

# **Learning Technologies and the Body**

Integration and Implementation in Formal  
and Informal Learning Environments

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# Introduction

## Technology Meets Body, Body Meets Technology

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### INTRODUCTION

It is often the case that when new theoretical perspectives about learning become more prominent within the world of education, so do new ways of thinking about technologies. The hope is that we have gained some new insight into how the most current technology of the time, coupled with the most current academic thinking of the time, can potentially change (and hopefully improve upon) the very hard work of teaching and learning. For example, it was only about a century ago when behaviorism rose to popular awareness in the United States. As many students of psychology and education know, behaviorism arose as a critical response to the introspective psychology most commonly practiced at the time, meaning that the use of self-reports and personal introspection were not considered to meet the high standards of scientific rigor, such as observability, measurability, and replicability. Behavioral psychologists, such as Edward Thorndike, John Watson, and B.F. Skinner, advocated instead that those who were seriously interested in the study of human behavior and were willing to do the work of advancing it as a reputable science should focus on the phenomena that were observable and measurable. Research attention moved to observable stimuli, response behaviors, and the associations that linked the two.

Basically, within the behaviorist paradigm, for an individual to 'know' something meant that an individual had acquired the proper set of associations required within a skill. This also implied that the individual had the necessary associations for the various component subskills. The ability to transfer this knowing meant that the associations had been mastered and the range of cues that generated a response had been expanded such that the behaviors would appear across all desired settings. The primary work for those who fashioned themselves designers of instruction was to do a kind of task analysis that involved: identifying of observable behaviors comprising some set of skills, decomposing those into their respective subskills, specifying the conditions in which a given skill or subskill would be needed, and then organizing an appropriate sequence for those subskills to be introduced so that the overall skill was mastered.

This was clearly a great deal of work, and it was thought to be something that could be supported with technology. This eventually led to a device, favored by B.F. Skinner, called a "teaching machine" (Skinner, 1960). The teaching machine essentially began as a desktop-sized box that could receive various kinds of paper and display portions of those papers selectively. One disc-shaped paper fed into the machine contained a preset list of questions or prompts—a program for the student to follow—and another paper was fed into the machine so that the student could write an answer or brief response to the currently presented question. A quick flick of a switch would show the actual answer to the question, and that could be compared to what the student had written. The student would move a lever one way if the answer was correct and her paper would be marked. Progress toward mastery of the skill that was being trained could be tracked based on the marks, and once the questions or prompts were answered correctly, a new skill or subskill program (i.e., different disc papers with more advanced questions or prompts) could be introduced and practiced until the student had demonstrated sufficient mastery of that program. Teaching machines allowed for customization and self-pacing for students, as the student could work at his or her own pace on a predetermined program suited to his or her current level of mastery.

Although the behaviorist paradigm continues to be popular in some educational circles, and technologies that maintain some of the same logic of interaction as teaching machines are still in use today, behaviorism eventually weakened as the dominant perspective for how we should conceptualize the mechanics of knowing and learning. In what is widely known as the "cognitive revolution" of the 1950s (documented in Gardner, 1985), new ways of thinking about learning and knowing emerged from the interdisciplinary collaborations of psychologists, artificial intelligence researchers, linguists, neuroscientists, anthropologists, and others who had interest and concern with the workings of the human mind. One of the core ideas of the newly emergent cognitivist perspective was that the contents of the human mind could be productively discussed in terms similar to those being used for a new technology of the time: the digital computer.

In essence, the cognitive perspective posited that the mental activities could be thought of in terms of knowledge representations and operations on those representations that produced what we might call cognitive behaviors. It was akin to thinking of the mind as a kind of computer that ran programs and had data structures. For example, in solving a multistep mathematics problem, a student would have a set of rules or knowledge structures that were invoked and from which solutions would eventually be derived. Errors could be due to faulty rules or insufficiently developed knowledge structures. With knowledge representations being the bedrock of understanding that served as the new premise for human mental functioning, it was much less acceptable for an educator or psychologist to look at resultant behavior alone and assert that an individual knew or learned

something. Instead, improved 'conceptual understanding' became the target and the processes by which conceptual understanding was reached became a topic of interest. New terms for talking about knowledge and how it was organized in the mind, such as 'schema,' 'mental model,' or 'productions,' appeared in the academic literature, and those became ways of labeling the things that needed to be created or modified in a teaching or learning intervention.

As mentioned earlier, the new technology of the time was the digital computer, and although it started as a room-sized behemoth, desktop-sized machines eventually appeared and became accessible. The learning technologies that followed and were influenced by a cognitive perspective were numerous. They included intelligent tutoring systems that could look at patterns of student responses to specific questions and prompts and infer current knowledge states and make adjustments or offer custom lessons and supports to support schema or strategy development (e.g., Anderson, Boyle, Corbett, & Lewis, 1990). These tutoring systems were informed by extensive cognitive research on problem solving in particular domains and on observations of how human tutors supported learners. They also involved task analysis and mapping of the content domain, but they became more attentive to the knowledge representations that students had and also had within them a more explicitly written knowledge representation of their own. This has largely been one of the primary ways in which artificial intelligence as a field has maintained its involvement in educational technology, and is still prominent and influential to this day.

