blend in relation to a goal and then using the blend as a tool to achieve that goal. As many have noted about representations and other mental structures, a structure in the absence of activity is meaningless (Greeno & Hall, 1997) and computation assumes that there is a reason for making the computation. Hence, for us completion is fundamentally about putting the blend to use. The third phase is elaboration. Closely related to completion, elaboration involves extending the blend by continuing to bring in new elements, running the blend as a simulation, and extending it to new situations. In our analysis, and for education more generally, this is perhaps the most important part of blending, as it is here where different semiotic resources are put in relation to one another in different combinations to produce new insights.

Materially Anchored Blends

A potential difficulty in using conceptual blends to inform educational research is that, consistent with the norms of cognitive linguistics, CB theory was developed from hypothetical cases rather than empirical cases. As a result, it can be seen as broadly applicable to almost every case of reasoning (Coulson & Oakley, 2000). Further, these hypothetical cases involving purely mental computations and blends can be difficult to verify. In response, many have considered the relationship between (observable) physical materials and conceptual content (Dudis, 2004; Hutchins, 2005; Lidell, 1998). Hutchins (2005), for example, extended this work to a number of empirical cases where one can see the computations in the blend being performed in the material world. These 'materially anchored blends' re-envision the composition phase as the construction of material objects that literally superimpose structures on top of one another. For example, in a historical case from nautical navigation, he shows how the 32 points of the compass rose, which represents the cardinal directions, is superimposed with solar time (i.e., a 24 hour clock), dividing 24 hours into 32 45-minute periods. Because these 45 minutes were a good approximation of lunar time and the difference between high tide on consecutive nights, this blended structure was then used to compute at what time high tide would occur at a given port. The blend in this case was external and the computation was done by manipulating the representational state of the material world. However, it is important not to read too far into Hutchins' examples, as this would preclude the option that some of the structures in the blend are not materially present but are instead made present by the subject through action, talk, or imagination.

Liminal blends

In our case, one of the central resources that is being blended with other semiotic resources is the child's own body, an example of a real space blend involving gesture or action (Parrill & Sweetser, 2004). In pretending to be an object in motion and physically moving in the AR world, students using their bodies-as-objects are blended with abstract symbols and rules articulated through talk. To understand this special class of materially anchored and embodied blends, we draw on the work of Ochs and colleagues (1996) who coined the term 'liminal worlds' to describe cases where "the distinction between the scientist as subject and the physical world as object is blurred" (p. 347). In a study of professional physicists trying to understand emergent theories of the atomic structure of condensed matter, Ochs, Gonzalez, and Jacoby (1996) found that scientists were, "taking on the perspective of (empathizing with) some object being analyzed and by involving themselves in graphic (re)enactments of the physical events" (p. 360). For example, in trying to describe a finding related to atomic spin, a scientist switched into first person language and imagined himself to be the atom as it moved through a series of transitions, saying things such as, "when I come down I'm in the domain state," (p. 331). Ochs et al. described these linguistic constructs where the participants moved between a normative scientific description of a phenomenon to more personal 1st person description as *liminal worlds*, because they were episodes in which objective facts were blended together with subjective reasoning from a first-person perspective. These liminal worlds created a qualitatively different set of resources from which to reason and were found to be productive in model and theory building. The LPP environment deliberately created this sort of liminal world where one's subjective understanding (and the resources that come with embodied cognition) is laminated onto the more formal and symbolic world of traditional computer simulations, and where students are supported in moving fluidly between the two.

Methods

Our analysis is grounded in the tradition of cognitive ethnography (Hutchins, 2003). Video tapes of a single lesson of second-grade students engaged in learning about friction were used to inductively examine how the conceptual blending framework applied to our data. The activity itself brings together students, teachers, physical materials, abstract symbols, and live video in an augmented reality simulation focused on modeling an object's trajectory through different types of friction. The class session occurred within a larger 15-week unit on basic physics. In this analysis, we attempt to trace what resources were being mapped together (composition), what inferences or computations were being made about the speed of a ball under different conditions (completion), and the way that the publicly available blend was elaborated through collaborative activity (elaboration). The case study student chosen for analysis, Marissa (a pseudonym), was fairly typical of the class as a whole. Most important for the present paper, her qualitative answers on the topic of friction showed that on the post test she understood the mechanism for friction, but still had difficulty in conceptualizing low or no friction environments. This was typical of our results for the intervention as a whole. In Enyedy et al. (2012), we reported that only 16 of 43 (37%) of the students received significantly higher scores on a question that addressed friction during the posttest than on the pre-test ($Z = 2.38$, $p = 0.02$). For example, when asked why friction slows and stops an object, Marissa explained: "Because the grass has a hard friction…It's bumpy and it sticks up to the ball, have to fight to get over it." However a little further into the question Marissa talks about what happens when the ball rolls onto ice: "It will go faster. Because it's just smooth surface." In this way, Marissa fits the profile of many of the students in the class in showing a promising but incomplete understanding of friction.

