Embodiment and Technology-Enhanced Learning Environments: Cultivating a New Community of Design Research

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I. Introduction

This chapter starts with the premise that exploring the meaningful connections that people make and the learning that can occur through embodied activities is a productive approach to research and design. The authors have independently led research and higher education instructional initiatives that have leveraged theories of embodiment to create new interactive designs and a new community of scholarship that takes seriously the role of physical engagement and the situatedness of learning. We describe some of these initiatives and attempt to make salient the ways that the embodiment perspective unites a diverse set of educational practices, and creates a fertile space for discovery and innovation.

As learning scientists, our interest in embodiment lies primarily in the role that the body plays in constructing knowledge and enculturating to new practices. We draw upon theories of embodied cognition that generally reject dualistic accounts of human reason that segregate the mind from body and portray it as an "abstract information processor" (Wilson, 2002). Notions of situated learning (e.g., Brown, Collins, & Duguid) have already extended the boundaries of cognition outside of the brain into the social and cultural contexts, but the embodiment framing places special emphasis on how sensorimotor processes—from touching objects to navigating cityscapes to performing gestures—affect and potentially augment learning and problem solving. Evidence supporting embodied cognition has been summarized elsewhere (e.g., Barsalou, 2008; Shapiro, 2010) and applications to learning environments are still nascent (Abrahamson & Lindgren, 2014), but generally merging embodiment with educational design involves finding ways to create meaningful connections between the actions of the body and the principles and competencies educators strive to cultivate (Glenberg, 2010). This could include finding ways for learners to create physical representations (gestures, models, etc.) of their understandings, or reflecting on the body's position in space and time, establishing anchors for creating new metaphors or new identifiers.

We believe that technology has a special role to play in facilitating embodied interactions and creating multimodal learning environments. The current digital landscape—mobile devices, tangible computing, ubiquitous sensors—creates opportunities for taking on new perspectives and reflecting on real time experience: several recent innovative technology-enhanced environments leverage embodiment to boost learning and engagement for students. These include a mobile augmented reality application for environmental science inquiry (Kamarainen et al., 2013), an immserive classroom simulation of phase changes (Enyedy et al., 2012), exploring whole-body interaction for collaboration (Malinverni & Pares, 2015) and understanding abstract concepts (Antle et al, 2013). New technologies also create opportunities for researchers, opening the door for multimodal methods to understand how different kinds of interactivity support learning processes. Contemporary digital media can be integrated less obtrusively with authentic social and collaborative activity, and tremendous amounts of automatically generated digital data can be mined for behavioral patterns and potentially used for new forms of assessment.

In the following sections we describe initiatives that illustrate both a bottom-up and top-down approach to embodiment. Issues of embodiment arise naturally from the practical research we do on learning with multi-modality, gesture, etc. It also becomes an explicit framing particularly when we teach and enculturate students or facilitate interdisciplinary networks of researchers. We conclude with some thoughts on how the embodiment lens can instigate powerful new designs, and create a synergestic community of educational practitioners and researchers.

II. Emergent Issues of Embodiment in Research and Design

Attention to embodiment and the inclusion of learning theory that accomodates an embodied perspective comes about naturally from work that explicitly engages people in physical activity. Here we describe two strands of research on student learning, one involving historical inquiry with mobile devices and the other examining gestural interaction with augmented reality science simulations. Both start with a concrete activity which we treat as the launching point for pursuing bigger questions and implications given an embodiment perspective. The first initiative addresses issues of research methodologies—how does one make sense of messy social and mobile activity and align with learning theory. The second initiative addresses issues of design—how does one instigate and iterate on the design of a technology-enhanced learning environment with explicit attention to facilitating how people move?

a. Methodological Approaches to Researching Embodiment

Researching the role of embodied forms of interaction for learning raises key methodological questions and challenges. A large body of educational research typically relies on 'talk' or verbal data in evaluating learning, both in terms of learning processes and learning outcomes. Once we move into the field of understanding the role of the body, for example, sensori-motor action, gesture or touch in learning, examining verbal interaction alone is not sufficient; research on embodied interaction necessitates a foregrounding of bodily forms of interaction (in conjunction with talk), both in data collection and analysis.