Also influenced by the cognitive perspective were multimedia systems that involved explicit, empirically tested design strategies to optimally present information in different modalities (e.g., pictures, animations, images, narration, written text) to support multi-channel information comprehension and, ultimately, the development of a particular mental model that could be mentally represented in some way by a student (e.g., Mayer, 2001). Multimedia tools like those, which could show how various systems work or provide an explanation of a scientific phenomenon, were also considerate of an underlying short-term and long-term memory architecture thought to be core to the cognitive perspective. Interactive simulation tools also became popular, with mental model development and refinement as a target for learners who used them as well. New ways of thinking about the relationship between human memory and knowledge as they related to skills emerged. The prominent artificial intelligence researcher and cognitive scientist Roger Schank pioneered the use of interactive computer-based learning environments called "goal-based scenarios," which would establish an authentic use context for learners working in the environment and provide just-in-time information and material to support new knowledge formation, consistent with then-current research on how and when knowledge was stored and updated and how knowledge storage was especially amenable to narrative structures (Schank, Fano, Bell, & Jona, 1993/1994). The key point to take

from this range of examples is the idea that the shift toward a cognitive perspective on knowing and learning was highly influential with respect to the design and development of new learning technologies. Different technologies emphasized different aspects of what was being learned about cognition, but when technology and cognitivism met, new ways of thinking about how to support learning emerged.

Arguably related to (and perhaps already contained within the cognitivist perspective, depending on who one speaks to) but often talked about separately by educational technologists, was the constructivist orientation toward learning. Constructivism, often traced back to noted developmental psychologist Jean Piaget, posited a central continuity in learning that involved prior existing knowledge structures being the basis from which new knowledge structures would be built. That is, we can come to know new categories or concepts in the world only through further refinement of older ones that we already knew. One of the most often recognized findings that came out of Piagetian constructivist research was the idea that learners, and in particular children, were not blank slates. They were active, sense-making individuals who had ways of understanding and interpreting the world around them that did not conform to the ways that adults and experts would necessarily expect. Given that observation and the core tenet that it was from old knowledge structures that new ones emerged, it made sense that giving children's ideas room to be articulated and to develop in the context of meaningful engagement with the world was an appropriate step for educators to take. Technologically, one of the most constructivist-influenced learning technologies came in the form of the Logo programming language (Papert, 1980). One of the main ideas that motivated the development and dissemination of the Logo programming language was that children had meaningful ideas to express and explore and could do so given an expressive medium and language that was both familiar but open enough to allow for a number of new individual creations and explorations. With Logo, children could explore new forms of mathematics and geometry and even create their own games or other interactive environments. These acts of exploration and creation required children to articulate their own prior intuitions and reconcile how things worked within the Logo programming environment with what they had expected. In this way, children simultaneously created computational artifacts and developed new knowledge all while very deliberately drawing on what they already knew or had experience with from their own pasts. With the modern-day resurgence of Logo-inspired programming environments, like Scratch, and with the DIY and maker movements, it is clear that this way of thinking about learning and learning technologies is alive and well.

Yet that did not preclude the arrival of other perspectives on learning, such as a sociocultural perspective. Granted, these already had been foreshadowed by or otherwise overlapped with some of the cognitive or constructivist learning technologies (i.e., both Logo and goal-based scenarios

were influenced by aspects of sociocultural theory), but there had been a threshold reached such that some academics and educators began to more actively critique traditional cognitive approaches. Instead, they favored ones that foregrounded context, culture, and participation in social practices. Sociocultural perspectives tended to be skeptical about the effectiveness of cognitively based approaches to designing learning technologies and instructional environments, in light of the observation that transfer was not easily observed. Also, there was the more heightened awareness that learning also took place in a range of real-world settings for a much broader set of purposes than to simply increase one's store of knowledge. As sociocultural theory developed, the argument was made that increasing one's participation in a group and becoming acculturated to ways of talking and doing things associated with a community seemed to be an important driver for learners in the wild.

