Becoming Reflective: Designing for Reflection on Physical Performances

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Abstract: Learners' physical performances can serve as focal objects for reflection and insight across a variety of contexts and content areas. This session brings together a set of projects that leverage the physical performances of learners, construct concrete and abstract representations of those performances, and investigate how learners reflect on and understand the relationships between their performances and target content—physics, health and fitness, data literacy and navigation, animal foraging, and climate change. The session will share findings and design principles from each of the studies around constructing technological scaffolds for physical performance reflections. The symposium highlights the various ways performance can be used to engage learners, and how different settings and learning goals affect the designs of performance representations.

Introduction

The use of participants' physical performances as a focal object has several potential benefits. It leverages peoples' (and especially children's) innate interest in the state and performance of their own bodies; the "quantified self" movement (Lee, 2013) is only the latest reminder of this phenomenon. Experiencing or witnessing the performance leaves little doubt as to the authenticity of the data set, nor, in transparent designs, to the relationship between performance actions and their representation as data. There may be immediate benefit (physical, cognitive, identity) to the physical performances themselves (Abrahamson, et al., 2012). Common to all of the designs presented here is the provision of opportunity and support for reflection, including both reflection-in-action (during performances) and reflection-on-action (before or after performances) (Schön, 1983). Each project, however, offers distinctive strategies for fostering reflection, differing in the goals of reflection, the objects of reflection, the nature of the reflective activity, and the temporal and social contexts of reflection. Taken together, these define a multi-dimensional design space for supporting reflective activities surrounding learner performances.

In the following we briefly describe each project, including a description of the participants, their performances, and the technologies used for capturing those performances. The remainder of each project description is devoted to addressing the following questions:

- *Goal(s) of reflection.* What is the purpose of reflection? How are the outcomes of the reflective process be used by participants?
- *Object(s) of reflection.* Beyond the performance itself, what facets of the performance are captured, and how are these represented and made accessible to participants?
- *Nature of the reflective activity.* How do participants work with and use the representations of their performances?
- *Temporal contexts of reflection.* How do the projects manage the scheduling, frequency, and duration of reflective activities?
- *Social contexts of reflection.* In what social contexts does reflection take place? What role do facilitators play in fostering reflection?

Tom Moher will serve as chair for the symposium. During the symposium, each speaker will briefly (10 minutes) present their intervention and their designs for supporting reflection. Discussant Andee Rubin will comment on the presentations, with the remainder of the session devoted to an audience-plus-panel discussion focusing on elaborating the list of design considerations outlined in this symposium.

Devices, Dashboards, Games, and Reflections: Quantitative Data and the Subjective Experience of Fitness Technologies

Cynthia Carter Ching and Sarah Schaefer, University of California, Davis

The Learning Sciences has long been interested in how engaging with various kinds of digital representations of information and experience can facilitate learning and transformative change (e.g., Linn, Clark, & Slotta, 2003; Quintana, et al, 2004; Songer, 2007; Pea & Maldonado, 2006; Scardemalia & Bereiter, 1994). Recently, with the widespread nature of handheld devices such as smartphones and other wearable or portable technologies, there is great potential for such representations to be inclusive of a broad swath of learners' experiences within and across multiple sociocultural contexts (White, Booker, Ching, & Martin, 2012). For the most part, however, these representation studies have been focused on acquiring knowledge and habits of mind of some academic domain (usually mathematics or science), or perhaps learning to see everyday life through a domain-specific lens. Immediate impact on learners' everyday behavior, however, is not the typical goal.

This study has as its explicit goal the development of a device-and-gaming model for the improvement of adolescent health, via awareness of physical activity patterns and increased physical exercise. United States childhood obesity rates have doubled for children from 7% to 18%, and tripled for adolescents from 5% to 18%, since 1980 (Ogden, et al, 2012). Demographic studies also find that these national rates are disproportionally higher in low-income and minority communities (Calzada & Anderson-Worts, 2009). Changing physical activity behavior in sedentary individuals is a critical piece of a comprehensive approach to health improvement; however, studies employing pedometers in particular as a motivator typically find short-term but not long-term effects (Gardener & Campagna, 2011; Schofield, Mummery, & Schofield, 2005). The overall inquiry that this paper comes from aims to develop multiple ways for youth to engage with commercially available pedometers and their data, including in a narrative-driven online game that converts pedometer data into action events, and then to examine (a) the meanings youth construct around the various representations they encounter, (b) their reflections on the ways these representations relate to the physical activity contexts of their everyday lives, (c) the effects of this combination of meanings and representations on physical activity behavior.