A research perspective that supports this is multimodality, which focuses on communication beyond language, to place emphasis on all communicative modes: movement, gesture, touch, gaze, body positioning as well as talk, or speech, and representational forms such as written text, audio, and image (Jewitt, Bezemer, & O'Halloran, 2016). The way the different modes are used is shaped by their social, cultural, and historical use. The meaning created or generated is a result of the active selection and configuration of modes by users during situated 'interaction-in-context'. Thus, multimodality refers to how people make meaning through their situated interpretation and design (how they select, adapt, or transform) of multiple communicative modes and the representational features available in a specific place and time. It offers a rich descriptive analysis of bodily forms of interaction, which is promising for studying embodied interaction in digital environments. However, a multimodal perspective typically relies on 'naturalistic' data drawn from everyday situated interaction, and does not make inferential links between communication and 'cognition', but rather indicates concepts of user 'interest' in their selection and use of communicative resources (Kress, 1997). Since the need to understand embodied learning to inform effective design is critical we took an interdisciplinary approach by studying the rich multimodality of emerging Technology Enhanced Learning environments while also getting at core cognitive/learning constructs of interest to psychologists. As part of the ESRC (Economic and Social Research Council) funded MODE project (Multimodal Methodologies for Researching Digital Environments), the subproject 'Researching embodiment in digital learning environments' brought together researchers from multimodality and psychology to develop a methodological approach that integrated a multimodality perspective with quasi-experimental approaches to provide insight into meaning making through embodied forms of interaction and communication.

We undertook four studies to show how the research design, data collection, and analysis was shaped by the multimodal /quasi-experimental approach. One study examined how gesture, fine and gross motor interaction, posture, orientation and gaze were used when collaboratively engaging in meaning making of science concepts (Sakr, Jewitt and Price, 2014); a second compared pre-school children's touch-based interaction through finger painting on iPads versus paper (Crescenzi, Jewitt and Price, 2014; Price, Jewitt and Crescenzi, 2015); and a third analysed how the design of a digital museum installation shaped young children's bodily interaction and communication (Price, Jewitt & Sakr, 2015; Price, 2017). Drawing on the fourth study of 9-10 year old students engaging in a mobile learning activity to support children's learning about history, we provide an illustrative example that highlights the opportunities and challenges of this methodological integration (also see Sakr, Jewitt & Price, 2016; Price, Jewitt & Sakr, 2016).

The role of embodiment emerges in terms of 'context' or situatedness that is central to shaping meaning making. Ideas around 'context' have also developed with technological change, most notably through technologies that integrate location-based features, social networking, and mobile computing generally. According to Dourish (2004) the idea of context here emerges from socially negotiated activity and can be constructed from features of the environment. A link therefore exists between action and meaning. With mobile technologies learning is no longer restricted to classrooms, increasingly connected mobile devices and similarly connected augmented environments can bridge gaps between learning contexts, and contribute to the construction of a broader knowledge base. The emergence of representation, when linked to action through a dynamic interrelationship with the environment offers new potential for learners to create meaning through resources that uniquely combine physical and digital information constructing meaningful contexts. In particular, their location-sensitivity can provide contextual relevance for digital augmentation, which enables "meanings of places [to be] augmented by data overlays" (Farman, 2012, p.39), supporting new identities and insights (Mills, Comber & Kelly, 2013). The use of photos and artefacts can make "history more meaningful and emotionally relevant" (Lerner, 1997 cited Jones, 2010), while simutaneouly bringing aspects from the past 'closer' and enabling student engagement in location with different time periods simultaneously.