Technologically, this led to increased emphasis by technologists on the creation of tools and environments for learners that allowed learners to participate in a set of practices analogous to what happened in the world around them. Even more powerful and more affordable computers were available, as were new devices and media players. When sociocultural theory met technology, this led to developing laser discs that provided anchoring scenarios so that math problems could be put into actual contexts (Cognition & Technology Group at Vanderbilt, 1990), giving children devices to collect data in the same ways that scientists collect data (e.g., Linn & Hsi, 2000), making tools to help students construct evidence-based arguments and explanations that bore greater resemblance to how scholars were thought to talk and write (Reiser, et al. 2001), customizing student-friendly visualization tools similar to what would actually be used by professionals in the field (Edelson, Gordin, & Pea, 1999), or even providing the same cutting-edge modeling tools to kids that are also being used by professional researchers and hobbyists (Wilensky, 1999). It also meant building technological supports for communities of learners, such as jointly shared online knowledge bases and forums for sharing of information and findings from investigative work and as a place for individuals to pose new questions that could eventually be taken up by the community (e.g., Kolodner, Owensby, & Guzdial, 2004; Scardamalia & Bereiter, 1993/1994). In other spaces, it meant creating environments for children to assume new roles and to engage with information in the ways that professionals do, as is the case with projects that ask kids to work as science journalists, focusing their efforts and their interactions with one another to facilitate the production of publicly shared news articles that report on their findings (e.g., Polman & Hope, 2014). Again, the key takeaway here is that a particular perspective on how knowing and learning should be understood coincided with changes in how we think about designing and implementing new learning technologies. Theory about thinking and learning fed into the ways in which we crafted and conceptualized technologies for thinking and learning.

This book has been prepared in recognition that yet another perspective is attaining prominence in education circles. This new perspective is one that can loosely be referred to as the *embodied* perspective. Simply stated, the embodied perspective takes seriously that our physical bodies actually play a very important and, until quite recently, overlooked role in how we think and act in the world. This orientation toward embodiment as central to human thought and action has already been amassing a sizeable (and still growing base) of empirical literature that has together been making the case that mind and body are far more interlinked than previously thought in other perspectives in psychology and in education. Presumably, this has consequences for teaching and learning, and if the patterns of theory and technology discussed earlier are any indication, then we should expect that embodiment will become a much more prominent issue when we think about learning technologies.

Recent activity seems to indicate that this has been the case. Within the past few years, research and development work has been underway at labs around the world to explore how bodies and technologies can come together in service of learning, but the efforts are still, understandably, quite new in comparison to the merging of theoretical perspectives and technologies described earlier. This book has been prepared to serve as an initial effort to bring some reporting of those efforts together into a single volume. The chapters in this book each provide snapshots from quite recent work that has been informed by and is otherwise concerned with how the body plays a role in knowing and learning.

As a collection, the pieces in this volume can be seen as representing a cross section of the current state of affairs for new learning technologies and human bodies. The volume benefits from the efforts and contributions of many established scholars and education researchers, but also brings in new voices and perspectives from those who can safely be predicted to be future prominent actors in the field. Although the collection is diverse, the common thread among all of the forthcoming chapters is the idea that something new and worthwhile can be explored and leveraged from within this new educational space that fits between body and technology. Many of the chapters are explicitly aligned with mainstream embodiment research in psychology, and for others, the connection is more subtle and looks to broader issues of bodily engagement and interaction. Before discussing what each author or set of authors brings to this collection, let us first consider further what is generally referred to when one talks about embodiment.

## EMBODIMENT AND EMBODIED COGNITION

In many ways, widespread academic interest in embodiment came in response to and as a critique against what were then mainstream ways of thinking about human cognition. Although those who were on the ground and doing

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the initial work of cognitive science research and cognitive modeling did not label it as such, critics have positioned the early cognitive work as biased toward the disembodied. The reasons for this characterization are many, but there were at least two major factors leading to it. The first was the emphasis on knowledge representations and processes that could be modeled computationally, given the kinds of technological infrastructure at the time. This meant that much of the terminology and language for talking about cognitive activity involved specification of representation and operations on those representations. For example, the kinds of questions that were asked about knowledge representation tended to be about whether knowledge was best represented as a list, as a special kind of conditional statement that had event-based triggers and subsequent actions that the system would execute, as goals with criteria to be met, as networks of information representing a concept, as a set of prototypes or exemplars against which similarity was judged, and so on. These approaches to talking about cognition implied that the inputs and outputs were a secondary consideration. The models that the researchers built and publicized through journals and presentations generally worked from the same sort of input and outputs that computers used—keyboards, punch cards, displays, printouts, etc. The major concerns were not about how objects were recognized or the sequence of motor actions needed to manipulate objects in the world (although there were some efforts in the areas of computer vision and robotics that considered these issues). The main focus for cognitive modelers was on determining how knowledge, once represented symbolically and in particular information structures, was manipulated to produce intelligent-seeming behavior (Newell, 1980).

A second factor that fed into the characterization of traditional cognitive science as being disembodied was the tendency for cognitive scientists to study domains and problems that worked well for computational purposes, but were not situated in real-world contexts. For example, figuring out how chess configurations were remembered (e.g., Chase & Simon, 1993), how a natural language parsing program that could move colorful blocks around in an imagined space consisting of blocks and a grid of locations where blocks could be placed (e.g., Winograd, 1980), and how to move pieces so as to complete the Tower of Hanoi stacking disc puzzle (e.g., Kotovsky, Hayers, & Simon, 1985) did not seem sufficiently informative to questions that dealt with the realities of how one actually approaches a cognitive task in the real world. To be fair, the work done in those lines of cognitive research was still quite rigorous and had made very substantive contributions to cognitive science. Yet the concern from those who helped push for embodied approaches was that the most prominent cognitive modeling work was tied to symbol manipulation and symbol-based knowledge representations and did not consider the body of the agent that would presumably be doing the work or the real scenarios in which problem-solving activities took place.

