Chapter 6
A Broad View of Wearables as Learning Technologies: Current and Emerging Applications

Victor R. Lee and R. Benjamin Shapiro

1 Introduction

Over the last decade, wearable technology has been generating increasing attention from educational technologists. At a base level, wearables offer a new form of mobile technology by freeing hands from carrying a handheld device. Smartwatches and fitness tracker bands are perhaps the most iconic of wearables, although many features included in such devices represent incremental steps forward from what has already been available in handhelds and other existing technologies. In light of that, the buzz around wearables may seem to be a letdown; they are little more than a new and unnecessary electronic toy for those who can afford to buy them. To that view, wearables will likely generate initial interest and then quickly fall out of favor (for example, consider the rise and fall of the asymmetrically designed Google Glass wearable camera and head-mounted display system). It comes as little surprise that there are skeptics who wonder aloud whether wearables and their enthusiasts will have much to offer to the future of education (Carr-Chellman, 2015, p. 19).

Ultimately, the uptake and impact of wearables in service of teaching and learning remain to be seen. However, our orienting position for this chapter is that the most effective forms and uses of wearable technologies for both formal and informal learning settings are still being developed and explored. Educational technologists should first recognize that wearables are not monolithic as a set of technology that will either succeed or fail for educational purposes. There is a diversity in devices and forms of technology integration and user experience. Smartwatches and fitness

V. R. Lee (✉)
Department of Instructional Technology and Learning Sciences, Utah State University, Logan, USA
e-mail: victor.lee@usu.edu

R. B. Shapiro
Department of Computer Science, ATLAS Institute, University of Colorado Boulder, Boulder, USA
e-mail: ben.shapiro@colorado.edu

P. Díaz et al. (eds.), *Learning in a Digital World*, Smart Computing and Intelligence, https://doi.org/10.1007/978-981-13-8265-9_6

trackers are just a subset of what is both available and possible. As with all educational technologies, the effectiveness and worthiness of wearables will ultimately depend on a multitude of social and human factors and vary from one setting to the next. Thus, in this chapter, a central argument is that the future questions asked by educational technologists about wearable technologies should be explicit about how those wearable technologies are intended to be used, and how those intended uses are supportive of specific forms of teaching and learning.

The chapter is provided primarily as a survey of some current and emerging applications of wearable technologies for both formal and informal learning environments. In the sections that follow, we describe examples of teaching and learning activities that incorporate wearable technology organized by the types of support that they provide in the learning environment. For instance, one of the support types we describe below relates to personal expression, and the examples therein examine how some wearables are used as a motivating and expressive context that can also provide encounters with engineering and design. The list of supports are not mutually exclusive of one another, nor do we view particular types of devices as being restricted to a single form of support. For instance, a wearable activity tracker could be made useful in a physical education class to help students reach certain health goals or help students to monitor and keep their heart rates in specific ranges. It could also be made useful in an electrical engineering class as an object to take apart and then rebuild for a predetermined use case. The wearable activity tracker is rather neutral with respect to how it is used. While certain functionalities are more prominent in a given technology or a given wearable platform, the onus is on educational technologists to conceive of and develop ways that the technology can be used. The educational technologist's role is to define how to support the attainment of some learning goals in a way that is considerate of the needs of a given setting.

In addition to describing some of the work that others are doing in related areas such as human-computer interaction, educational technology, and learning sciences, we will provide two more detailed accounts of wearable technologies that, as used in the manner we propose, support the collection and examination of records of bodily experience. These receive more detail in part because they are our own projects, and thus we have direct knowledge of challenges, needs, and opportunities. However, we also believe that the ability to obtain and ask questions about records of bodily experience is an especially promising direction for wearable technology design and research for learning that has not been as prominent in the extant literature. The two examples are intentionally divergent in the types of technologies that are used (off-the-shelf devices vs. custom-made) and whose bodily experience is being examined. This is done in order to show the breadth of possibility when one pursues this direction of design and research.

2 Compelling Qualities of Wearable Technology

Broadly speaking, the category of "wearable technology" can extend to any designed object that is worn by the body, such as clothing, jewelry, protective gear, or performance improving equipment. In considering the advantages wearables have, we have considered the different roles that wearable objects have played in the past and continue to play in various societies and cultural practices (Eicher & Evenson, 2014). However, we recognize that in current times, when one hears "wearables" and "wearable technology", the common inference is that there is some form of digital augmentation in the form of a microprocessor or circuitry integrated into the wearable. Digital technology-enhanced wearables will be discussed in the sections below.

There are three qualities of wearables that make them compelling as an emerging technology. First, wearables do not necessarily need to be actively held with one's hands. To be worn is to be carried on the body in some manner. This allows for the digital technology embedded in a wearable to remain present on a person for hours or days without requiring attention. Wearables can "tag along" while we do other things, making it possible for someone to focus on completing difficult jumps and turns on their skateboard and rely on their GoPro camera to catch a record of the sick moves that were completed. This redistributes what forms of work are being done by various individuals and technologies in the system. Other examples of this redistribution include the ability to compute location on a GPS watch without a user having to reference maps, stars, or signs around them while on a hike, or to know how many flights of stairs were climbed during the day without paying conscious attention to moments of ascension and keeping a tally.

