2 Getting into the Cue

Embracing Technology-Facilitated Body Movements as a Starting Point for Learning

Robb Lindgren

An aspiring pianist faces challenges on several fronts. A child taking piano lessons, for example, is typically being exposed to music theory for the first time, and there is much to be gained from understanding how the instrument works—its mechanisms for producing sounds, how it is tuned, and so forth. But perhaps the biggest challenge to playing the piano is simply knowing how to move. Proficient piano playing necessitates a nuanced physicality comprising specialized and refined movements of hands and positioning of the body. In recognition of the bodily complexity required, piano instructors will frequently employ an instructional technique of having the student place her hands on top of the instructor's hands as they play scales or simple tunes. As the instructor and student engage in this exercise it is the student who is reciting the notes and articulating the connection between the music she is reading and the movement of her fingers. So while the instructor is providing the engine that drives the physical activity, the work of developing the associations between symbolic note, the pressed key, and the resulting acoustics is of the student's manufacture. The anticipated outcome of this instructional approach is really the essence of playing the piano—knowing how to move your body and operate an instrument so as to enact a piece of music, accessing the symbolic representations of notes and measures by turning them into action.

This type of physical coaching as a means of developing knowledge in a domain is certainly not unique to playing the piano. We find body-based approaches to instruction in numerous skill and performance areas, such as manufacturing and repair industries, medical professions, such as surgery and dentistry, and sports. Tennis coaches, for example, will put students through intense body modeling exercises that often involve the instructor micro-shaping a student's stroke and body position. Correspondingly, there are new technologies with these body-based pedagogies built in, such as haptic devices that help students of tennis adjust body position prior to a shot, and a wealth of sophisticated video and analytic software that help a player make fine-tuned adjustments. The commonly held assumption is that these hyper-refinement techniques in the various disciplines just listed are employed so that specific movements can be performed over and over again, such that the ideal hand positions for cleaning teeth or the effective body posturing for initiating a high dive can be executed instinctually. The ability to train these kinds of bodily actions to the point of being reflexive—popularly referred to as ‘muscle memory’—may certainly be part of the rationale behind body-shaping techniques, but it cannot be the whole story. The tennis player who had her stroke fashioned by her coach is not likely to find success through the rote performance of precise body action irrespective of weather, court surface, opponent characteristics, and so forth. Tennis players, masseuses, surgeons, and mechanics all trade in finely tuned motor performance, but these are actions that by necessity can be adapted to the environment and context of execution. The tennis player’s stroke is not a mindless chain reaction of muscle activations; it *knows* something about the physics of a hollow fuzzy ball zipping through the air. This is not a form of knowing that a tennis player is likely able to express through equations or even exact verbal descriptions; rather it is knowing that is seemingly contained within the actions themselves, cultivated over numerous cycles of body shaping, performing, and implicitly processing the feedback they receive. Akin to the piano student resting her hands on the hands of her instructor, we learn much of what we know about the world by responding to its cues, moving in ways that are adaptive for the skills and performances we aspire to achieve.

This perspective on the connection between knowledge and the body is consistent with theories of embodied cognition (Barsalou, 2008; Glenberg, 2010; Wilson, 2002) and approaches to embodied learning (Abrahamson & Lindgren, in press; Black, Segal, Vitale & Fadjo, 2011) that are echoed throughout the book. These theories are rooted in the basic premise that body movement and how people interact with the physical world have profound effects on cognitive processes, with research supporting an embodied foundation even for higher-order and abstract concepts (Boulenger, Hauk, & Pulvermüller, 2009; Gallese & Lakoff, 2005). Importantly, if it is the case that cognition is grounded in the sensorimotor activity of our bodies, then expanding the body’s repertoire of movement and available forms of physical interaction with the environment will create fertile soil onto which we can lay the seeds of new learning. It also follows that learning interventions may be enhanced by cueing learners’ bodies to perform specific actions that are believed to facilitate a particular type of conceptual development. However, identifying and prescribing the performance of specific body movements is not a trivial undertaking. We do not always have the luxury of other humans available to shape our movements in optimal ways, and in many cases having other people micro-cueing your physicality will be intrusive. Fortunately, there have been tremendous advances in immersive, tangible, and digital visualization technologies that make it possible to shape not simply how people are thinking or how they allocate their visual attention but also how they move.