For the past year, we have been working with an after-school program at an urban middle-school in Northern California, putting Fitbit™ activity monitors on approximately 30 youth ages 12-14 and talking with them about their reactions to the devices and their own data. Of the youth in our project, approximately 85% are on free and reduced lunch at school, 95% are non-white, and 67% speak a language other than English at home. Our data corpus consists of continuous device syncs during the four months in 2013 that students wore the devices, focus group discussions and individual interviews with a subset of students, multiple questionnaires and inventories, and pre-post BMI measurements. One of our first questions was how youth would react to wearing the devices themselves and the representations of their physical activity that the devices generate. Figure 1 shows two types of Fitbits™, both with digital displays that rotate (via a button or tap-screen) through numerical and graphical symbol representations of steps walked, calories burned, miles traveled, and flights of stairs climbed.

Figure 0. Device Display.

Figure 2. Commercial website dashboard display.

When we talked with youth about their experiences wearing the devices and the information they were getting about their physical activity, their talk focused primarily on the immediacy of looking down to find out, right then and there, how many steps or calories they had logged for a strenuous activity. Youth also discussed a great deal about subjective constraints that the data were not accounting for (such as "not everybody can walk to school"), or inaccuracies that they felt were giving them less "credit" than they deserved (such as questions about how many stairs counts as a "flight," and what happened if they rode bikes instead of walked). In most cases, however, the discussions were about the affordances of the device for immediate feedback, not about aggregates or larger patterns.

One of the ways that we hoped youth would reflect on aggregates or larger patterns was in looking at their profiles on fitbit.com. The commercial website associated with the Fitbit™ device has many more affordances for engaging with multiple representations of data. Figure 2 shows a snapshot from the first author's profile from 10/31/13, wherein the daily activity graph shows how activity is distributed over hours of the day (including a four-mile run in the morning and taking kids trick-or-treating in the evening). Yet when we engaged in project activities taking youth to their profiles and encouraging them to look at their online data, they seemed confused or uninterested in the representations. Many of them needed help to decipher the graphs, and they did not make easy connections between what they saw on the graphs and their everyday activities until we prompted them individually asking specific questions such as, “what did you do yesterday between 5-6 pm that got you these steps?” In general, however, youth were not motivated to spend much time on their profiles.

Figure 3. Game interface display.

A third way for youth in our project to interact with representations of their physical activity is through a game interface, which will hopefully prove more compelling than the online profile graphs. On this aspect we have been working with an indie game developer, Funomena, to create *TERRA*, a narrative-driven online game (Figure 3). In *TERRA*, players are space explorers who have landed and set up individual domed bases on a desolate and uninhabitable planet, with the goal of completely terraforming it within a limited number of weeks so more of their people can come live there. Players explore and terraform the planet using energy generated by real-world Fitbit™ steps they’ve taken, which are boosted by the metrics of their home base. As the game progresses, the landscape of the world they create becomes an aggregate representation of their synced activity over the variable timeframe of the game campaign, with each player’s landscape reflecting not only strategic in-game decisions but also the extent of their daily fitness. Investigating the effect of this in-game representation on youth insights about their activity and behavior is the goal of the coming year of the project.

Getting Lost and then Found in Physical Data

Victor R. Lee, Utah State University

This presentation draws upon two research and design activities that were both oriented toward providing fifth-grade students with opportunities to collect and reflect upon large amounts of data from their own physical activities while at school, using wearable physical activity data sensing technologies. In both efforts, students’ reflections were anchored by canonical representations of those data, such as computer-generated timelines and histograms. Also, a design decision was made in both activities to ensure that while students would be directly involved in the process of generating data from their own physical activities, an instructor or facilitator working with the students knowingly withhold, at least initially, information about which specific activities from the data collection phase were associated with which portion of the computer-generated data representation. The rationale for this withholding of information was twofold. First, this added uncertainty was intended to encourage students to collaborate with their peers in reconciling the specific features of a given data representation with their recalled experiences of a physical activity. This is comparable to an approach demonstrated by Nemirovsky and colleagues in which episodic feelings of a bodily experience can be seen through conversation as becoming “fused” with representations of those experiences (Nemirovsky, 2011; Nemirovsky, Tierny, & Wright, 1998). Second, there was a methodological goal of eliciting students’ ideas by requiring additional acts of explicit coordination for representation interpretation processes that are often both rapid and fleeting and may require prompting to uncover (Lee & Sherin, 2006).