A second compelling quality of wearables is their relationship with presentation and disclosure. Several wearables are visible and are made part of our public appearance. This allows others to make inferences, some of which we attempt to engineer in how we design our public appearance. Take for example how wristwatches can serve to present an individual as athletic (a sport watch), academic (a calculator watch), oriented toward outdoors activities (a Garmin GPS watch), or to communicate wealth (a designer watch). For fitness tracking, the gold standard of step counting has been hip-worn devices that can detect motion from foot impact with the ground. However, wrist-based wearables have become far more popular and taken on a variety of different styles as the wrist is more visible, making the wearable a conversation starter, and a way to communicate something about one's values, interests, and resources. On the other hand, wearables can also be discrete. They can hide from view and still be present by keeping their size small or by integrating them into other objects that are already worn. For instance, discreet devices now exist on the market that are worn on one's waist to help track breathing patterns and posture (e.g., *Lumo Lift*, *Spire*, etc.). Individuals with Type 1 diabetes may wear a continuous glucose monitor that attaches to their skin and fits underneath their shirt so that their status as a diabetic is not immediately visible (e.g., Lee, Thurston, & Thurston, 2017). The amount of flexibility designers have with respect to form factor creates opportunities that have yet to be fully explored.

Finally, wearables can serve as extensions of self. Taking the example of a person with Type 1 diabetes, a wearable glucose monitor acts as an important replacement for a part of the body that does not work normally. Other major medical devices that are necessary for continued survival that must be worn or attached to one's body impact the sense of personal identity that patients experience, with some seeing themselves as part machine or a form of cyborg (e.g., Raia et al., 2014). This also extends to medical devices that are not essential for survival, but can change quality of life, such as hearing aids. Some individuals also seek to go beyond technology that can be worn and instead voluntarily implant technology, such as magnets or sensors, under their skin to alter and explore what their bodies can perceive (Heffernan, Vetere, & Chang, 2016). Those individuals appear to sense and know the world in new ways because of the augmentations and modifications that are on (or in) their bodies. These may appear rather dramatic as examples, but they do raise questions about where are the boundaries of one's self. Others, particularly in cognitive science, have posed similar questions about where the human and their mind begins or ends (Clark, 2008), with one of the most famous examples being a blind man sensing the world around him with a walking stick (Bateson, 1971):

> Consider a blind man with a stick. Where does the blind man's self begin? At the tip of the stick? At the handle of the stick? Or at some point halfway up the stick? These questions are nonsense because the stick is a pathway along which differences are transmitted under transformation, so that to draw a delimiting line across this pathway is to cut off a part of the systemic circuit which determines the blind man's locomotion. (p. 445)

A fundamental point made in this oft-cited example by Bateson (and also made thoughtfully by others, such as Hutchins (1995)) is that the unit that is the thinking human is not as clear cut as would be suggested by the boundary of our skin. Considering wearable technology, this question of boundaries can be further blurred partly because the technology can be always there and, in the examples discussed thus far, take on more essential roles in various tasks. Granted, it may still be a while before wearables consistently do the critical work in various learning environments as providing life support,[1] but it represents a possible direction in which we may be heading. It is a different way of thinking about technology that has been typically afforded a desktop computer or handheld mobile device. More work remains to be done, but in the examples of how wearables are being used in learning environments that follow, strands of these qualities of wearables—their ability to be always present, their flexible presentation and disclosure, and their connection to self—appear in what various research and design teams have been engineering and studying.

[1] Although, it is worth noting that worn body cameras in law enforcement are beginning to play increasingly important roles in shaping public opinion about differing accounts of citizen-officer encounters, driving community activism, and serving as evidence in high stakes court cases, all of which are sites where learning still takes place.

3 Forms of Support Provided by Wearables in Education

In this section, we provide a survey of uses and projects involving wearables in formal and informal education settings, organized by types of support that we have identified. The list is not exhaustive. Rather, it is intended to help articulate some common themes that are appearing in educational technology-related fields.

3.1 Wearable Technology to Support Personal Expression

Wearables can build upon the ability to be a form of public display. This has been one way in which electronic textiles, or e-textiles, have been used in educational settings.

Although often presented as an important strand of the Maker movement in education, a number of recent and current e-textiles projects allow for students to build their own wearables by creating clothing items, badges, and other accessories that are enhanced with electronic and digital components. At a minimum, a simple electronic textile project could involve a coin cell battery, wire, and an LED. What often makes electronic textiles unique and amenable to wearability has been the integration of "high" and "low" technology and the use of conductive thread in place of wire. This mixes the "softer" medium of cloth and fabric with the "hard" silicon of microcontroller boards and metal wires of actuators.

A compiled volume on electronic textile projects, *Textile Messages* (Buechley, Peppler, Eisenberg, & Kafai, 2013), documents a number of examples and applications of electronic textiles that range from custom and interactive handbags to hats to sweatshirts that double as turn signals (see Leah Buechley's Turn Signal Biking Jacket[2]). One of the recognized potentials of electronic textiles is that it challenges western gendered views of various cultural practices, such as computing and sewing. Searle & Kafai (2015a) has documented how the use of electronic textiles can serve as a bridge for engaging in new practices that students may not otherwise explore because of dominant gender norms. For instance, in their work with adolescent youth, Searle & Kafai observed that many young men expressed the greatest pride in their increased sewing ability when working with e-textiles while young women found pathways into computing. Introductory electronic textiles experiences, often involving starter wearable projects such as the creation of light-up bracelets and electronically-enhanced t-shirts, have shown documented learning gains in disciplinary content (e.g., Tofel-Grehl et al., 2017). Circuitry knowledge has been shown to increase from multi-week engagement with e-textile projects involving wearables (Peppler & Glosson, 2013), as has introductory knowledge related to computing and craft production (Lee & Fields, 2017).