The purpose of this chapter is to discuss body cueing and its role in instigating new learning. I briefly examine how cueing has been employed in psychology, education, and professional training research in the past, and describe studies suggesting the possibility that cueing physical movements can be an effective way to instigate, sustain, and extend learning processes across a wide range of domains. I specifically discuss the role that digital technologies can play in cueing body movement that engenders learning, and I offer a few examples from my own research on using embodied cues as a way to cultivate conceptual development. The chapter concludes with some guidelines for utilizing body cueing in educational designs.

A BRIEF HISTORY OF CUEING FOR LEARNING AND TRAINING

'Cue' is a versatile term with a myriad of definitions, but one that is particularly useful for current purposes is 'anything that excites to action.' Cues can emerge via any of the sensory modalities, and they pull us into the environment through the simple mechanism of asking us to respond. Cues can be ignored, but many of the world's cues are wholly seductive. Paved sidewalks and numbered pages in a novel generally keep people on a prescribed path. Blaring alarms and foul smells will, for the most part, keep people from entering troublesome areas. The word 'cue' has a long history in research in visual psychology, and it shares some underlying ideas with the notion of an 'affordance' (Gibson, 1977), but the terms should not be used interchangeably as a cue is more explicit in its call to action. A red octagon does not afford stopping; it is telling you in no uncertain terms to do so.

The application of cues to materials and environments designed for learning is by no means a new idea. Many classic studies in cognitive psychology examining basic processes of learning and attention have shown the significant effects of using cues to guide visual focus. The Posner (1980) cueing task, for example, uses arrows and highlighted regions of a display screen in advance of stimulus presentation, and this paradigm has been used in numerous studies to explicate the mechanisms of attentional shifts (e.g., Green & Woldorff, 2012). More recent work in perceptual psychology and education has focused on the roles of cues in instructional diagrams and animations, such as the finding that participants scored higher on a posttest of biology concepts when an animation cued their attention to pertinent subsystems (de Koning, Tabbers, Rikers, & Paas, 2009). Grant and Spivey (2003) conducted a particularly insightful study of learning and visual cueing (with the provocative subtitle "Guiding Attention Guides Thought") showing that participants' problem-solving performance could be improved by directly cueing them to look at the visual features of the problem that were given the most attention—as measured using eye-tracking technology—by individuals who had solved the problem previously. This is an experimental finding that is consistent with anthropological work on how experts in domains such as archeology will cue the attention of novices as a way of transmitting critical knowledge and developing "professional vision" (Goodwin, 1994).

Whereas the research literature on visual cueing has been fairly steady, research on body cueing has been more sporadic, with studies arising from specialized areas of psychology and human performance. In their review of social embodiment, Barsalou, Niedenthal, Barbey, and Ruppert (2003) describe how positioning people's bodies in specified ways can alter their affective and motivational states. In one study, for example, participants who were asked to assume an upright body positioning outperformed participants instructed to maintain a slumping position on a puzzle-solving task, presumably due to the disposition of confidence and perseverance that an upright stance conveys (Riskind & Gotay, 1982). The efficacy of 'power poses' (e.g., leaning over a table with raised shoulders) has been supported by neurophysiological measures showing elevated neuroendocrine levels compared to more passive poses (Carney, Cuddy, & Yap, 2010).

The specific methods of shaping physical behavior and cultivating motor skills vary across disciplines, but the theme of body cueing has had a significant presence in the area of training and professional development over the last half century, including research on sports training (Ackland, Elliott, & Bloomfield, 2009), occupational safety (Hale, 1984), and military training (Gagné, 1962). Much of this research has focused on how to effectively design technologies, such as simulations, to administer these cues. A Department of Defense report on aircraft simulations from the 1970s, for example, discusses the how to implement "kinesthetic cues" that guide pilots to perform specific actions (Matheny, Lowes, Baker, & Bynum, 1971). For surgeons and other medical professionals the mastery of precise body positions when performing certain procedures has critical importance. In many respects medical education has led the way in recent years in innovative techniques for body cueing, combining rigorous instructional interventions with advanced simulation technologies as a means of refining what are typically referred to in medicine as "psychomotor skills" (Satava, 2001).