This study aimed to understand the role of technology in mediating embodied forms of interaction, and the implications of this for students' meaning making. To do this we explored how mobile technologies might support history learning through fostering different embodied experiences of place, the reimagining of space, and emotional engagement – an important component of history learning (e.g. Foster & Yeager, 2001). A learning activity was purposefully designed for the iPad using *Evernote* (freely available and easily configurable by everyday users, making it accessible to teachers) to engage students in exploring experiences and events of the Second World War (WWII) that were directly associated with their local Common. This was an intervention study, that drew on concepts of multimodality in the design to exploit different modes of communication in the form of digital artefacts (texts, photos and audio notes) linked via GPS to specific physical locations. These 'notes' were represented by flags on a digital map of the local Common and were positioned relevantly to physical features and the information contained in the notes. Students could also make their own digital artefacts (photos, text, sound files) during the interaction.

Sixteen pairs of students aged 9-10 years used the iPad app for 25-30 minutes to freely explore historical experiences on their local Common, and compare these with their present day experiences. A researcher accompanied each pair to video record their interaction, and manage any technical issues.

Our analytical lens drew on multimodal processes and transcription ideas, using a grounded theory approach with 3 key stages; *(i)* Immersion in data to produce a rough multimodal transcript and identify themes; *(ii)* Sampling of episodes in the data where emotional engagement was prompted or supported (e.g., use of language explicitly expressing emotion; gesture like clenched fist); and *(iii)* detailed time-stamped description of each episode, focused on modes of bodily movement, orientation, posture, gaze, gesture, facial expression, interaction with iPad and talk (Figure 1).

	A: I think it was because if there was… **A looks up** B: because this is a big place **B raises both arms, lowers one and then the other quickly** …like a war, And… **B uses his left hand to gesture at the space, his gaze is in the same direction as this gesture, looking out into the space** …it's like… **His other arm comes up to refer to the space** …proper big.… **B turns 90 degrees, dropping both of his hands, his gaze shifts back to A** …You could just plant them anywhere
	A: and if like a bomb was coming **A accompanies this statement with an arm gesture beginning above her head and coming down towards the ground, indicating the dropping motion. She turns her gaze back towards the iPad, and takes hold of it with both hands.** …Then it could … B:… it could explode the whole ground. **B gestures with arms first crossed then uncrossed to gesture horizontally across the ground** A: and the guns could just like shoot up B: yeah. Just shoot **A looks back at iPad** B: you'll look at the grenades and the guns will just keep shooting **B gestures with hands in rhythmic repeated way up and down**
	A: (reading from iPad) 'how does the idea of guns on the common make you feel?' **A looks up from the iPad and into the distance** A: Er, it makes me feel **A looks back at the iPad momentarily, then up again** …quite sad, because, like, the common's a nice place, but then… **B looking around** B:… there's no point in having a fight here. There are other big places **B gestures with hand palm open to indicate 'elsewhere'** A: yeah it was a nice green land. And London isn't exactly a nice green land and its nice to have a green space

Figure 1. Example Transcription (parental consent obtained for images to be published)

From this transcription we can see that the students are creating a shared visualization of the event that is seeded by information they are getting from the iPad, providing a re-imagination of place. Similarly, after hearing an audio of soldiers marching near a concrete paved area on the common, they linked this activity to this location through their own physical enactment of marching. Students also took photographs of their current environment to link physical features to past events conveyed on the iPad, for example, they photographed holes in the tarmac pavement that 'represented' bomb craters. This suggests they were actively configuring their experience in conjunction with the mobile-based activity. We can identify how these multimodal resources provide a basis for understanding how students construct meaning, we can see how the embodied – in situ - nature of the experience, together with the physical resources, such as holes in the tarmac, paved areas, led to key place holders and physcial markers of historical events. Thus students created 'signs' with new meaning attached. Such markers or signs act not only act as memory prompts, but also formed the basis for re-imagining 'place', and for reflection and interpretation of the digital texts provided (Price et al., 2016). Furthermore, the combined acts of reflection, interpretation, re-imagining and comparisons to present day life helped to foster emotional engagement with the past (Sakr et al., 2016).

Similar to Bennet's (1995) reflections from museum interaction, the mobile history study showed how through the acts of walking and experiencing the common in conjunction with key digital 'objects' or 'artefacts', the students created narratives where they considered themselves in relation to other people and events in history. For example, the sounds of birds singing in juxtaposition with imagining bombs falling; or the feeling of being squashed in the dark, underground shelters in comparison with the light and space they experienced on the common. Through this, features of the common took on new meaning for the students.