Findings

In an activity aimed at having students explore the effect of friction on motion, the teacher lays out a life-sized game board on the floor —in reality a long strip of paper marked off into several squares. The students take turns 'playing' the ball and deciding how the speed of the ball changes as they receive force cards or friction cards. At the same time, an overhead camera records the play space and projects a live feed on a white board mounted to the wall, and overlays the friction and force cards with symbols on the video feed. That is, the student, force cards, and friction cards on the carpet space in turn appear in the video space as a black ball, forward-facing red arrows, and backward-facing red arrows (see figure 1a and 1b).

Figure. 1a and 1b

In this first section, we demonstrate *composition*, how disparate resources from distinct spaces in the classroom become mapped together to create the life-sized board game environment. That is, we show how the discourse between students and instructors in addition to the material anchors—despite being spread out over time and in the classroom—fuse together or join side-by-side into a board game blend.

Composing the Floor space. The first space established in the activity is the floor space—a 10-foot long, rectangular sheet of white paper marked off into a dozen 10'' x 10'' squares. Three squares have real sheets of flooring material—linoleum, carpet, and an outdoor welcome mat. Researcher 1 notifies students that they will need to place cardboard patterns in the appropriate places so that the computer knows the correct amount of force or friction in each game square. The floor space is marked with multiple resources: cardboard patterns, paper, students' bodies, and floor materials.

Composing the Narrative space of playing a game. Researcher 1 helps to establish the overarching narrative structure. Researcher 1 sits down with the students on the carpet and initiates a whole-class discourse that explicitly maps the conventions of game playing onto the physical floor space. She makes a sweeping gesture from the start to the finish of the paper board game, showing the spatial trajectory typical of a board game.

Composing the overhead Live Feed space. As the activity unfolds, students quickly orient towards a live feed from a camera mounted directly above the carpet space and pointing downward. The camera feed is projected onto the white board. That is, if students look toward the white board, they can see live video of the carpet (and themselves moving around) seen from a bird's eye perspective. This creates a mapping between students' first-person perspectives and the camera's third-person perspective.

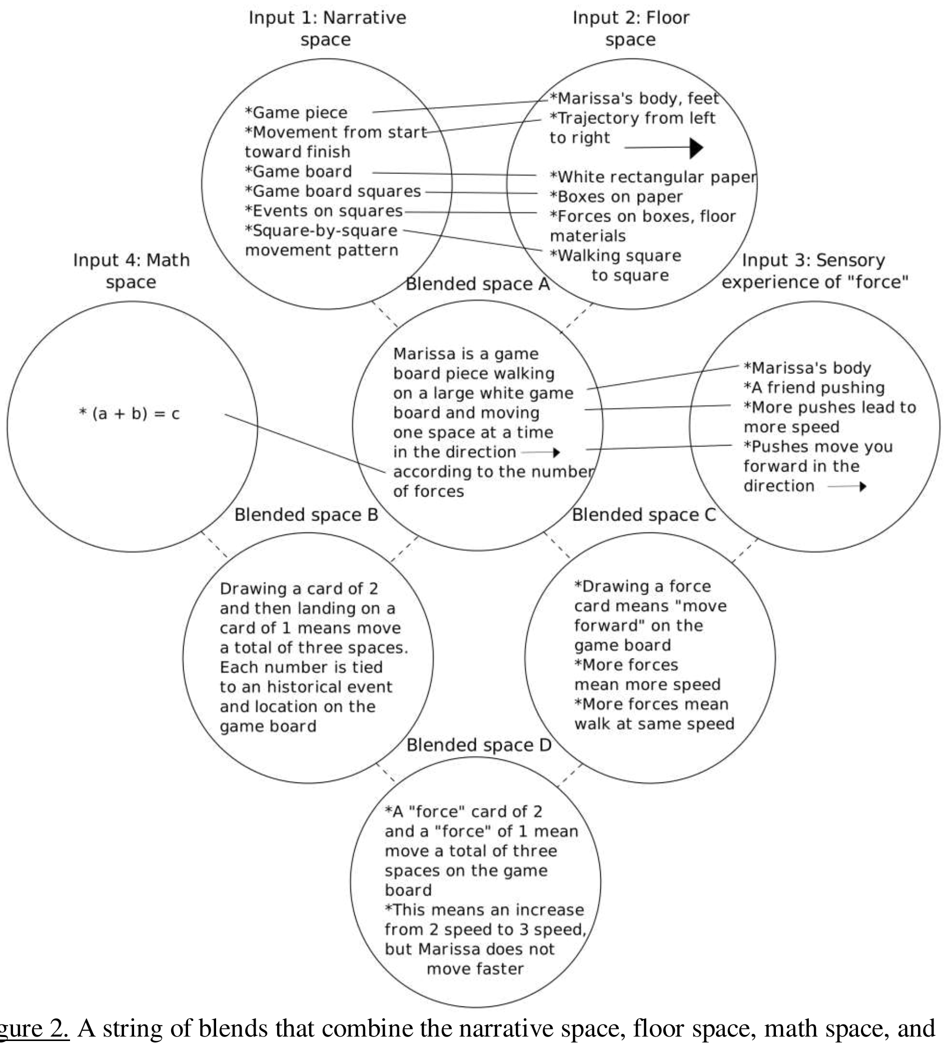
Composing the Video Symbol space. Researcher 2 hands Marissa one of the flat cardboard symbols and says, "Marissa, do you want to hold the ball while you walk?" This interaction blends Marissa's first-person experience of her body, the video image of her body, and the animation of a ball into one object. Other cardboard pieces appear as colored symbols in the live feed space, floating on top of the carpet. The ball symbol appears on screen as a black ball and the 2-force cards appear on screen as two horizontal red arrows (see figure 1b).