BODY CUEING AND THE DEVELOPMENT OF ACADEMIC KNOWLEDGE

Compared to a long history of body cueing in training and skill development, research that demonstrates the effects of linking academic topics to the structure and movement of learners' bodies is nascent. There are some recent studies, however, that show benefits of classroom interventions that build from students moving in specified ways in elementary mathematics (Shoval, 2011), elementary science (Plummer, 2009), middle school and high school kinematics (Solomon & And, 1991), and undergraduate astrophysics (Richards, 2012). Many of the curricular interventions that have been developed around student movement are based in Piaget's constructivism and creating experiences that put students in a state of disequilibrium (e.g., Kamii, & Devries, 1993). Druyan (1997), for example, describes body-cueing activities that are designed to generate "kinesthetic conflict," such as having elementary students hop a zigzag path as a way to confront beliefs about conservation of length.

A recent strand of Susan Goldin-Meadow's work on gesture in mathematics examines the effects of explicitly prompting students to gesture while reasoning. In one series of studies, elementary students who were told to gesture while solving algebraic equivalence problems produced more new insights and were more likely to benefit from formal instruction compared to peers who were instructed not to gesture (Broaders, Cook, Mitchell, & Goldin-Meadow, 2007). Importantly, these learning effects have also been shown with specific cues for *how* to gesture, such as instructing children to put their fingers in a 'V' formation when referencing the addends of an equation (Goldin-Meadow, Cook, & Mitchell, 2009). This line of research supports the idea that correctly cued body movement can precede learning and understanding, and the prospect that "we can thus change our minds by moving our hands" (Goldin-Meadow, 2011, p. 595).

Body-cueing interventions have strong potential, given their ability to build upon the substantial literature articulating the embodied foundations of knowledge in various academic domains, such as science, mathematics, and the humanities (e.g., diSessa, 1993; Lakoff & Núñez, 2000; Slingerland, 2008). There is also emerging evidence for the critical role of teachers' and students' body and hand movements in educational discourse (Alibali & Nathan, 2012; Johnson, 1989; Nemirovsky, Rasmussen, Sweeney, & Wawro, 2012), suggesting the utility of explicitly prompting embodied interactions around academic content. Students' bodies can be cued as a means of grounding their understanding in a kinesthetic simulation of a novel domain, or also as a means of adopting a more knowledgeable perspective and enacting expert practice (Lindgren, 2012).

BODY CUEING WITH TECHNOLOGY

What makes body cueing as a way to bolster learning activities especially promising are recent advances in hardware technologies and human-computer interaction (HCI) that effectively engage the body in controlling and communicating with simulations and other types of computer applications. Dourish (2001) coined the term "embodied interaction" as a way of anticipating the coming revolution in how people interact with computer software and to emphasize that the design of these technologies must consider how people make meaning from their actions and experiences. Since then a wealth of new devices and platforms—tablets and touch screens, motion input sensing (Microsoft's Kinect, Leap Motion), mixed reality environments, accelerometers and other sensor technologies, haptic devices (gloves, joysticks), wearable computing and augmented reality glasses—have entered the mainstream, making it possible to interact with computers using natural physical modalities, such as touching, gesturing, and locomotion. These emerging technologies have truly changed the paradigm for HCI, creating environments that enable and encourage action, what Kirsh calls "enactive landscapes" (Kirsh, 2013). However, the ability to fully engage the body in interactions with digital technologies does not mean that their interfaces always resonate with our body-based intuitions and our natural processes for learning, nor does it guarantee that these technologies can effectively cue the kinds of body movements that have shown promise for engendering new concepts and new understandings. For instance, the ability to interact with screens and other surfaces through touch has elevated the degree to which people can achieve "direct manipulation" in their encounters with computers (Shneiderman, 1993). Users are able to grab, flick, and activate digital artifacts in much the same way that people manipulate physical objects in the real world, whether on a handheld, tablet, or tabletop device (e.g., Antle, this volume), and there is some evidence to suggest that this type of digital interaction can be beneficial for cognitive processes, such as spatial memory (Tan, Stefanucci, Proffitt, & Pausch, 2002). Comparative studies are beginning to show that touch interfaces are more effective for learning specific concepts, such as multiplication, than traditional mouse-driven interfaces (Paek, Hoffman, & Black, 2013; see also Fails et al., 2005). Because tangible interfaces often do not 'touch you back,' their ability to cue movement may seem limited, but interactive visual landscapes that offer rapid feedback and strategically placed action-contingencies (e.g., 'touch here now or lose the game') can be quite effective at orchestrating an individual's movements, as well as structuring more complex activities, such as group collaboration (Dillenbourg & Evans, 2011).