Researching notions of 'embodiment' through different digital interaction contexts made salient some important synergies and fundamental differences between a social semiotic multimodality and a cognitive perspective. This created both tensions and challenges as well as benefits in terms of how we research embodiment in emergent digital interaction contexts. One tension from a multimodality perspective was the need to undertake observation of interaction with designed interventions, rather than traditional naturalistic interaction, which is central to a social semiotic approach. However, this 'need' also provided opportunities for applying a multimodal analytical approach in new research contexts, ie interaction with emerging digital interfaces. Another key tension arose in analytical practices – not from the foregrounding of bodily forms of communication, but rather from the focus of analysis. Psychology analysis typically takes a holistic approach, using all of the data to look for patterns of interaction, while multimodality identifies key relevant points of interest from the data to undertake in depth analysis. Collectively we needed to manage this tension. Given the data we generated, we were able to draw on analysis of the patterns of interaction to inform key points of interest, combining aspects from both analytical perspectives. For cognitive research, drawing on a multimodality perspective provided a more focused lens for inferring information to inform the design of research interventions, data collection and analysis, particularly in terms of transcription practices, coding and analysis of modes. For multimodality this work offered opportunities for theoretcial development e.g. in terms of identifying 'new' modes of communication, such as, touch. A key consideration moving forwards is to engage with multimodal description to theoretically inform notions of embodied learning, as we have above, through an understanding of how specific resources and experiences are used to build new insights about history, create new memories through physical and digital markers, and form the basis for re-imagining the meanings associated with 'place'.

b. Designing Gesture-Enhanced Simulations that Facilitate Learning

In this second program of research the embodiment perspective feeds directly into the design of learning technologies, and a focus on the gestures that students make informs the iteration of simulations that accept gestures as input. The initial rationale for creating these simulations came from a set of studies showing benefits of having students bodily involved in learning (e.g., Glenberg, Gutierrez, Levin, Japuntich, & Kaschak, 2004; Goldin-Meadow, Cook, & Mitchell, 2009; Plummer, 2009). In the area of technology, Lindgren, Tscholl, Wang, and Johnson (2016) showed that whole-body gestural interaction with computer simulations led to higher gains than mouse and keyboard interactions with the same simulation. Other digital environments have been shown to effectively support productive social learning using motion tracking and various shared displays to facilitate collaborative interactions (e.g., Enyedy et al., 2012; Johnson-Glenberg, Birchfield, Tolentino, & Koziupa, 2014) These studies demonstrate that having students move in meaningful and natural ways that align with target knowledge and practices can improve learning outcomes. Importantly, it was not simply having learners perform any kind of movement that led to gains in these studies, rather these were body actions that were carefully designed by the researchers and informed by their understanding of the target concepts, and in some cases, how experts have been observed to move when engaging with these concepts.

None of the aforementioned studies, however, conveys precisely how to proceed with designing learning interactions that achieve these meaningful connections with core knowledge and expert practice. Here we briefly describe the experience of applying ideas of embodiment to simulation design from the GRASP Project—GestuRe Augmented Simulations for supporting exPlanations. The goal of this project was to create computer simulations that would encourage students age 11 through 13 to make representative gestures with their hands while offering explanations for observable science phenomena (the Earth's seasons, gas pressure, etc.). Current science standards are putting more and more emphasis on student construction of explanations and identifying causal mechanisms (e.g., National Research Council, 2012). However, while we knew that we wanted to create a simulation that allowed students to develop their explanatory ideas using their hands, we did not know at the outset what these particular gestures should be. There were some constraints put on us by the particular technologies we were using—in this case we had decided on the Leap Motion device, an upward facing camera that rests in front of a laptop computer and is capable of creating real-time models of student hand movements such that they can be used to interact with software applications. However, the larger issue was selecting gestural input that was commensurate with the focus on causal mechanisms that we were trying to elicit from the middle schools students we were working with.