Composing Math. The final input space involves simple mathematics: adding two integers. The math space projects structure into the blend during multiple moments of the activity. We detail the completion and elaboration of these input spaces in the sections below.

Episode 1: *Completing* the blend of narrative, game board, and sensory experience

The activity begins with Marissa and Researcher 1 standing at the start of the game board. After Marissa draws a "force of 2" card, she takes two steps forward and pauses at the second square. Marissa's small steps are a somewhat trivial completion of the very complicated blend that has been collaboratively constructed. She has blended together several of the available resources to compute the number of squares she is supposed to move on the game board. The number of squares moved in turn is used to represent the constant speed she would be traveling. The narrative space of the board game—the game piece, board, dice, movement along a track, and event cards—offer the conceptual framework that structures movement of the body (see Figure 2). The carpet space offers the elements of Marissa's whole body, a white rectangular paper, squares on the paper, bits of paper, and cards with information about force numbers. Marissa, the instructors, and other students experience the fusion of the narrative and carpet space. The blend is now publicly available for others to comment on, elaborate, or re-mix. In this episode, Marissa and Researcher 1 discuss Marissa's speed after she lands on the second square, which contains a symbol for 1 force.

> Researcher 1: Well, what did you start with? (pointing at Marissa)
> Marissa: (Turning her shoulders to look back at the start square) Two…three
> Researcher 1: So you're going two and then you're going three because…
> Marissa: (Turning her shoulders again to look back at the start square) I st—I had two.
> Researcher 1: (Pointing to the start square) You had two (and then pointing to the second square) and then
> you landed on a…
> Marissa: Three
> Researcher 1: (Leaning in to take a closer look at the second square). A three?
> Marissa: A one.



<u>Figure 2.</u> A string of blends that combine the narrative space, floor space, math space, and sensory memory space to produce a numerical representation of speed.

Researcher 1 and Marissa's discussion of speed involves mathematics rooted both in the physical resources in the room and in the narrative structure of the game board. Marissa has a chance to provide a description of her speed within the context of the blended narrative and floor spaces. The math input space (a + b) becomes an additional tool to evaluate the events in the narrative and the floor blend. There is a 2-force symbol that advanced Marissa from the first square and there is a 1-force symbol on Marissa's current square. In the blend, Marissa can combine these two moments in the journey—the initial 2-force and the 1-force—to tally the total forces accrued.