Besides providing youth with new visions of how technology can be infused into different media, electronic textiles provide a platform for personal expression. Kafai, Fields, & Searle (2014) have documented how aesthetic considerations in the design

[2] https://www.instructables.com/id/turn-signal-biking-jacket/.

of electronic textiles can be a critical driver in pushing for new learning. In their case studies, the desire to make a textile project have a certain look led to exploration and discovery of new techniques and considerations in circuit design. Electronic textiles are also an appealing medium through which cultural knowledge can be valued and expressed. Culturally relevant projects have sought to connect students to community and family-based craft knowledge and also found ways in which personal interests within mainstream youth culture can be expressed through custom-made e-textile wearables (Searle & Kafai, 2015b). This allows for expressing values and history within an indigenous community or even affinity for a professional sports team.

This particular manner of deploying wearable technology tends to privilege youth agency and voice and follow with the constructionist paradigm of creating a public artifact while developing new understandings. While making wearable e-textiles can be time consuming, they have so far been well-sustained in educational technology research through supportive out-of-school (Peppler & Glosson, 2012) and classroom-based (Buechley, Eisenberg, & Elumeze, 2007) curriculum, portfolio platforms (Peppler, Maltese, Keune, Chang, & Regalla, 2015), and community support websites (e.g., instructables.com).

3.2 Wearable Technology to Integrate Digital Information into Social Interactions

The digital technology incorporated in wearables fundamentally involves manipulations, transformations, and transmissions of information. Commercially, this may take the form of a smartwatch that converts barometric pressure changes into numerical values and transmits that information via Bluetooth to smartphone. In educational settings, other forms of information transmission, largely emphasizing peer-to-peer interactions, have been appearing. These information exchanges add and integrate new layers for social interaction.

Smart badges have been among the most classic instantiations for storing and transmitting information during face-to-face social interactions. An early example developed out of MIT was a modification of the typical plastic-encased, paper-printed conference badge that states the name and affiliation of academic conference attendees. The new form of wearable technology badge, dubbed the "Thinking Tag", was worn by conference participants who went to different stations to answer multiple choice questions to share their opinions on some topic (Borovoy, McDonald, Martin, & Resnick, 1996). For instance, a pre-planned question asked with whom of a list of pre-selected celebrities would you most want to have dinner or which of three major concerns about the future of the internet do you feel was the most urgent. When a conference attendee stood across from another attendee, a different number of LEDs on the badge would light up to indicate how many answer responses they had in common. The underlying idea in this activity was to encourage and facilitate conversations by making information (i.e., responses to a common set of questions) more public and easily exchanged. Learning about one another would then take place through these augmented conversations.

This model of “smart badges” that are worn during face-to-face interaction have been extended to support participatory simulations in classrooms, especially with respect to learning related to complex systems content. For instance, Klopfer, Yoon, and Rivas (2004) provided students with modified Thinking Tag badges to enact two forms of complex systems simulation activities with middle and high schools. One system modeled the spread of disease in which one student’s tag was “infected” with a virus, and their face-to-face interactions with other students in the class created a risk of spreading the infection. Ultimately, students can see from their own interactions how quickly diseases can spread and experience the logistics curve typically used to model disease spread. This form of activity also generated questions about what factors impacted the immunity of the population (i.e., the entire class of students) and individuals within the system (i.e., specific students and the badges that they wore). The other system described by Klopfer et al., used Thinking Tags to help students learn about Mendelian genetics. Each badge encoded a set of traits and interactions with other students wearing badges yielded different organism outcomes related to survival. The students could use their experiences interacting with other students to state what benefits were associated with what traits and how they were modeled in the badge simulation.

A more recent badge-based participatory simulation project involved students using badges and their interactions with one another as simulating the network structure of the early Internet (Brady, Orton, Weintrop, Anton, Rodriguez & Wilensky, 2017). Students’ badges were categorized as network endpoints, data packets, and routers. During the simulation, the “data packets” interacted with various “routers” whose badges provided partial destination address information that help direct the data packet badge wearers to other “routers” until they reach their intended “endpoint”. Through the simulation, the students saw how different strategies of sending data packets impacted the number of nodes needed to efficiently send information. They also encountered physical instantiations of network terms such as “bandwidth” and “congestion” as they existed within that network architecture, particularly as student queues formed at different routers since only one pair of badges could interact with one another at a time.

More developed instantiations of these simulation and information transmission projects through wearables remain to be completed. The novel use of wearables for learning purposes capitalized on the ability of wearables to remain present on the wearer and mediate information exchanges that could ultimately lead to new forms of learning interactions. In these examples, the wearables were “piggyback riding” on face-to-face interactions. This created a new potential information layer that supported new ways for learners to both engage with complex ideas and to spark new conversations.