To address this challenge, we began by conducting interviews with students, without using interactive technologies, where we simply asked them to try and explain the phenomena we described to them. These were challenging topics that students often struggled to explain, so we often prompted their thinking with new ideas ("Another student told me that gases are made of something called molecules…") in an effort to observe the explanations develop. Of central interest was the role that gestures played in the formation of these explanations, and what kinds of gestures specifically affected this process. An illustrative case is that of Jada and the topic of gas pressure. Jada was asked to explain why a plastic syringe with the end blocked off could be pushed down partially, but not all the way, and that when you let go of the plunger it popped back out again to its initial position. At first Jada struggled with the notion that air could do anything. When asked about what was in air she said "*you usually think of air like there's nothing, it's like nothing*." After this she was introduced to particulate ideas of matter and shown a computer display with air molecules bouncing around like balls. With this new conception in mind, she was able to start constructing mechanistic explanations about the plunger, and the gestures she performed appeared to scaffold these explanations.

> **Student:** So like, umm, this is like a barrier [she holds up her right hand flat with her fingers pointed outward (Figure 2.a)]. So, like, if it's not, if it's far back here. And there's like a lot of molecules [She taps the fingers of her left hand against the palm of her right hand (Figure 2.b)] So the molecules are like not touching the barrier a lot of times. Very few times. And when the syringe is pushed in there's like, there's still the same amount of molecules, it's just there's more pressure because the molecules are pushing against the barrier. [now her left hand is a close fist and she's showing it pushing against the palm of her right hand (Figure 2.c)].

Now that she had adopted what seemed to be a productive gesture scheme for representing the molecules inside the syringe, the researcher probed further for an explanation of why the plunger pushes back out. At first she is not sure, but when she reintroduces her gestural representation she is able to give a fairly good account of the mechanism.

> **Interviewer:** And then why does the, why does the syringe pop back out when, when you let go of it?
> **Student:** I don't really know. I mean. I thought I knew, but I just couldn't really know how

to explain it.
I: Okay. What are your ideas?
S: I guess it's like the atoms are like, they are pressed against the barrier. But when you take your hand off, there's not a lot of pressure pushing against the atoms. So the syringe falls backward. Or the barrier. And it doesn't really have a lot of, and the atoms stop hitting it as many times as it did before. [At this point she does use her hands to show the molecules hitting the syringe, but seems to be emphasizing the infrequency of this hitting by having her fingers move far from her other hand (Figure 2.d)]