Importantly, the numerical total represents units of force tied historically to specific events in the narrative, both conceptually and physically. In the same way, Fauconnier & Turner (1998) note that, "In the blend, but not in the original inputs, it is possible for an element to be simultaneously a number and a geometric point" (p. 147). Marissa's reasoning, in this context, incorporates integers, forces, historical moments in the game, and specific spaces on the game board. Speed, in turn, is construed in terms of the (history of the) game board narrative and in terms of the physical semiotic structures of the game board. The concept of speed becomes housed in numbers and in locations on the game board, not in the actual speed with which Marissa moves her body between squares.

Episode 2: *Elaborating* the blend to reason about friction

After landing on the force square in the previous episode, Marissa prepares to advance three squares, where she will land on the linoleum slab used to represent a low friction surface. She walks slowly from one square to the next, and when she steps on the linoleum, Marissa, who is wearing socks, slips slightly forward with her right foot. Researcher 1 initiates a dialogue with a question about what will happen next:

> Marissa: I slip? (followed by three exaggerated motions swiveling on the linoleum back and forth in socks)
> Researcher 1: Oh, we have an interesting situation…
> Marissa: I'm SLIPPING! (co-timed with feet intentionally sliding on the linoleum; arms raise up slightly)
> Researcher 1: Marissa is going speed 3, and then she landed on the linoleum. So she says she might slip. What's that going to do to your speed?
> Marissa: Make it faster.
> …
> Marissa: Because, because, if there's a 3, and I'm going very fast (steps back one square and faces forward), I would land on this and I would slide (walks forward and slides her feet forward in a controlled way on the linoleum; then returns to standing on the linoleum tile), because it's slippery.

In this episode, the experience of placing feet on actual linoleum causes the blend to be remixed and the computation to produce an unexpected answer. Marissa's initial slip, and her memories of slipping on linoleum in socks (an event she later describes as "freaky" and "scary"), leads her to the conclusion that her speed will increase. This inference emerges from an interaction between blends that draw on different source inputs.

The game board blend described in the prior episode fused the number of forces with the number of game board squares. In the blend, greater forces instantiate as greater numbers of squares traveled on the board. Speed, similarly, is represented as the number of squares Marissa can traverse given the forces on the game board. Marissa, then, despite receiving a strong force of three, can slowly walk from square to square; the kinesthetic response to force is never projected into the blend. However, as Marissa walks slowly from one square to the next in the current slipping episode, she steps on the linoleum and encounters a new input to the blend: the kinesthetic experience of actual slipping. The slip happens fast relative to the deliberate, slow pace of walking. Marissa simulates her prior slip several times on the linoleum square and cries out in jest, "I'm slipping!" From a blending perspective, Marissa integrates two embodied representations of speed—the slip on the linoleum and the slow walk—despite that one of those representations was an incidental representation of speed (see Figure 3). The walk between squares represented a default walking speed that never increased with increases in force. That is, even though Marissa had increased her "numerical" speed on previous turns, she never walked any faster. The distance traveled on the game board represents speed in the blend, not how fast the body moves. The result is that Marissa construes the linoleum as increasing her speed even though the increase is relative to the red herring *walking* experience of speed. The numerical depictions of speed are selectively projected into the blend as independent entities. After Marissa draws the conclusion that she will speed up in an embodied sense, she decides to bump up the numerical representation of speed from 3 to 4. This episode reveals that blends can be used to produce both normative and non-normative inferences depending on how the emergent structure is elaborated.

Episode 3: Comparing the computer's blend to Marissa's blend

At multiple points throughout the activity, Researcher 1, Researcher 2, and Marissa establish a mapping between Marissa's journey through the floor space game board and the ball's journey through the live feed space projected on the white board. Researcher 1 notes early on that the cardboard symbols in floor space are "for the computer" and will appear as symbols in the live feed space. Researcher 2 both hands Marissa the flat cardboard square for the ball, asking "Marissa, do you want to hold the ball while you walk?" and asks Marissa, "Can you bring me the ball?" upon which Marissa brings over the cardboard square. The ball, in other words, becomes synonymous with the cardboard square symbol and also takes the same journey as Marissa, albeit seen from an overhead view on the classroom wall instead of on top of the white paper on the carpet.

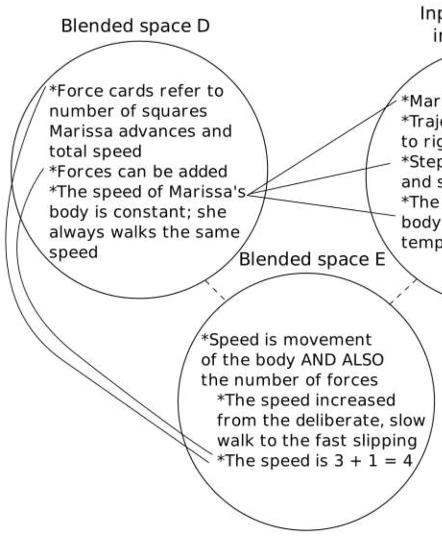


Figure 3. Blending the quantitative representation of forces and the physical experience of slipping.