3.3 Wearable Technology to Support Educative Role-Play

Custom wearables can support learners in trying out different roles than the ones they normally occupy when they are made highly visible and connect to some other referenced entity or world. To some extent, this was suggested by some of the previously mentioned examples involving e-textiles, where students could express affiliation to specific communities, and participatory simulations, where students could be infectors or pretend to be anthropomorphized data packets. However, educative role-play touches upon, but does not necessarily occupy the exact same design space. For role-play, the wearable technology is intended to preserve some form of fidelity to another person or living thing and encourage the wearer of that technology to behave in a manner comparable to that which is being publicly signaled by that wearable item.

An example of a participatory simulation in which role-play is involved is the *BioSim* environment (Thompson, Danish, & Peppler, 2017) that encourages young children to use custom hand puppets that look like bees and wearable indoor location tracking technology as they forage for nectar and pollinate large "plants" located around the classroom. The goal of this design is to help students learn both structure and function relationships between bees and plants as well as complex systems relationships in bee colonies. The use of the bee puppet encourages students to enact the bee role within the simulation and promotes specific forms of engagement and interaction among students (e.g., bees cannot verbally communicate with one another using words, and the bees' body movements are thought to be a form of communication). The bee puppet also cues students into thinking about how to engage with artifacts in the room (i.e., large flowers that are part of the simulation). Instead of leveraging their human abilities, students move and communicate with one another using the affordances of the bee body and simulated bee brain. Notably, it is not the case that humans' capabilities are strictly greater than bees: while humans have spoken language and bees do not, bees can fly while humans cannot. Students in BioSim role-play bee by emulating a communicative bee dance with their puppets and "flying" around the room. This role-play supports careful consideration of how bees communicate and interact with one another and their environments in ways that are sharply different than humans' capabilities.

Another animalistic wearable role-play approach has been demonstrated in Leilah Lyons and her colleagues' work with the *A Mile in My Paws* interactive climate change zoo exhibit (2015). The intention of this exhibit was to help patrons better understand the impact of climate change on various animal species. In her use of wearable technology, she and her design team created an experience where patrons role-played polar bears. The patrons wore large weighted bear gloves that had been equipped with accelerometers so that the gloves could detect motion and transmit that information to a live display reporting calorie expenditure and distance traveled. The humans role-playing as polar bears were then tasked with foraging for a preferred food source (i.e., seals) located on sea ice. The exhibit then presented various scenarios using actual data and satellite imagery from the years 1975, 2010, and forecasted data for 2045 as rising global temperatures cause more sea ice to melt. These different scenarios and the requirement to paddle in the heavy gloves helped demonstrate the extra survival pressures that are placed on polar bears as the amount of sea ice decreases and more water appears between icy regions. By paddling their glove-covered arms, the zoo visitors experienced an embodied sense of how much harder a polar bear must work in order to work to survive under changing environmental conditions.

A Mile in My Paws and *BioSim* are both wearable-supported role-play activities focused on understanding animal biology and ecology, but they addressed different aims using different types of wearables. *A Mile* is primarily about empathy cultivation, achieved by immersing humans in a life-or-death task of progressively escalating impossibility. The wearable affords a narrative experience wherein the fun of strapping on a pair of bear gloves and frolicking across the arctic changes to one where the bear is struggling to survive in an environment inundated by life-threatening changes precipitated by climate change. By identifying as the bear, learners feel the consequences of a shrinking polar environment. Yet the actual abilities of the bear body make little impact on the experience. In principle, another animal could be used in the simulation, or even a simulated human who must seek food and shelter in response to scarcity caused by climate change. In contrast, *BioSim*'s task structures are deeply shaped by the abilities of bees: the conceptual learning goals of the activity are intimately shaped by the abilities of the bee body and bee brain, as are the range of allowable student actions to accomplish those goals. The student experience is designed to emphasize the contradistinctive work of accomplishing communication and movement in ways that are disjoint from human capabilities. This distinction is revisited in another example below.

3.4 Wearable Technology for Just-In-Time Notification in Complex Learning Environments

Many people who use a consumer wearable are familiar with notifications and reminders that are communicated by the device. For example, when an appointment is upcoming or a text has been received or the wearer has been sitting for too long, a smartwatch will often buzz and show that information to notify the wearer immediately, with the underlying assumption being that the user wants that information and will respond at the time of notification. While personal experience suggests that there is more work to be done (as some reminders can be frustrating and undesired, although Afergan, Hincks, Shibata, & Jacob (2015) offer one compelling alternative), the potential use cases, especially for classroom teachers who must continually respond to and notice important events in complex settings, are now being developed. This connects to the potential of wearable technology to alter our sensing processes and our general awareness of the environment.