Thus, through the 1980s and beyond, when cognitive science was becoming a more recognized program of research, embodiment and embodied



cognition began to emerge. It is worth noting that some of the core ideas of embodiment—namely, the importance of physical bodies and the role of physical action in learning—were not new ideas in scientific history. (Even Piaget grounded the conceptual development in sensorimotor activity of babies, as did others.) However, a series of arguments were put forward from embodiment-oriented cognitive scientists that made the case for a new way of thinking about thinking. Briefly, I review three.

The first of those three comes from noted cognitive linguist George Lakoff and his collaborators. In various publications, they put forward arguments for embodiment as being central to the development of human conceptual systems, in part by turning to the use metaphor in human thought and language as evidence (e.g., Lakoff, 1980; Lakoff & Johnson, 1980). Generally speaking, an examination of human language is rife with metaphors that can be traced back to a spatial basis for their original meanings. We characterize life as a 'journey,' which suggests an object moving through space in a particular direction. We keep certain negative feelings 'inside' that can eventually amass to the point that they must be released. If we are too busy, we may put certain tasks 'aside' or 'drop' a project entirely. When learning new material we grasp 'new ideas' or the message can go 'over our heads.' Through examination of these kinds of statements and the conceptual relations therein, one can see that metaphors are all eventually grounded in some aspect of physical bodily experiences. That is, we are ourselves objects that move through space and we can track objects as they move across our visual field or are grasped or released. This is fundamental to our experience as embodied beings that can visually track things and shift positions. We also draw on our embodied experiences of having manipulated physical objects that can be contained, carried, transported, and released. Other metaphors involve sensory experiences, such as the perception of heat ('She was burning with rage,' 'He kept cool in spite of all the critiques') or weight and resistance ('Having to shoulder all the responsibilities at home,' 'As she visited and said her good-byes to her coworkers, there was a definite lightness in her step').

This use of language, according to cognitive linguists, is not for purely aesthetic or poetic reasons. Rather, this is how we make sense of the world. The sheer volume and consistency with which certain metaphors are used makes the case that these metaphors underlie our conceptual systems. And the basis of these metaphors is our bodies. In fact, they tie back to particular kinds of representations (i.e., image schemas) that are based in our sensory and motor systems. Cross-cultural research shows also how other languages can encode alternate image schemas as a basis for thinking about abstract concepts, such as time (Núñez & Sweetser, 2006). In fact, the argument has been made that mathematical understanding is also fundamentally embodied, drawing heavily on particular image schemas that give rise to set theory and notions of infinity (Lakoff & Núñez, 2000).

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From the noted cognitive linguist George Lakoff and his publications, they put forward arguments related to the development of human conceptual systems and the use of metaphor in human thought and language (Lakoff, 1980; Lakoff & Johnson, 1980). Generally, human language is rife with metaphors that serve as a basis for their original meanings. We characterize an object moving through space and time, and certain negative feelings 'inside' that can be released. If we are too busy, we may 'drop' a project entirely. When learning a new skill, the message can go 'over our heads.' The use of metaphors and the conceptual relationships between them are all eventually grounded in our experiences. That is, we are ourselves objects that can track objects as they move across our field of vision. This is fundamental to our experience of visually tracking things and shifting positions. Our experiences of having manipulated physical objects, carried, transported, and released. Other experiences, such as the perception of heat ('She cooled in spite of all the critiques') or weight ('I bear all the responsibilities at home,' 'As she looked at her coworkers, there was a definite light-

ness') are not for purely cognitive linguists, but rather, this is how we make sense of the world. The consistency with which certain metaphors are used in these metaphors underlie our conceptual relationships between our bodies. In fact, they tie our experiences (i.e., image schemas) that are used in our systems. Cross-cultural research shows that we encode alternate image schemas as a basis for our concepts, such as time (Núñez & Sweetser, 2009). It has been made that mathematical understanding is embodied, drawing heavily on particular concepts and notions of infinity (Lakoff &

Another prominent argument in favor of embodied cognition came from Lawrence Barsalou (1999), who posited a theory of perceptual symbol systems in contrast to the physical symbol systems hypothesis that had dominated early cognitive science. The core idea of perceptual symbol systems was that the encoding of what had been treated as knowledge in the traditional physical symbol systems hypothesis could be more productively thought of as involving the use of modal neural systems associated with sensory regions of the brain and nervous system. That is, when we think of an object such as a car, we do not simply cue the mental equivalent of a feature list of components commonly associated with a car, but rather we also cue up some of the neuronal channels and regions that are activated when we actually see a car. It is not the same as having them all activated and actually 'seeing' a car that is not present, but rather it uses much of the same neural hardware involved in the initial act of perception. This means that the parts of our brains (and bodies) involved in perceiving and also using physical objects in the world are involved in our ability to later think about those objects as well.