Haptic technologies go a step further by applying weight, torque, friction, inertia, vibrations, and other movement to a user's experience, simulating realistic interactions with physical objects or administering physical feedback or prompts (e.g., pressure applied to the arm to indicate a procedural error). Haptic technologies are being used primarily in military and medical training applications, but some studies have looked at how these technologies can facilitate understanding in school domains, particularly in science. Han and Black (2011) found, for example, that gear simulations using both kinesthetic (rotating a joystick) and force feedback were more effective than non-haptic simulations in enabling elementary schools students to construct "multimodal representations" of mechanical processes. There is tremendous potential to use haptic technologies not simply to give people realistic physical experiences but also to utilize physical cues to guide them through the experience. Haptic devices can assist learners in positioning their bodies when conducting an experiment: they can augment a tool such that it suggests proper operation, or they can guide learners to move their hands in ways that correctly simulate physical processes, such as molecular interactions.

A third type of digital platform with cueing potential is mixed reality (MR) technologies, immersive environments that comingle the real and virtual, falling in the spectrum between the real-world and purely digital environments (Milgram & Kishino, 1994). Rather than requiring touch or offering physical feedback, these environments often blend natural human movement and orientation in the world with digital augments and overlays. The ability to extend embodied actions with high-fidelity visualizations and real-time feedback has been touted for its potential to promote educational outcomes (Hughes, Stapleton, Hughes, & Smith, 2005; Kirkley & Kirkley, 2004), and studies have begun to show concrete learning gains for engaging with MR technologies for learning in formal disciplines, such as science (e.g., Enyedy & Danish, this volume; Johnson-Glenberg, Birchfield, Tolentino, & Koziupa, 2014). Much like tangible interfaces, the cueing capacity of MR relies largely on the landscape of visual imagery that incites action, but in the case of MR the digital space is often immersive and is able to elicit gross body movements and more complex physical activity. The challenge with all these technologies, however, is effectively mapping the kinds of movements that come from using a digital interface—cued or otherwise—with explicit learning goals. This is an issue, sometimes referred to as "gestural congruency" (Segal, 2011), that is especially important for body-cueing technologies; it would be disadvantageous to prescribe movements and actions if they do not directly support (or even hinder) the targeted learning outcomes of the intervention (Lindgren & Johnson-Glenberg, 2013).

EXAMPLES OF BODY CUEING WITH TECHNOLOGY FOR LEARNING

I now offer a few brief examples of projects I have worked on where the objective was to cue the bodies of learners using emerging technologies as a way to instigate new understandings.