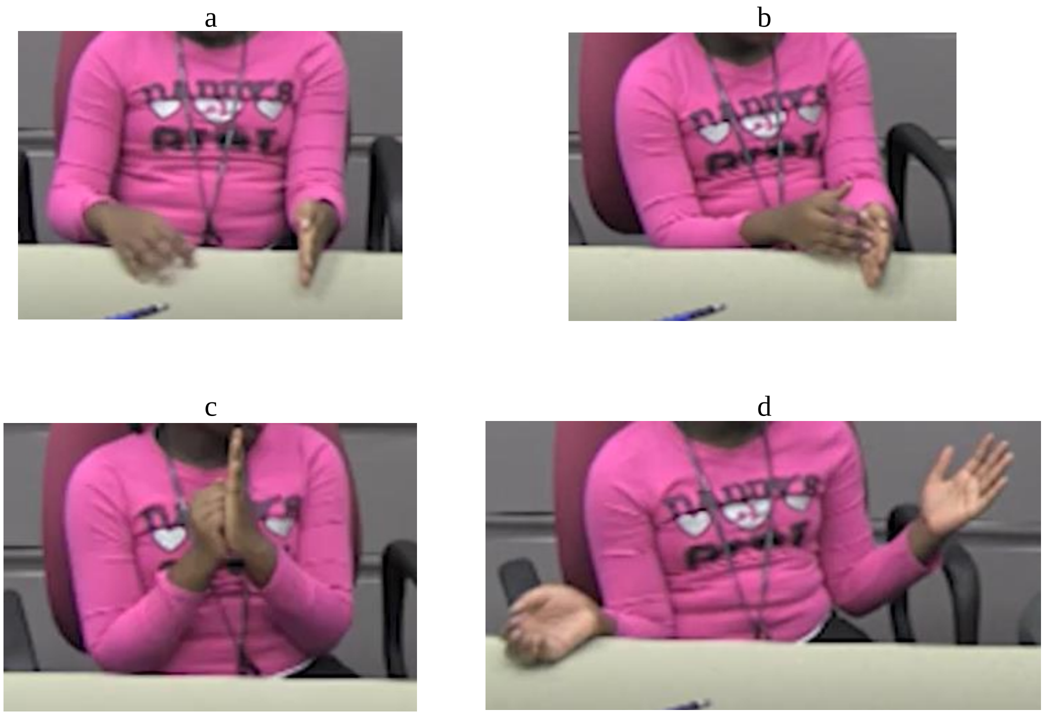

Figure 2. The sequence of gestures that Jada performed over the course of giving an explanation about gas pressure inside a closed syringe.

A close look at the embodiment that Jada employed in her explanation became the inspiration for the gesture-based simulation design shown in Fig 3. To use this simulation a student represents the wall of syringe with one flat hand, and uses the closed fist of the other hand to represent the molecules (a closed fist was used because the Leap has difficulty recognizing individual fingers). By hitting the fist against the palm of the other hand rapidly, the frequency of collisions increases and the simulation shows the volume of the enclosed space decreasing. If the user slows down the rate of collisions, the volume increases. This interface scheme is quite unique compared to the majority of available computer simulations of similar phenomena where the user typically controls things such as the volume of the container directly, often by changing a numeric parameter or dragging with a mouse. However the traditional interface scheme also seems prone to leaving students unaware of the core mechanism that caused gas pressure (the collisions of molecules) and focusing instead on a description of the observable elements.

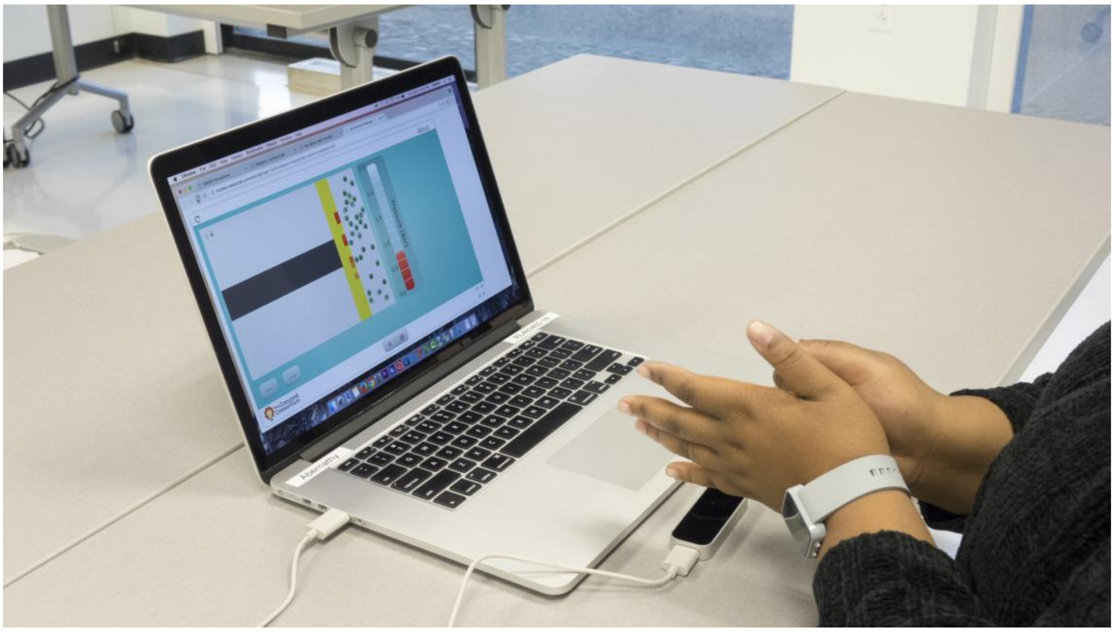

Figure 3. The GRASP simulation of air pressure where a user controls the simulation by representing the frequency by which the molecules are striking the surface of the container.