One example of this for teachers, following from the model of smartwatch notification, has been discussed by Quintana, Quintana, Madeira, & Slotta (2016). In the computer-supported collaborative learning literature, "orchestration" has increasingly been used to describe the facilitation work that must be done within and across collaborative learning activities (Dillenbourg & Fischer, 2007). A classroom teacher might need to coordinate the use of various software tools for students, immediately encourage specific kinds of classroom discourse with just-in-time prompting, announce and direct transition between learning activities, and adapt planned activities in response to what she believes is appropriate for the students at a given moment. While one promising model for supporting this is to help teachers develop more robust knowledge for pedagogical practice and to enhance their ability to notice critical classroom events (Sherin, Jacobs, & Phillipp, 2010), wearables and their notification capabilities could help to redistribute some of the cognitive work that is involved in orchestration. In Quintana et al. work, Apple Watches were explored as a tool to provide notifications at timed intervals to remind teachers keep track of lesson flow relative to allotted time (e.g., asking the teacher if there are any groups ready to present to the class, reminding them that ¾ of the class period has passed and a synthesis discussion should take place, etc.) and to send notifications of student progress to the teacher (e.g., a student group had just submitted some documents to a common digital workspace or another student group has not appeared to make any posts to a common digital knowledge sharing space). In initial focus group responses, teachers appeared to find a wearable device-based notification system preferable to a handheld notification as they could be more discrete in obtaining the notification (i.e., not draw attention from students as the teacher looked at a phone) and could provide teachers with an ongoing sense of how students in the class were doing if they had to dedicate more attention to one subset of students on that day.

An alternative notification-based approach was recently proposed with mixed-reality smart glasses in classrooms that use intelligent tutoring systems (ITS) (Holstein, Hong, Tegene, McLaren, & Aleven, 2018). Here, the idea is to overlay icons and images over the teacher's eyeglass-view of students and workstations. This could then provide a form of real-time augmented reality analytics related to student progress and mastery within the ITS, according to the ITS metrics. Other views through these smart glasses could provide "deep dives" with specific students when the teacher gazes at a specific workstation with a student seated at it. The wearable display would then show the teacher what immediate challenge problems a student is encountering on their workstation screen and a brief history of their performance on similar problems in the ITS. Such information could enable the teacher to be better equipped to provide student assistance and spend less time diagnosing where a student is having difficulty.

A comparable system using mixed-reality eyewear has been attempted in a university setting (Zarraonandia, Aedo, Diazm & Montero, 2013), in which clicker response systems that allow for students in large lectures to provide projected feedback to the instructor about their level of understanding of lectured content can instead be transmitted directly to the instructor's worn display system. While that approach can be a form of private, just-in-time notification to the instructor to adjust her information delivery without disrupting her lecture, it is worth noting that it could deprive students of the sense that their struggles and concerns with the classroom instruction are more widely shared, as can be made visible in more traditional classroom response system configurations where classroom poll results are projected for all to see. However, all of these examples provide a glimpse of how teachers, in particular, can be provided with information in new ways through wearables and have their abilities to notice classroom sentiment and events in new ways.

4 Wearables to Obtain Records of Bodily Experience

Having surveyed some of the manners of support that wearables provide in various educational projects, we now turn to one other form of support that has been the focus of some of our own projects. This form of support is to enable learners to examine records of bodily activity that are obtained from wearable devices. In some respects, this connects to growing interest in embodied cognition as it relates to learning technologies (Lee, 2015). The underlying assumption for embodied learning technologies is that some knowledge of bodies—tacit or explicit—can play a critical role in the development of new understandings. For example, moving arms at different rates and constructing new sensorimotor schema may help students develop new intuitions of rational number (Howison, Trninic, Reinholz, & Abrahamson, 2011), stepping in certain directions to think about numerical order may support better understandings of the number line (Fischer, Link, Cress, Nuerk, & Moeller, 2015), and forming geometric shapes with the body on a large field (Hall, Ma, & Nemirovksy, 2015) or on a computer screen may help in the learning of geometry (Nathan & Walkington, 2017).

For wearables, we are interested in what we already know about what bodies do and encounter in routine activities. We know, for instance, that a day is typically filled with standing, walking, and sitting. We also may know more specifics about when those activities take place. While we may not know that information exhaustively, it may be that we know enough to begin to ask questions and inspect records of routine behavior in a way that makes routine bodily experience into a novel inquiry. Furthermore, our understanding of bodily experience need not be restricted to simply our own bodies. It can relate to other people, or to other organisms as well. In the examples that follow, we present one project (led by Lee) that involves students examining school day movement using more conventional off-the-shelf technology. In the other (led by Shapiro), learners are using pets as their focus and drawing upon what they know and care about with respect to their animal companions to develop ways to obtain records of animal sensory data and to examine that data in order to gain more insight into how pets experience the world.

4.1 Inspecting Routine School Day Activities with Commercial Activity Trackers

For several years, Lee has been involved in a multi-year design-based research project involving fifth and sixth grade classrooms to develop new activities for learning elementary statistics content such as variability, distribution, measures of center, and comparing across data samples. This project, referred to as the *Physical Activity Data Project*, involved the use of commercial technologies such as high speed cameras and fitness trackers that have included heart rate monitors, hip-based step counters, and wrist-based activity trackers in its most recent iteration. The guiding assumption was that these off-the-shelf technologies could be re-purposed in classrooms to build upon students' knowledge of their own activities and the automatically obtained records of those activities to devise ways to bootstrap understanding of statistical ideas such as outliers and central tendency. For instance, students may know when they had an unusual pattern of activity due to a field trip or class assembly and be able to thoughtfully consider if data collected from such a day should be considered an outlier and what effect its inclusion would have on the rest of a week's worth of movement data.