In contrast to the aforementioned work of Nemirovsky and colleagues, a fairly long time delay between the bodily experiences and the representations to be inspected was also introduced. This was necessary because the wearable sensing technologies used were commercial, designed with specific capabilities and users in mind. Such devices are typically designed to support physical training and wellness goal attainment, as may be common for competitive athletes or active adults (Lee & Drake, 2013). As such, the data analysis software that was packaged with these devices tended to support summative reports of overall physical activity for periods of time longer than what is typically allowed during a portion of a school day. While those were real limitations, these commercial devices at the same time also provide a freedom of mobility and diverse set of features and capabilities that still made them in some ways more desirable than comparable devices designed primarily for children and schools (Lee & Thomas, 2011). So, to make the commercial devices work for the educational research and design purposes, small tools were developed to obtain fine-grained activity data (on the scale of individual seconds or minutes) that was stored on the devices but generally kept out of view of the intended users. These data were then provided in the TinkerPlots dynamic data visualization software (Konold & Miller, 2005), which was designed based on empirical research on student’s intuitive reasoning of statistics and data

(Konold, 2007; Lehrer, Kim, & Schauble, 2007). This extraction and conversion process necessarily added in a time delay on the scale of several minutes.

Given that students had direct embodied experience with performing the physical activities that produced the data, that the exact match between data representation and experienced bodily activity was deliberately withheld, and that there was a necessary time delay between activity and data-supported reflection, the students were to some extent, 'lost' at the time of reflection. They knew and could draw on a few different resources and such had some familiarity with the terrain in which they had been placed, but determining what they were looking at and coming up with actionable interpretations constituted a metaphorical 'wayfinding'.

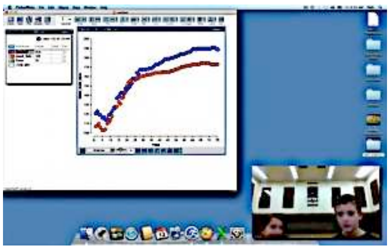

Figure 4. Two students participating in the running activity (left) and then working together to identify who was associated with which set of data (right).

This presentation proposes this spatial metaphor of data interpretation as a wayfinding process in a space populated by recalled aspects of bodily experience coupled with representational features in a data display. The first activity in which this metaphor is used is one where pairs of students participated in a running activity involving each student simultaneously running around their school gymnasium but with each student running in a different way (forward, backward, or sideways depending on which lap they were completing). Their task was to determine which time-ordered line of recorded second-by-second heart rate data in TinkerPlots was theirs. The second activity to be analyzed with the 'wayfinding' metaphor was a portion of full class design experiment during which students calculated the distances of each of their strides using three different distance inference methods they had invented that each involved a combination of Fitbit activity trackers, high speed cameras, and rulers. In both the heart rate and stride length activities, students proceeded to test ideas about which set of data was associated with which activity based on pairings of specific recalled experiences with visual features on the data displays that were especially salient. Much as one might familiarize themselves to a new city by identifying some familiar landmarks and orienting themselves relative to those them, these students familiarized themselves with the data by way of identifying and orienting their recalled experiences relative to temporary 'eventmarks.' While this wayfinding process in data interpretation could be traced to the design decisions and constraints associated with the two activities, the suggestion made by this presentation and supported by other observations from the research project is that 'eventmarking' is actually a very sensible, and likely typical, way for people to make sense of inscribed data representations of what would otherwise be, in absence of a body sensor and performance capturing technology, ephemeral lived experiences.