Evidence in favor of this has come out of studies by Art Glenberg and colleagues who showed quicker reaction times for individuals who, unbeknownst to them, needed to take response actions to prompts on a screen that mapped onto a brief description of a similar physical action (Glenberg & Kaschak, 2002). For example, research participants were quicker at pushing a button that was closer to their body after seeing the words "open a drawer" than they would be if they needed to push a button further from their body; they were faster at pushing a button away from their body if they saw the words "close a drawer" than they would if they needed to press a button closer to their body. This and other studies suggest that even in text comprehension when we are interpreting written symbols, we are cuing the same systems that are involved in actually enacting the movement, which leads to the quicker responses in the experiments. Further studies of simulated and enacted actions suggest comprehension and recall improvements in kids as well, providing further support for understanding being in some way embodied (Glenberg et al., 2004). Together, it seems that our minds use information from how our bodies engage with the world to engage in thought.

There have been a number of other experiments showing some sort of connection between physical bodily experience and thought. For instance, making a fist or assuming a power pose can change one's perceived level of confidence even when the research participant is not aware that the body manipulations they are producing—a fist shape or a pose—are associated with confidence (Schubert & Koole, 2009; Carney, Cuddy, & Yap, 2010). The same has been found for smiles that are covertly elicited by asking participants to hold an object in their teeth. Individuals participating in experiments manipulating facial muscle activation have different responses to humorous information later (Strack, Martin, & Stepper, 1988), further

suggesting that manipulating the body manipulates how we think. In another study that examined how our physical experience with temperature can influence our opinions of others, research subjects who were asked to hold a hot beverage a few moments before meeting a confederate judged the confederate as being more interpersonally warm than if they had been asked to hold a cold beverage (Williams & Bargh, 2008). In subtle ways, it appears that our bodies influence our thoughts.

And finally, a third group of arguments in favor of embodiment comes from those who view cognitive activity as extending both through and beyond the body (e.g., Clark, 2008). This is actually a quite different take on embodiment than the previous two, in that the physical body itself and its sensory and motor apparatuses figure less prominently. However, it is quite compatible with a perspective that has become more prominent in the education research literature—namely, a number of education scholars have argued that cognition and learning are fundamentally situated phenomena and the product of individuals acting with specific tools in specific contexts (Brown, Collins, & Duguid, 1989). This overlaps to a degree with both the cognitive and sociocultural perspectives described earlier, but these ideas have also been appropriated as ones central to an embodied perspective. The embodied argument is that if we truly want to understand and model thinking and learning as it works in real life, we have to be far more accountable to how knowing and actions are embodied in physical and social settings. To some extent, there are some ways that the physical bodies and sensorimotor apparatus are at work. Examples of those include looking at how people intelligently use space and manipulations of objects moving in space as part of the problem solving (Kirsh, 1995), how the physical environment and the mind are actually a dynamic coupling in which features of the environment are carefully exploited for cognitive processes (Clark, 2008), or how gesture serves as a critically important means for communicating, thinking, teaching, and learning (Alibali & Nathan, 2011; Church & Goldin-Meadow, 1986; Goldin-Meadow, 1999). In the world of human computer interaction, a field also heavily influenced by cognitive science but also ready with its own critiques of traditional modeling approaches, approaches that consider human meanings and interactions in settings of work and action are also being strongly advocated (Dourish, 2004). The key idea here is to look at the individual's activities as they are embodied in a meaningful activity and in a meaningful place rather than think about how the body changes or determines the ways in which information is stored or encoded. Although a diverse set, arguments that affiliate with this orientation toward embodiment and how it surpasses traditional cognitive approaches all in one way or another suggest that researchers look at how people interact with one another in space and place and use objects in the environment around them in meaningful and generative ways. It is a broadening of scope from the

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the body manipulates how we think. In our physical experience with temperature differences, research subjects who were asked to meet a confederate judged the meeting as warmer than if they had been alone (Williams & Bargh, 2008). In subtle ways, it can change our thoughts.

Arguments in favor of embodiment come from the activity as extending both through and beyond the body (Williams & Bargh, 2008). This is actually a quite different perspective from the previous two, in that the physical body and sensorimotor apparatuses figure less prominently. It comes with a perspective that has become more prominent in research literature—namely, a number of researchers have argued that cognition and learning are fundamental and the product of individuals acting with their bodies (Brown, Collins, & Duguid, 1989). In both the cognitive and sociocultural perspectives, these ideas have also been appropriated from an embodied perspective. The embodied argument is that we should understand and model thinking and learning as activities that are to be far more accountable to how knowledge is gained in physical and social settings. To some extent, it is argued that the physical bodies and sensorimotor experiences of those include looking at how people manipulate objects moving in space (Kirsh, 1995), how the physical environment affects a dynamic coupling in which features of the environment are exploited for cognitive processes (Clark, 1995), as a critically important means for communicating and learning (Alibali & Nathan, 2011; Goldin-Meadow, 1999). In the world of embodied cognition, a field also heavily influenced by cognitive science, its own critiques of traditional modeling approaches consider human meanings and interactions that are also being strongly advocated (Dourson, 2005). It is to look at the individual's activities as meaningful activity and in a meaningful place where the body changes or determines the ways of thinking and learning or encoded. Although a diverse set, the orientation toward embodiment and how it is being approached all in one way or another are all about how people interact with one another and with objects in the environment around them in various ways. It is a broadening of scope from the

skin- and skull-based boundaries of traditional cognitive science and pushes for consideration of how bodies in situations are used to bring about desired ends.