Example 1: *MEteor*—Cueing the Body to Enact Asteroid Trajectories

The *MEteor* environment is a large, interactive MR simulation that uses a laser scanner and floor-projected imagery to help middle school students develop intuitions about how objects move in space (Figure 2.1, left). A single participant walks out onto the floor and attaches herself to a digital asteroid that she subsequently launches into an area of simulated outer space with planets and other objects that have the ability to affect the asteroid's movement. Once the asteroid is launched with a certain velocity from a certain position, it moves according to an accurate simulation of the forces being applied, and the participant must stay with the asteroid by making real-time predictions about its trajectory. The game objective is to hit various targets on the opposite side of the platform, but the learning objective is for the child to correctly move the way that an asteroid moves when under the influence of gravitational forces (e.g., changing direction, changing speed). The idea is that prompting learners to move in this way as part of the simulation will make them more receptive to formal ideas about concepts, such as gravitational acceleration or the notion that objects in orbit will move faster when they are closer to the mass they are orbiting. A number of interface conventions were put into place to cue the learners toward a correct enactment of an asteroid's trajectory, including a tracking circle that followed the participants and changed color from green to red as they got farther away from the asteroid. The most salient cue, however, was the movement of the digital asteroid in the simulation, which would often traverse a path that the students did not expect, inciting them to adjust their bodies and change course. This was an especially compelling cue because when they first began using the simulation participants were told, "You are the asteroid," and so when it visibly diverged from participants' trajectories, it meant not only that they were not succeeding at projecting its movement but also that they were making a departure from the interaction scheme that was established at the outset.

The body cues in *MEteor* generally led participants to improve in their performance in subsequent trials, often rapidly. For example, in one of the simulation scenarios participants are tasked with hitting a target with their asteroid that is near a large planet. Most participants begin the scenario by launching the asteroid directly at the target, only to discover that their asteroid is pulled off course and sometimes even collides with the planet. For the body-cued participants this means that they must scramble to catch up, moving away from their target in order to maintain the association with their asteroid. What the participant does next is important. In a sample of 41 middle school students who received the *MEteor* body cues, 76% of them made substantial changes to the position, angle, or speed of their launch on the second trial. By comparison, in a group of 36 students who used a desktop computer version of the same simulation (i.e., no body cues), only 51% of these participants made the same adjustments to the second trial. A logistical regression model showed this difference to be significant (p = .031).

Additional studies utilizing the *MEteor* platform indicate that these changes in participant performance and interactive experience as a result of using a body-cueing simulation can translate to higher learning outcomes. In one study it was shown that participants who used the full-body *MEteor* simulation had higher scores on a physics inventory posttest, as well as more positive ratings on a science attitudes assessment compared to participants who used the desktop version of the simulation (Lindgren, Tscholl, Johnson, Glasshoff, & Moshell, 2014). Importantly, this research has also shown that simulation body cues can lead to some basic differences in how students make representations of science systems. In studies where students using the *MEteor* simulations were asked to make sketches of one of the scenarios, participants who received the body cues were more likely to draw dynamic or action-oriented elements (e.g., arrows showing movement) and less likely to draw surface details of the simulation, such as background imagery (Lindgren & Moshell, 2011).

Example 2: *Waves*—Collaborative Cueing to Create Interference

The *Waves* simulation also employed projected imagery on a large floor surface, but motion input sensing was accomplished using ceiling-mounted Kinects, which allowed for multiple simultaneous users. *Waves* is a simulation of transverse waves that a learner controls with her body by moving back and forth past an inferred axis (Figure 2.1, right). The learner essentially embodies the wave's periodicity with his or her movement. Two participants are positioned on the platform, each controlling their own wave, but the wave that is consequential is a third wave that is the mathematical sum of the two participants' waves. This composite wave must be constructed such that it fits within a fixed goal on the opposite end of the simulation floor, meaning that the two learners must work together, putting into effect concepts of constructive and deconstructive interference. The source of body cueing in the *Waves* simulation is different than in *MEteor*. In *Waves* the body cues come from the movement of one's partner—reacting to his or her movements in an attempt to create an aggregate wave that meets the desired specifications (e.g., amplitude).

Research on the *Waves* simulation and its effect on learning and engagement is still in its early stages, but preliminary data from an implementation at a local science center suggests that the body cues originating from social interplay (e.g., "move over here," "get in sync with me") are quite powerful in shaping and improving learner performance within the simulation. Unlike the tracking circle that changed color in *MEteor*, which was often ignored, participants in *Waves* were visibly invested in appropriately responding to their partner's movement to meet simulation objectives. The social body cues also elicited conversations between participants and among observers that occasionally ascended above a discussion of simulation mechanics to conceptual issues, such as the properties of waves and where waves can be

Figure 2.1 Left: A middle school student moving with an asteroid in the *MEteor* simulation. Right: Two science center visitors working together to use the *Waves* simulation.

observed in the world. A key lesson from this project is that impactful body cues do not have to come from digital technologies alone, but rather these technologies can and should work in coordination with the social learning context to compel target body movements.