The majority of the activity on this project since the development of this simulation has been observing students use the simulation and attempt to offer explanations both during and after its use. Over the course of over 50 interviews just on the topic of gas pressure, we have made numerous insights about how students are leveraging their embodiment to made conceptual headway, and we made several observations that have led to changes to the simulations design. Many of these changes are detailed in Wallon and Lindgren (2017), but a couple highlights include the addition of “ghost hands” that help students make a connection between their hands and the elements of the simulation. For example, when a student first attempts to use the simulation, a semi-transparent hand shows up on screen that guides the students to use a flat hand to represent the wall. After the student does this successfully, the ghost hand disappears and the wall changes color to indicate that it is actively under the student’s control. Embodied interactions seem to be particularly effective when a student feels that they are part of the system they are engaging with, and so the goal with the GRASP simulations is to embed their hands in a realistic way into the phenomena to give them explanatory power. We have also made smaller changes to the simulation, such as adding red dots on the digital syringe wall to indicate when a collision occurs as a way to emphasize these collisions as the causal mechanism. Although the timing of the red dots do not necessarily synchronize with the tapping of the hands, the rate of collision is matched, and students seem to understand that their action is controlling the average rate of collision within the simulation.

From a design perspective, an analytical focus on embodiment can serve both as the instigator of design as well a way to assess and iterate upon existing designs. In the case of GRASP, we looked for ways that embodiment appeared to naturally augment student thinking and reasoning, and we found ways to elicit that same kind of embodiment from a digital interface. Once the simulation was prototyped, we observed closely the ways that students used them, and we asked probing questions such as “what do you think will happen if you do this” and “what do your hands represent here?” The focus is not only on what the students say, but what things they try to do with their hands, and how these experiences affect how they gesture after using the simulation. We have been in a constant cycle of collecting data about what meanings and what connections students are making, and modifying the design in ways that potentially improve these processes.

III. Bringing Students, Researchers and Practitioners Together Around Themes of Embodiment

a. Embodiment Training and Research Activities

Developing new communities around embodiment and embodied design that engage researchers and enculturate students are critical to progressing the field of technology design and understanding interaction and learning in body-based digitally mediated learning environments. Teaching and research activities for students, early career and established researchers and practitioners foster capacity building in this area.

Both authors independently led research seminars and training for PhD students and early career researchers to introduce participants to contemporary theoretical perspectives of and analytical approaches to 'embodiment.' This meant exposing participants to challenging philosophical and psychological works from authors such as Martin Heidegger, Maurice Merleau-Ponty, Andy Clark, and Alva Noë, with the goal of applying these ideas to the specific context of interaction with digital technology. For example, in the US, participants worked with teachers in a local primary school to design an embodied learning intervention, to collect data, and make interpretions of the experience that would inform future design iterations. In the UK a summer school provided opportunities for discussion of key issues and challenges of researching embodiment in learning contexts. For example, there were debates around questions such as 'What is the body?', 'Why does the body matter in the context of digital technologies and learning?', and 'Why would a particular body action help someone learn something in literacy or history or math?'. Hands-on workshops provided the opportunity to work practically with ideas and methods introduced, through detailed walkthrough of video data analysis examples and application of the analytical process to their own data. Table 1 shows example questions that helped focus video data viewing under key themes selected for that particular exercise. A plenary session raised key challenges around definitions of embodiment, identifying the unit of analysis, transcription practices, and tensions involved in moving from descriptions of interaction to inferences about learning.

Bodily constraint	**Enactment**	**Physical-digital mapping**
How might we describe 'bodily constraint' – what does it look like? How does 'bodily constraint' affect interaction? In what ways? What communicative messages does it send out?	What are people doing with their hands? How are people positioning their body? When does action become gesture? What are other people around them doing?	What is the person doing and how does the digital representation reflect this? How do people interpret the physical-digital mappings? Can you describe/ define the physical-digital mappings?
What does this tell us about the relationship between embodiment, digital technology and learning?		