Action and Reflection in an Embodied Foraging Simulation

Tom Moher, Alessandro Gnoli, Anthony Perritano, Paulo Guerra, and Brenda Lopez-Silva, University of Illinois at Chicago; Mike Tissenbaum, James Slotta, Rebecca Cober, and Cresencia Fong, University of Toronto

Over the past year, we have developed a learning environment designed to support upper elementary learners' construction of understandings surrounding animal foraging behaviors. In *Hunger Games*, classroom learners enact foraging within the context of a sequence of increasing challenging simulated conditions of competition, resource depletion, sociality, and predation. The instructional unit is designed to develop understandings of the factors that foraging animals use to guide their decisions in selecting food patches, as well as the ways in which populations of animals distribute themselves among available resources. Students' (individual and aggregate) behaviors during enactment of the foraging simulations serve as objects of inquiry for reflective activities.

Early in the design of *Hunger Games* we made the decision to stage foraging as an embodied activity. We were inspired by a longstanding practitioner tradition of using embodied activities with physical materials (e.g., chickpeas, M&Ms) to introduce foraging concepts, and felt that an embodied approach had several potential advantages over a distributed screen-based approach (Goldstone & Ashpole, 2004). First, it more closely models the locomotive and visual demands on foraging animals. Second, it affords an unconstrained social context for activity, allowing students to share strategies spontaneously within the action space. Third, it allows for the emergence of deceptive and despotic behaviors (e.g., misinforming others about patch yields, physically blocking access to food patches) with parallels in the animal world. Finally, we felt that using an embodied simulation had strong motivational potential for upper elementary school learners.

In *Hunger Games*, each student in the classroom is provided with a small stuffed animal ("squirrel") that serves as his or her "avatar" during the activity (Figure 5). Students forage by moving their squirrels among a set of "food patches" of varying quality distributed around the classroom, gaining energy as a function of the elapsed time in the patch, patch quality, and competition within the patch (i.e., the presence of other squirrels) (Figure 6). Food items (e.g., acorns) are not explicitly represented, avoiding the demands on teachers for both

Figure 5. RFID tags are embedded in plush toys serving as "avatars" for student foragers.

Figure 6. Students foraging at food patches. Hidden RFID readers detect tags embedded in stuffed animals.

preparation (e.g., counting out large numbers of small items representing food) and data management (aggregating individual performances into representations of group performance). Students falling victim to predation (signaled on smaller displays adjacent to each food patch) are considered "injured," and given a short "time out" period in which their squirrel cannot gain calories even if located in a patch; this allows us to introduce predation without forcing children "out of the game" prematurely.

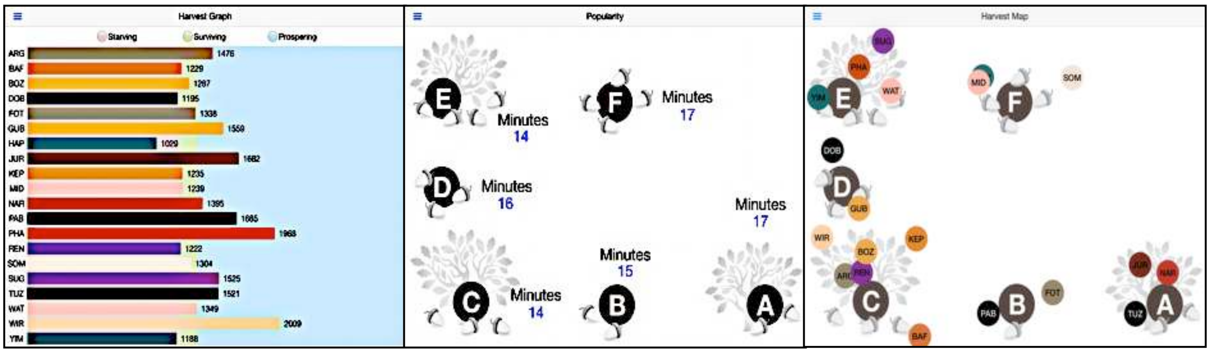

Figure 7. Public ambient displays used during foraging bouts. From left to right, the Harvest Graph (distribution of individual caloric gain), the Patch Popularity map (aggregate whole-class time spent in patches), and the Marauder's Map (the current location of all squirrels currently foraging).