The typical classroom arrangement involved issuing a wearable activity tracker (e.g., *Fitbit Flex* device worn around the wrist) to every student in the classroom to wear throughout the school day. Data from these devices were automatically transmitted to anonymous online accounts and then accessed using a custom web tool developed by the project team that could obtain subsets of data from one or more students depending on the query being made. For instance, the class may have wanted to compare the number of steps taken per minute during PE on a given day from all students in the class so that they could compare the activities of the boys and girls in class.

Some of the infrastructure, besides several dozen Fitbit devices, is further described in Lee, Drake, & Thayne (2016) and summarized here. First, computers already in the classroom were converted into covert antenna stations so that data could be obtained from several activity tracker devices passively throughout the day. Data from the devices were stored by Fitbit and reported back to users as total values or in 15-min increments because their primary users are assumed to be adults with smartphones and working professionals whose schedules conform to those increments. However, school schedules must be very resourceful with respect to instructional time, and may have recess scheduled at a seemingly specific time such as 10:12–10:27 AM. That required us to extract data by the minute with a data grabber tool. Additionally, the raw data was a long table of numbers that could be made more dynamic through visualization software (i.e., *TinkerPlots* data visualization software) (Konold & Miller, 2005). Once those data were presented in a visualized form, they were projected so that students could develop narratives about their activity data, raise concerns about what did and did not get captured by a wearable device, and pose questions that could then be used as investigations for themselves or for

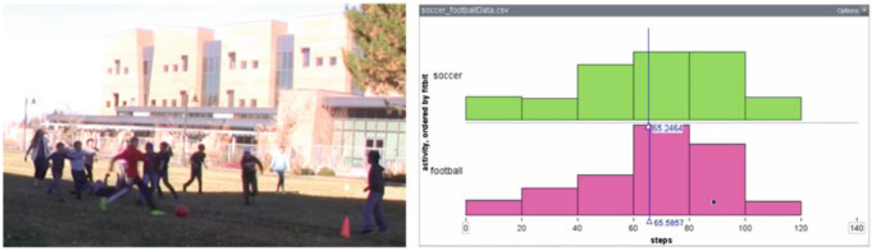

Fig. 1 Students playing soccer at a participating school and the resultant data from the entire class that were extracted, cleaned, and analyzed by a student group that wanted to see if soccer (top) and (American) football (bottom) had meaningful differences

the entire class to pursue. Depending on the activity, they would access their own individual data or collections of class data.

Recess was a time we discovered as especially exciting for students to explore, as the students had more knowledge about the activities of recess than their teachers and could provide testimony to what they and their friends had done. This would produce disagreements among students that could be reconciled by examination of their activity tracker data. As an example (Fig. 1), in one fifth grade class, students who examined data about their school day activity had noticed that their most active minute (based on the number of steps taken) came from a morning recess when that student and his friends were playing (American) football. That led to animated student posturing where a group of male students claimed football was the toughest game because of that single data point. For students who felt differently and who also believed that the football students were relying on too little data, they devised a data investigation where they extracted data of classmates playing both football and playing soccer on two days and organized those data into a histogram. They filtered out students who they recalled being non-participants and times when the gameplay had not actually started even though it was part of recess (i.e., setting up the field) given their review of data points. They then found that the overall shape of the distributions was largely the same and the mean values were nearly identical, leading them to conclude that despite what the basketball boys had thought, soccer and football at recess for their class were equally demanding activities. The rivalry between playgroups motivated statistical investigation and comparison, and firsthand experience with data collection supported the exclusion of data points in the analysis (data cleaning).

A second example comes from a sixth grade class at a different school where discussions of students' recess data, as obtained by Fitbit devices and represented in *TinkerPlots*, yielded questions about whether students who were using the jump rope at recess had their jumps count as steps on the devices. After extensive classroom discussion of how they could evaluate that, as the wearable devices issued to them did not provide a numerical display for them to check immediately, the students devised an experiment where different groups of students would primarily walk or jump rope

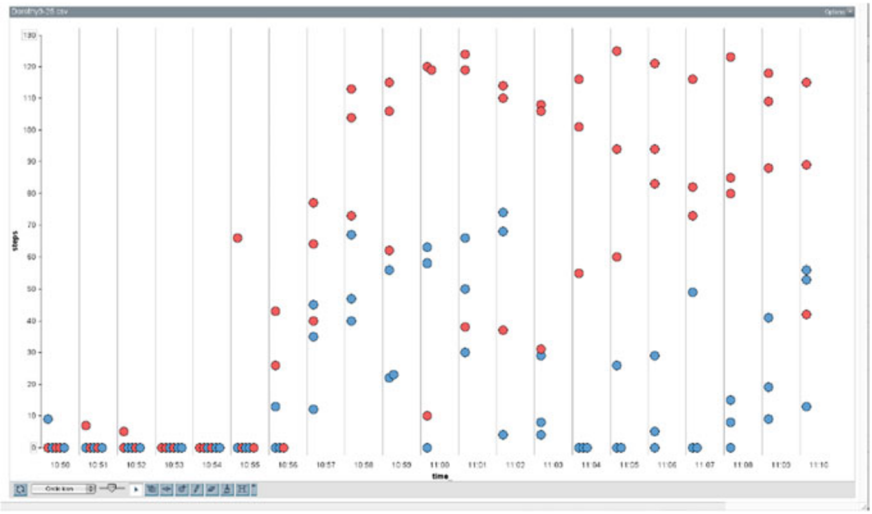

Fig. 2 Data from students during a designed walk (topmost points) and jump rope (bottom most points) comparison experiment to determine if jumping was counted as steps by a Fitbit activity tracker. The students realized upon examining the data and peer discussion that jumping involved a great deal of stationary time and they would need to design a new experiment that eliminated the stationary time