As shown above, interaction and collaboration is used to establish a direct and public blend between Marissa, the narrative journey, and the image of the ball. In the blend, cardboard and arrow depictions of forces move Marissa and the image of the ball. The participants work to align the elements in the floor space, live feed space, and symbol space according to the narrative structure of the board game. With this blend firmly established, Researcher 2 organizes a comparison between Marissa's journey and the computer's depiction of the ball's journey:

> Researcher 2: Let's try to see if the computer agrees with her (Marissa's) prediction.
> …
> Researcher 2: So the question is, when we run this, is it going to speed up or is it going to slow down when the ball hits the linoleum, right? (moves the cursor in the live feed space to point to the linoleum square). So, Marissa, you said, when the ball get's here, it's gonna get faster, right?
> Marissa: Where?
> Researcher 2: Right here (moving the mouse up and down)
> Teacher: Look at the screen, Marissa.
> Marissa: Yeah.

If the fusion between Marissa and the ball was implicit before, the mapping now becomes public and explicit. Researcher 2 refers to "Marissa's prediction" of what happens "when the ball get's here," while pointing with the cursor to the live feed space. Marissa's early movements with her own body on carpet space are collectively realized as a prediction of how the computer will show the ball moving in live feed space. Marissa, at first, does not realize that Researcher 2 is pointing toward the live feed space. Up until this point, the journey had been extremely focused on the carpet space; cardboard symbols were merely "for the computer." Now, the spaces have become fully integrated, and Marissa quickly agrees that her earlier embodied prediction corresponds with how the ball will interact with linoleum as determined by the computer.

Despite that the inputs to the computer blend remain completely hidden—there is no mention of how the computer generates the simulation—Marissa is strongly impacted by the computer's prediction. The computer shows the ball rolling across the game board in the live feed space and then slowing down at the linoleum (the opposite of her earlier prediction). Marissa, after agreeing that the ball did slow down on the linoleum, maps the experience "back to the input spaces" (Fauconnier & Turner, 1998) of her earlier movement. She introduces a caveat to her earlier prediction: "If I go on this (walking to stand on the linoleum square), I could slip (acting out the slipping with her right foot) and then I would fall and then it would make me go slower because I would slip." Marissa introduces the event of falling on the linoleum—which would slow her down—in order to match the computer's prediction of the ball's journey across the game board. Marissa and the ball have been fused to such an extent that the computer's prediction invites Marissa to backtrack and revise her own prediction. Importantly, she revises her prediction by adding the event of falling rather than changing her inferences about linoleum friction.

Discussion

In these three episodes, we see mathematics and physics rooted in a game board narrative, a physical game board, bodies, and augmented-reality symbols. Toward the end of the activity, the computer simulates the normative model of *the ball encountering friction* using the representations Marissa had already put into action, which leads Marissa to revise the description of *how her own body encounters friction*. The augmented reality activity establishes a liminal world blend between Marissa and the ball that allows for a dialogue between Marissa's first-hand experiences and classical physics simulations. Importantly, the computer receives high epistemic credibility as a source of how balls move on linoleum. This finding begs for the study of interactions between social others (e.g. teachers and peers) and the cognitive spaces that people blend to produce inferences.

The liminal blend allows continuity between past and present sensory experiences and the ball's classical response to force and friction. Once the ball and Marissa become coupled in their trajectory through the game board, Marissa comes to believe that the events that the ball encounters according to the computer in the live feed space need to match how she moves through the floor space. The blend simulating the journey of Marissa/ball call for Marissa to look back at the inputs to her own blend and think about her experience in new ways. However, this integration does not happen in a vacuum. The kinesthetic experiences are read into a narrative and into semiotic infrastructure that creates two contrasting roles for the body. Is the body enacting the movement of the game board player or an interaction with the physical surface? Is speed the mathematical total of forces or how the body responds to walking and slipping? The blend combines these inputs, making predictions based on the resources in this environment problematic. Conceptual blending, in this way, shows how resources gather meaning against the ground of other resources, and how accounts of learning need to consider integration across these resources.

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