Example 3: *Siqur*—Avatar Cueing in a Training Simulation

Avatars represent yet another important way in which bodies can be incorporated into learning technologies (e.g., Okita, this volume), and also involve participants learning to become responsive to cues. This project involved a custom-built training simulation called *Siqur*, where a user guided an avatar around a spacious virtual environment, addressing safety concerns. In addition to bolstering a learner's mental model of the work space and his or her knowledge of potential safety hazards, the simulation also sought to address the learner's physical awareness and body positioning in environments where making errors can be disastrous (e.g., manufacturing and other industrial facilities). Typically, training cues for these types of simulations are given by showing learners the environmental conditions that require a response, and then performing a visual demonstration of the appropriate response procedures. In other words, learners must infer the correct behavior of their bodies by observing the physical actions of others. In the design of the *Siqur* simulation, we built in a feature that cued the correct actions by showing them being performed *from the learner's own perspective*. For example, if learners navigate their avatar through the simulation environment and fail to address a safety issue, the simulation responds by seamlessly taking over control of the avatar and performing the correct actions. From the learners' perspective it appears as if they are performing the actions themselves, perhaps empowering the learner with a sense of competence and confidence. The simulation is subsequently reset to the point where an error was made, and the learner must now perform the correct action under his or her own control. In the *Siqur* simulation body cues are administered via an avatar by tapping directly into a learner's first-person system of visual perception.

A study of 56 college-aged participants unfamiliar with the target knowledge and procedures was conducted in which approximately half of the participants received the perspective-based cues and the other half received standard text box cues that told participants what they should be doing in the current situation. With this type of training it was critically important that learners develop a big picture understanding of the environment and what tasks need to be performed where, and thus after using the simulation participants were asked to draw sketches of the environment, showing critical features and indicating where intervention was needed. Figure 2.2 shows comparisons of participant sketches in terms of how many correct task locations were shown (left) and how many "surface details" or superfluous elements were included in the sketches (right), based on whether they

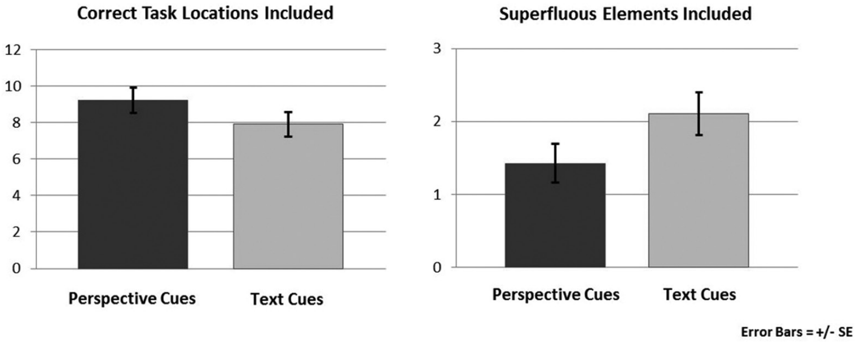

Figure 2.2 Average number of correct task location (left) and number of superfluous elements (right) included in participant sketches.

received perspective cues or text cues. An ANOVA showed a significant interaction between the scores of participants on these two variables by condition: *F*(1, 54) = 6.53, *p* = .014. Compared to the text cues condition, participants in the perspective cues condition included more task-related locations in their diagrams and fewer non-task-related elements. The results suggest that seeding avatar interactions in virtual environments with embodied cues can effectively build a learner's knowledge of critical task domains.

CONCLUDING REMARKS: GUIDELINES FOR BODY CUEING

The preceding examples are intended to be illustrative of the possibilities and the constraints involved in body cueing with digital technologies, but they are certainly not exhaustive of the many different design approaches or the various technologies that can be brought to bear. However, reflecting on these experiences and thinking generally about the implications for designing interventions that involve cueing lead to a few important considerations for researchers and educational designers aspiring to implement this approach.