during recess and compare the values (Fig. 2). However, upon inspection of the data the next day, they found that while there tended to be less steps taken by those who jumped rope, they were unable to tell if jumping was registered as a step by the device because there were several minutes when jump ropers stood and waited for their turns to jump. Furthermore, the jump ropers walked to reposition themselves in preparation of their jumps and to get out of the way and return to line after completing their turns. This came about when students began to debate what these records of their recess showed and why, and ultimately led to a new experimental design (Drake, Cain, & Lee, 2017). From this, the students were engaging in thoughtful reflection of data and how to design experiments that could produce data to support conclusions in response to questions they were asking.

The *Physical Activity Data Project* has yielded encouraging findings with respect to how a unit that involves these wearables and accompanying lessons fare against traditional elementary statistics units taught in these same classrooms (Lee & Thomas, 2011; Lee, Drake, Thayne, 2016). The use of commercial wearables created a durable, quantified, shareable, and partially contestable record of school day experience. (e.g., whether jump rope gets recorded validly). The examination of these records of their bodily experiences then led to new learning interactions that would have been difficult to engineer without the use of the wearables.

4.2 Intersubjective Sensation Wearables with Pets

The *BioSim* and *Walk a Mile in My Paws* examples presented above illustrate ways in which role-play using wearables can support biology education. In *Walk a Mile*, awareness of the impossibility of polar bears' survival is generated through empathetic perspective taking (e.g., starving to death while role-playing as a beleaguered polar bear). In *BioSim*, role-play consists of limiting one's use of innate human abilities (spoken language) while pretending to enact actions that exceed human capabilities (flying). We conceive of the role-play in *BioSim* as a sort of intersubjective action: humans studying bees learn by acting in Bee-like ways. This intersubjectivity primarily lives in the role-play, for which the wearables primarily function as props. Nothing about them fundamentally constrains human action to its bee-like capabilities; nor do the wearables actually enable people to fly.

Recently, Shapiro and collaborators Mike Eisenberg, Joe Polman, Annie Kelly, Christine Chang, Chris Hill, and Nicholas Gonyea have begun their *Pet Project*, an effort to investigate how wearables for *intersubjective sensation* can support scientific investigation and engineering by young people and their families. Within the project team's own homes, the sensory worlds of pets are frequent subjects of discussion (e.g., *What is the dog hearing?*), an observation that motivated the investigators to wonder about how such curiosities could motivate young people's scientific inquiry into animal sensation. The basic premise of the project is that young people will design and conduct scientific experiments, complemented by reading of scientific literature, to develop answers to questions that they have about pets' sensory capabilities (e.g., *Do dogs see color?*). These answers will, in turn, be used to parameterize customizable wearables that can be used by humans to step into the sensory worlds of animals by producing records of animals' bodily experiences. This, in turn, is intended to catalyze further inquiry.

For example, a group of young people interested in the topic of dog color perception might attempt to train their dogs to respond differently to different color cues, eventually noticing that their pets cannot reliably distinguish red from green, but can distinguish yellow from blue. The reason for this is that dogs' eyes have a different set of color receptors in their eyes (functional for yellow and blue) than those contained in human eyes (which detect red, green, and blue).

Having discovered the scientific fact of dogs' dichromatic color perception, students might then wonder *What's it like to have dog vision?* At that point, they might don augmented reality "goggles" created by the *Pet Project* team. These goggles consist of a low-cost Google Cardboard plus an augmented reality app capable of rendering a real-time camera video feed into a customized video output (e.g., using a dog vision function to transform the colors and sharpness of the input into dog-like color and acuity). Here, records of *animal* experience are created. Generalized, this approach can support Doggy Vision, Cat Vision, Bee Vision, or any other re-rendering of the visual field desired, given suitable input devices. The team has already developed a prototype Doggy Vision mobile app (for Android and iOS), which it has recently begun using to design and pilot learning experiences.

Fig. 3 (left) View of bucks from Shapiro's dining room and (**b**) (right) same photo rendered with dog color sensitivity and acuity

When using Doggy Vision, it is strikingly and immediately apparent how different dog vision is to human vision. The importance of these differences rapidly becomes apparent when investigating *why* dogs sometimes seem to behave in peculiar ways. Shapiro's dogs, for example, ignore bucks lounging behind his house, but immediately freak out when those animals begin to move. One explanation for this may be that they cannot see unmoving deer against a background of green grass; this explanation is well-supported by Fig. 3a, b.

In addition to designing wearables for visual remediation, the *Pet Project* team has working prototypes for ultrasonic hearing and for wearable whiskers. We note that these technologies offer possibilities for intersubjective sensory augmentation that categorically exceed what Doggy Vision can support. Whereas dog vision is strictly less powerful than human vision, dogs, cats, and many other creatures can perceive sound far outside of the human hearing range. Similarly, many animals' whiskers (or similar features) are far more mechanically sensitive than human whiskers; some are capable of electrostatic sensing in addition to mechanical detection. Wearables that emulate these sensory capabilities offer the potential for young people to actually hear or feel the world in the ways that animals do (e.g., to notice sounds that they would otherwise be deaf to), and therefore transcend beyond the sort of role-play props that the wearables in projects like *BioSim* are. They provide records of animal experience that some learners did not realize were ever present in the first place.