Table 1: Example questions to guide video data viewing

Drawing on these activities, a free online open access self-learning resource about embodiment was developed (MODE embodiment training): including a glossary of key terms related to research on embodied interaction in digital environments (MODE embodiment glossary). It includes entries on approaches (e.g. 'Phenomenology', 'Embodied Cognition'), concepts (e.g. 'Touch', 'Gesture') and technologies that foreground bodily interaction (e.g. 'Tangibles', 'Haptics'): The training sessions brought together an interdisciplinary mix of researchers (sociology, art, performance, psychology, media and communication studies, literacy and education studies, human computer interaction, design, and architecture), demonstrating the broad reach of 'embodiment' as a theory, lens, and concept in research across a variety of contexts.

b. Move2Learn: A Nascent Researcher-Practitioner Network

In addition to developing student and researcher communities, as illustrated in the previous section, it is also critical to develop researcher-practitioner networks. These networks are instrumental in ensuring that the most current research findings and verified methods are being put to use in educational practice and are accessible to the general public. They also ensure that researchers are using authentic contexts and meaningful learning situations as the focus of their investigations. The importance of research-practitioner collaborations has been emphasized in education and the learning sciences previously (e.g., King & Dewitt, 2013), but we believe this is especially important for embodiment work where examining naturally occurring embodied interactions is essential and can be difficult to generate in the artificial confines of a research laboratory. We describe here below one emerging researcher-practitioner effort that the authors have been cultivating for the last couple years. While other networks on different aspects of embodiment and design are needed and welcome, we believe the Move2Learn network embodies—pun intended—several of the characteristics and key challenges of this new frontier of research and design work.

Move2Learn is a recently funded Science Learning+ Project supported by the NSF, the Wellcome Trust, and ESRC. This project brings embodiment-themed networking and collaboration to an international scale; it also brings university researchers together with educational and museum practitioners in ways and at a scale not seen before. We believe the success of this unique network rests on the fact that we are targeting the places (i.e., science centers) and developmental levels (i.e., preschool children) where embodiment occurs quite naturally and without much constraint. We are interested in characterizing how gesture and other forms of physical engagement interact with science learning outcomes across a broad range of cultural venues. Practitioners and researchers will collaboratively study young children's physical engagement across a variety of science exhibits to develop a shared understanding around embodied interaction and, specificly, the role of particular actions and gestures in supporting children's conceptual development around scientific ideas. As part of this work we will extend current measurement tools to develop an observation isntrument that will enable practitioners and researchers to both inform the design of new exhibits to foster key identified actions, and to evaluate the degree to which the design of exhibits does foster specific actions. The collaboration has wide outreach networks within educational practice (both informal and formal) and academia, that offer opportunity for widespread impact. In addition, the project is designed to iteratively engage with a number of science centres across the UK and US to develop a model of practitioner-researcher collaboration.

IV. Final Thoughts

We conclude this chapter with some with some key design and research considertations when specifically addressing issues of embodiment. First, consider research methods that expand observation of human activity beyond what people write and what they say to embrace what they *do*. We encourage researchers to explore ways that questions can be answered by taking note of the actions people are taking and the physical metaphors they are invoking. Second, when building new environments for human activity, consider ways to leverage modes of communication and learning that engage the body. In other words, how can new designs take advantage of what we know about how people move through space or how they gesture or how they interact with objects? How can we exploit digital interfaces to augment/enhance physical experience, e.g., with abstract ideas, across time periods, across different spaces? Third and finally, we urge researchers to use and continue to develop expertise on embodiment from both academic and "real world" sources. When creating a new interactive experience, or simply trying to understand what is happening when one is engaging with an existing interactive, there is value in drawing on *both* the theories of embodiment philosophers as well as tapping into the practical experience of teachers or museum practitioners. We are optimistic that the current enthusiasm around embodiment and education, paired with these considerations, will lead to productive and insightful new endeavors.

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