1. *Base the selection of cues on movement associated with competent performance.* One approach to designing body-cueing interfaces is to simply try an assortment of cued movements and evaluate their respective learning effects. It is possible, however, through developmental studies or studies of expertise in the target domain, to know ahead of time what kinds of movements are optimal for learning and reasoning in that area. Similar to the eye tracking study by Grant and Spivey (2003) described earlier, it may be possible to capture the embodied actions that lead to understanding and successful problem solving, and to deliver these 'expert' movements back

to learners in the form of cues. But identifying and capturing these critical embodied acts are not trivial undertakings, and could require extensive field and lab study prior to even beginning with interface design. I have just begun one project, for example, that seeks to understand the embodied hand movements that students engage in when constructing effective explanations of science phenomena, with the ultimate objective of designing intuitive web simulations that respond to users' natural body-based expressions when reasoning about the physical world.

2. Seek out models from outside domains for acclimating learners to new cueing schemes. One of the most difficult aspects of cueing people to enact prescribed body movements is effectively communicating what it is that you want them to do. Anyone who has ever tried to follow 2-D instructions for putting together a piece of 3-D furniture knows how problematic this communication process can be. But if furniture assembly instructions are a subpar example of body cueing, then a superior example can be found in contemporary video games. The challenge for video game designers is that players desire to be immersed in complex and realistic practices and activities (e.g., warfare, detective work, building and manufacturing, etc.). And yet, if a video game cannot communicate to players in less than 5 minutes how to navigate the environment and operate requisite tools, it is likely that the player will put the game down and never come back. Thus, games in recent years have adopted a number of innovative techniques for quickly getting a player up to speed on what actions will lead to success. These techniques include showing 'ghost' depictions of the desired in-context actions that players can use as a model, embedding AI-driven collaborative agents that essentially scaffold the activity through partial performances or making provocative suggestions, or simply paving a linear action path through an ostensibly open environment by making salient the desired actions and disabling or discouraging alternatives. Although video games present a promising model for how to communicate body-cueing schemes, designers would be well served to examine other fields as well, such as physical therapy, training and simulation, and the martial arts.

3. Make cued movements visible and give opportunities for reflection. A challenge to using body movements as a foundation or even as a metaphor for instigating new learning is that humans often maintain a certain level of unawareness, or at least a lack of attention to, the movements that they engage in. It would be a terrible idea, for example, to try using the movements I execute when tying my shoes as the analogical basis of learning anything. Because whereas tying my shoes is an effortless kinesthetic task at this point in my life, it would be extremely awkward for me to try to articulate how my hands operate to perform this task. For movements onto which new learning is built, this suggests two things. First, the most effective kinds of cued movements for learning are likely to be novel, movements that have not been automatized and that require thoughtful effort to perform them. Second, learners should be offered a way to observe and reflect on these movements, whether this be a playback feature where they can watch the movement in first-or third-person, or by presenting some form of real-time metrics that allow learners to observe what their body is doing with respect to the important features of the target learning domain. Physical performance is an essential part of embodied learning, but equally important is learners being able to see how their actions are an enactment of the concepts they are trying to understand.

The space for research and innovative design in the application of embodiment to learning and technology-enhanced environments is expansive. This includes physical and virtual manipulatives, avatar-based virtual environments and robot interactions, inquiry activities augmented with GPS or physiological sensors, and the various other innovations described in this volume. The focus of this chapter has been specifically on the potential to design interactive learning environments that excite the body to action—technologies that cue our movements and subsequently trigger new inferences or create anchors for lasting memories. It is a fiercely challenging design space that will require rigorous investigation into the cognitive affordances of bodily movement as well as pushing the limits of computer interface design. It is also a design space with enormous potential and great likelihood of payoff, validated by many of our most significant learning experiences, where people in our lives have pushed, pulled, or shaped us into a state of understanding. They are moments of powerful and transformative learning, all of which started with a cue.

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