Though still early in its course, we believe that the *Pet Project* approach of wearables for remediating experience of the world through intersubjective sensation offers enormous potential for science education that is situated in practices of empathy and perspective taking. It leverages interest and curiosity about our animal companions and produces records of animals' bodily experiences that can be inspected and compared to already familiar human sensory experience.

5 Summary and Future Directions

This chapter has presented a survey of recent, current, and emerging uses of wearable technologies for education. It has proposed a characterization of how wearables can be made supportive that can build upon existing ubiquitous wearables (e.g., smartwatches) or involve newly imagined use cases and models for teaching and learning. We have articulated some of the specific features of wearable technology that are appealing for educational technologists, knowing that more will be identified in the future by others. Of special interest to us has been how wearable technology can be used to represent records of bodily experience. The examples we discussed in depth (i.e., some of our own projects with wearables, including the *Physical Activity Data Project* and the *Pets Project*) were provided to illustrate the breadth of the potential design space.

As some of the most amplified voices in society that espouse the benefits of wearable technology are highly technocentric and do not always recognize the complexities of education and the needs of learners, it is appropriate to be skeptical of claims that any given wearable technology represent singular solutions to challenges we face as educational technologists. However, educational technologists should still remain open to the many different ways that wearables are being deployed currently. We also should remain receptive to the premise that wearables can remediate relations between learners, content matter, practices, and ultimately learning experiences in powerful ways. Our recommendation for those who write about wearable technology in education in the future is that they carefully consider the sociotechnical system that is involved and make explicit in their arguments about wearable technology how they envision a wearable technology will support teaching and learning. We have introduced some language in this chapter, in the forms of a simple classification and articulation of educative supports that could be used by others. These include descriptions of the support offered by wearables in terms of personal expression, integration of social interactions, role-play, supporting notifications, and inspection of bodily records.

As technology continues its onward march toward portability and ubiquity, coupled with the presence of more researcher and technologist voices that will inevitably propose wildly different new ideas for how wearables could be used for educational purposes, we expect to see exciting new developments. For example, e-textiles are evolving such that they are increasingly supporting new display capabilities and interactive behaviors (Devendorf et al., 2016). New research is underway that is making notification systems commonly found on commercial wearables smarter with respect to how and when they alert a user (Afergan et al., 2015). New physiological measures (such as electrodermal activity, which is now detected by some wearable technology products—see Cain & Lee (2016) for one example) have the potential to increase the situational awareness of wearable technology to make future devices even more supportive of complex learning activities at the most desirable times.

Furthermore, we close with the observation that as far as wearable technology is concerned, there are important loci of innovation that we should be monitoring and where partnerships should be developed. Take as an example cosplay culture as an extension of educative role-play. At comic book and gaming conventions, it is common to see individuals of all ages and gender identities dressing as characters from fictional universes. For instance, one might dress as Sailor Moon or Iron Man and walk through a convention floor striking iconic poses, reciting famous lines, re-enacting fight scenes, as well as posing for pictures with other guests. Cosplayers often build their own costumes, which involves substantial mathematical reasoning as patterns and measurements must be customized to build a new outfit, mask, or accessory. Moreover, technology is encountered when lights and other effects are integrated into the costume, as could be done when creating a light-up version of the arc reactor for the Iron Man suit example mentioned above or in the creation of a LED-enhanced cyberpunk outfit for a cosplay event (Bender & Samson, 2015). Cosplay in itself also represents a form of literacy practice in which characters and premises from established fictional universes are remixed into new narratives that are enacted through our bodies (Knobel & Lankshear, 2007). Thus, this use of wearable technology creates new opportunities for a number of content areas and competences to be enacted, that can range from mathematics, engineering, and the humanities. Similar directions could be pursued with performing arts and rave communities, where innovations in costuming and clothing are continually being made in order to attract attention, express aesthetic appreciation, or even protect wearers of the technology from predatory behavior (Letourneau et al., 2018). Beyond looking at traditional educational settings, technologists would be best served by also looking at other communities where innovations in wearables are also appearing.

The future of wearables in education remains to be determined. It may be that wearables will not find an enduring place in the larger educational ecosystem (Carr-Chellman, 2015). However, that is not a foregone conclusion. Educational technologists currently have the opportunity to articulate what kinds of wearable technologies show the greatest promise. It is our view that we now have the opportunity to be imaginative in our endeavors—by either conceiving of entirely new technologies or new uses for existing technologies. At the same time, it is important that we be grounded in our design rationales. As researchers and designers, we should state how a wearable will be supportive of specific educational aims. Thus far, some promising examples we have summarized in this chapter suggest the field of educational technology may be beginning to take steps in those directions.

Acknowledgements This work reported in this chapter was supported by funding from the US National Science Foundation under Grants No. DRL-1054280 and IIS-1736051. The opinions expressed herein are those of the authors and do not necessarily reflect those of the National Science Foundation.

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