So whereas there are nuances and variations in the arguments favoring embodiment, there are some common ideas that open up new theoretical territory with respect to the body, embodiment, learning, and knowing. The first is that the physical body itself matters in a much more consequential way than past traditions of psychological research have addressed. Body states influence what we know and notice and how we behave. Body experiences and body movements serve as a kind of grounding for meaning and understanding. Our actions and our sensorimotor experiences serve as a kind of building block from which other understandings are built, with some going as far as saying that it is from them that all understandings are built. Furthermore, bodies are situated in times and places with other people and in the midst of activities. Body movements are purposeful, and body experiences are feedback to our interactions in the world. Thus, a commitment to embodiment not only thinks about how sensory and motor systems encode understandings in the world. It is a commitment to how meaning is made for a given individual. A commitment to embodiment also means thinking about what bodies do and why in a material and social world.

### A CHANGING TECHNOLOGICAL LANDSCAPE

In addition to the emergence of arguments for understanding our thinking and learning in terms of embodiment, we are experiencing a rapid change in the technological infrastructure and support that can sensibly bring bodies to technology and vice versa (e.g., Lee, 2013). It had previously been only in the realm of science fiction that gesture-based control interfaces could be imagined, but now many families have in their own living rooms motion-sensor devices that respond to hand waves and body movements. Touch screens and interactive surfaces that no longer require a mouse are becoming more widespread in homes and in classrooms. Miniature accelerometers have made it so that we can take our own movements or the shaking of a handheld device and turn those into meaningful information. By using our bodies to simply touch, tap, drag, or shake, we can make technology behave in entirely new ways.

Computers that were stationary on a desktop used to be the norm, and it was only the privileged few who could afford a miniature computer that could rest on their lap or travel with them to and from work in a dedicated carrying case. Now, there is talk of wearable computing that can come in the form of discrete activity tracking bracelets or cameras that attach to one's glasses. We can carry GPS devices that record where we have been and where we are going. Computing is becoming tangible, with programming

being done with physical blocks and objects placed next to one another. Computers can be sewn into our clothes and worn throughout the day. Our bodies are increasingly becoming a way for us to interact with and use technology, and the possibilities are just beginning.

However, these new interaction paradigms and the popular attention that has been generated have both largely been geared toward exploring spaces of possibility for new user interfaces, for productivity, or for entertainment. A force feedback game controller that rattles when the player is injured is a great way to bring more sensory experience into a video game, and gesturing over images can be much quicker and more intuitive for image editing than searching for a specific button on a screen or recalling an obscure keyboard shortcut to do the same work. Yet these kinds of ways of engaging the body with technology are not really addressing issues of teaching or learning. Beyond making some objects easier or more pleasant to use, how should we go about creating technologies and technology-enhanced experiences that support students in thinking about new material, engaging in new practices, and developing new understandings of disciplinary content and the world around them?

Formulating the beginnings of an answer to that question is the aim of this volume. The expectation should not be that we are at the threshold of a superior solution for learning, as the ability to learn is in itself a complex phenomenon and one that is not, in any obvious way, modality specific (e.g., Pashler, McDaniell, Rohrer, & Bjork, 2008). However, there will certainly be some occasions when bodily engagement can be an especially effective means for achieving some learning goals and impacting certain domains. There will also be times in which the new technologies that work with the body will ultimately help to tell us something new and important about how and when we learn. As it stands right now, the intellectual momentum and the technological resources are both available to achieve these aims. Yet it is still early. How we can create technologies and experiences that thoughtfully bring body and technology together in service of helping us learn remains largely unspecified. Certainly more will be written in the future, but for now, we can turn to the chapters that follow as one starting place.

## OVERVIEW OF THE VOLUME

The chapters in this book are organized in three thematic parts. The first part speaks to a set of broad challenges and opportunities that come about when we try to bring issues of embodiment to the world of learning technologies and vice versa. The chapters in this part speak to issues that transcend individual contexts and speak to basics of process and procedure for those who are interested in designing and using new learning technologies that, in some way, leverage or incorporate bodies.

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ction paradigms and the popular attention both largely been geared toward exploring new user interfaces, for productivity, or feedback game controller that rattles when that way to bring more sensory experience scrolling over images can be much quicker and more engaging than searching for a specific button on the keyboard shortcut to do the same work. Engaging the body with technology are not teaching or learning. Beyond making something to use, how should we go about creating enhanced experiences that support students' intellectual, engaging in new practices, and developing interdisciplinary content and the world around

of an answer to that question is the aim of technology should not be that we are at the threshold of something new, as the ability to learn is in itself a complex task, not, in any obvious way, modality specific (e.g., see Bjork, 2008). However, there will certainly be ways in which engagement can be an especially effective means of learning goals and impacting certain domains. We need to embrace the new technologies that work with the body to give us something new and important about how to learn. Right now, the intellectual momentum and the body are both available to achieve these aims. Yet it is the new technologies and experiences that thoughtfully engage the body together in service of helping us learn remains to be seen. More will be written in the future, but for now, these are the questions that follow as one starting place.

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organized in three thematic parts. The first part challenges and opportunities that come about with embodied learning to the world of learning technologies. The chapters in this part speak to issues that transcend the basics of process and procedure for those who are learning and using new learning technologies that, in turn, engage the body.

The two chapters in this part that speak to central considerations about how understanding is grounded by embodied experience come from Abrahamson and Lindgren. Abrahamson (Chapter 1) begins his chapter by drawing from an engaging personal anecdote that serves to highlight an important message: learning scientists and educational technology researchers must communicate with greater clarity some of their central commitments and recommendations in order to have a meaningful impact. For Abrahamson, one of the core commitments he states is that meaning is grounded in embodied experience. As such, he recommends that one way to produce greater clarity is with frameworks such as embodied design, which is an approach to using everyday and digital materials to help students have embodied experiences that eventually lead to a mathematical understanding. In a similar vein, Lindgren (Chapter 2) proposes “cuing” as an organizing structure for thinking about how to design body-based learning technologies. As he argues in his chapter, much of what we try to cultivate in learning experiences is a set of responses to cues. With new technologies that can read body movement or otherwise incorporate bodily activity and the field’s greater awareness of embodiment’s role in learning, we can create technology-based environments that help to cultivate cue-based responses (both physical and cognitive).

The other two chapters in Part I focus more on specific considerations and opportunities for particular breeds of embodied technologies. Antle (Chapter 3) discusses some of the specialized affordances of multi-touch interactive table technologies. These are an instance of embodiment in that the interface paradigm depends critically on human touch. Importantly, she raises the issue that with the increasing availability of this class of display interface, researchers must think carefully about how to design experiences not only for a single body but also for multiple bodies. A core concern of hers is peer collaboration. As she discusses, there are clusters of design decisions that can bring about useful design features in an interactive surface, and she illustrates these with two learning environments she has built with collaborators. Okita’s chapter (Chapter 4) focuses on when bodies are given to the technology. She refers to these as embodied artifacts, and they include objects such as avatars and robots. Using these technologies and their real-world analogues, Okita considers opportunities associated with the “learning-by-teaching” paradigm. Specifically, she asks about when and how recursive feedback—the feedback a human tutor receives from watching a (virtual) tutee complete a task for which the human did the teaching— influences learning. As she describes, using embodied artifacts like this is a powerful way to engage learners and to study the influences of feedback on learning. Her chapter shows how new embodied technologies can help us to understand the process of learning.

The second part of the book emphasizes efforts to bring and understand learning technologies and bodies together in formal learning environments. These include classrooms, schools, and other training sites. These have been some

of the main locales for researchers and designers of learning experiences. One unique feature of these chapters is that they all examine means for disrupting the standard ways of facilitating learning through new technologies and pedagogical approaches that directly involve the active movement of students' bodies.

First, Enyedy and Danish (Chapter 5) describe the rationale and design of a technology-enhanced learning environment that involves mixed reality in an elementary classroom to allow students to playfully learn about the topic of force. Using children's socio-dramatic play and body movements across the floor as a resource on a classroom-sized grid system, they show how students draw on bodily experience, the space available to them, and the records obtained by the technology to come to new and more refined ways of understanding elementary physics.

Next, Hall, Ma, and Nemirovsky's chapter (Chapter 6) explores new spatial scales for student exploration with technology. The domain of emphasis is geometry, presented at a "walking scale" rather than a "paper scale." Walking scale geometry involves students (and a group of pre-service teachers) drawing and performing geometric operations on shapes that they create by moving their bodies to different locations in space. As they show through three case studies, the activities involved in creating and manipulating these shapes and figures reveal a great deal about the very nature of how mathematical practices can be productively understood as the product of spatial, representational, perspectival, and social coordinations.

Then, in the chapter contributed by Smith, Berland, and Martin (Chapter 7), coordination is also considered, but this time in the sense that it is an issue of students coordinating first- and third-person perspectives while doing computer programming. Using a new mobile device-based programming environment dubbed IPRO, students are able to plan and execute the programs they are writing or planning while moving around as robots in a large open space. These authors discuss the design rationale for IPRO and the learning activity and proceed to discuss, by way of two cases of students who used IPRO, how coordination between perspectives can lead to improved computational thinking.

Finally, Fischer, Link, Cress, Nuerk, and Moeller (Chapter 8) report on a body of experimental research with early elementary students who are at the age where they should be developing a mental number line. Building on appropriate literature related to early numerosity, this team conducted a series of experiments with children using a dance mat controller, a Kinect motion sensor, and an interactive whiteboard to manipulate positions on a number line. As they discuss in their chapter, all of these technologies that involved more substantive bodily engagement produce greater performance on number line tasks than carefully constructed controls. Although they have not yet implemented their interventions in classrooms, the findings they report from the students they have studied have direct implications for future uses of such interactive technologies in schools.

ers and designers of learning experiences. One is that they all examine means for disrupting learning through new technologies and pedagogy to involve the active movement of students' bodies. Chapter 5) describe the rationale and design of a learning environment that involves mixed reality to allow students to playfully learn about the concepts of socio-dramatic play and body movements on a classroom-sized grid system, they show how they use their own experience, the space available to them, and technology to come to new and more refined understandings of elementary physics.

Smirnovsky's chapter (Chapter 6) explores a new way of exploration with technology. The domain is presented at a "walking scale" rather than a traditional geometry involves students (and a group of friends) moving and performing geometric operations on a grid; and performing geometric operations on a grid by moving their bodies to different locations in space. In three case studies, the activities involved in using these shapes and figures reveal a great deal about how mathematical practices can be productively integrated with spatial, representational, perspectival, and

described by Smith, Berland, and Martin (Chapter 7), but this time in the sense that it is an issue of first- and third-person perspectives while doing so. Designing a new mobile device-based programming environment where students are able to plan and execute the programming while moving around as robots in a virtual world. The authors discuss the design rationale for IPRO and intend to discuss, by way of two cases of student coordination between perspectives can lead to a more integrated learning experience.

Smith, Nuerk, and Moeller (Chapter 8) report on their work with early elementary students who are at the beginning of developing a mental number line. Building on their work with early numerosity, this team conducted an experiment with children using a dance mat controller, a Kinect sensor, and an interactive whiteboard to manipulate positions on a number line. In their chapter, all of these technologies that they used daily engagement produce greater performance than traditional carefully constructed controls. Although they are not fully integrated into their classrooms, the findings of their interventions they have studied have direct implications for the use of these technologies in schools.

The third part of the book focuses on learning technologies and bodies in informal learning environments. As of late, there has been growing (and much needed) awareness in the education research community of the important role of informal, non-school-based settings for learning. In the first chapter of this part, Lee (Chapter 9) argues that non-school-based settings have value not simply as a setting for learning but also as a source of inspiration for those who do the work of designing school-based learning activities. His view is that when designing new learning experiences, examination of these informal spaces can help to reveal useful tools and ways of relating to technology that can be productively imported into other spaces. He presents two examples of how he and his team have looked at informal groups using body-tracking technology to inform the design of learning activities for schoolchildren.

In the next chapter, Lyons (Chapter 10) presents examples of technology designs that involve the bodies of people who visit zoos and museums. As she notes, these informal learning spaces create different design demands than what one might have at school or in an after-school center. Exhibit designers must consider the very short time a learner will be at an exhibit and also the fact that there will be a group of observers who are not actively involved in using equipment placed at an exhibit. These two issues present major challenges for technology that uses bodies at an exhibit. The examples of exhibits she shares, which include swimming like a polar bear under different polar ice conditions or using one's body to explore information obtained through the census, examine and discuss these challenges. This chapter provides results from initial evaluations of the two sample exhibits, and it also provides an excellent discussion of some additional challenges associated with having users use their bodies to work with exhibits that involve complex data visualizations.

Looking in other informal spaces, Ching and Schaefer (Chapter 11) present a novel design effort to merge the automatic tracking of youths' everyday bodily activity with an accessible online game that goes above and beyond many typical models of "exergaming." Drawing inspiration from the quantified self movement, one of their major goals they describe is to help students in an after-school club to reflect on their everyday levels of physical activity. After providing some of their rationale for the design of the game and activity tracking experience, Ching and Schaefer provide a vivid account of the experiences and concerns of the youth who participated in the project. This chapter raises a number of important issues related to when and how youth feel they can be active during the day and what kinds of access to technology are actually available to diverse youth populations.

The final chapter is another piece that looks at how people (and, in particular, researchers) can learn about learning with new body-based technologies. The technologies that Umphress and Sherin (Chapter 12) have in mind are wearable video cameras, a kind of experience capture



device that is seeing increasing use in educational research practice. The chapter provides two examples, including one that comes from the backyard of a family home and another that comes from a math classroom, to show what unique insights we can gain from the use of wearable cameras. The authors of this chapter also show that even with technologies that are worn on one's person and seem to fluidly capture a first-person perspective, producing a special form of coherence for educational and social science researchers who rely on video data.

Following this chapter, the last of the three main parts, a brief closing chapter by Lee (Chapter 13) reflects on ideas presented in this volume and speculates on possibilities for the future.

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In the last of the three main parts, a brief closing chapter reflects on ideas presented in this volume and the future.

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