Hunger Games is designed to support both reflection-in-action (during foraging) and reflection-on-action. During foraging bouts, participants have access to large animated public displays depicting the number of calories each squirrel has gained, the cumulative patch utilization, and the current locations of all of the squirrels (Figure 7). These representations are designed to support students' in-the-moment decision-making, but also to help learners develop understandings of how their actions impact the public representations (bar graphs, maps), setting the stage for post-activity reflection on their performances. Reflection on action is supported through the use of a community knowledge-building application (Figure 8). In that application, students are provided with representations of both individual and aggregate data reflecting their performance during foraging bouts. At the aggregate level, they have access to an interactive version of the Harvest Graph that allows them to sort the distribution of individual caloric gains according to various strategies surrounding patch quality, competition, frequency of moves, etc. At an individual level, students are provided with a "move tracker" that allows them to replay the step-by-step patch switches that they made within the context of the state of the system at the time of their decisions; this tool is used to support learner reflection on the effectiveness of their moves and to prepare for subsequent foraging bouts. Finally, the application provides a threaded discussion tool to support development of community knowledge around a series of structured discussions.

Following a pilot study in Fall 2013 (Gnoli, et al., 2014), we are currently enacting a four-week Hunger Games unit with three classrooms of grade 5 (10-11 years of age) students, focusing on learners' appropriation of resources during foraging and knowledge construction. Our presentation will review our experiences in those classroom enactments.

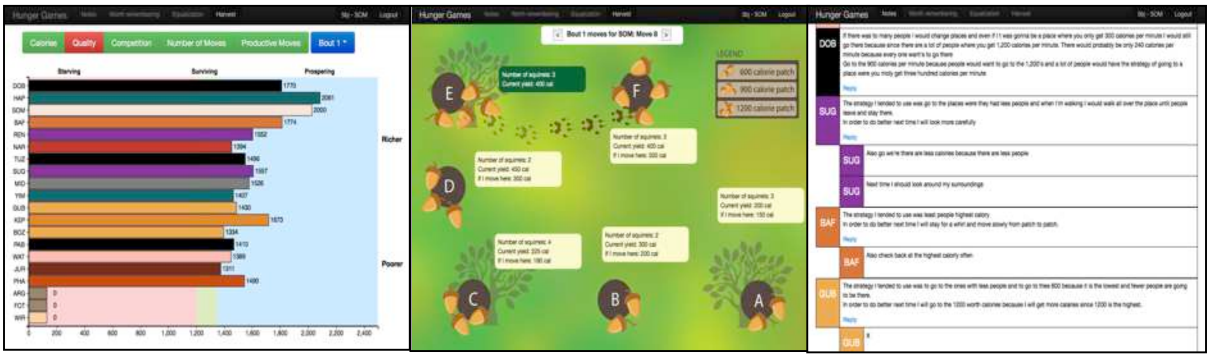

Figure 8. Tablet-based application to support individual reflection on action and community knowledge construction. From left to right, the sortable Harvest Graph, move tracker, and threaded discussion tool.

Distributed Acts of Reflection: Embodied Acts to Focus and Filter a Jointly Produced Reflection

Noel Enyedy, University of California Los Angeles and Joshua Danish, Indiana University

Dewey (1933) defined reflection as “active, persistent, and careful consideration of any belief or supposed form of knowledge in the light of the grounds that support it and the further conclusions to which it tends” (p. 91. as cited in Spalding and Wilson, 2002). In this paper we explore the potential for supporting this kind of reflection in mixed-reality environments that combine embodied activity with augmented reality to support groups of early elementary students in reflecting upon and thus revising their developing ideas about the physics concepts of force and motion. Using data from the Learning Physics through Play (LPP) project (Enyedy et al., 2013), our analysis highlights the co-constructed nature of reflection in an embodied learning environment. Our analysis suggests that this form of mixed-reality environment provides unique opportunities for reflection.

The LPP environment is designed around the assumption that play, particularly embodied socio-dramatic play, can provide a unique opportunity for children to explore complex ideas. Specifically, we build on Vygotsky’s (1978) definition of play which notes that play always includes both an imaginary situation and a set of rules. In this framework, the imaginary situation supports students in reflecting about the rules of the situation even when those rules might otherwise be beyond students’ ability to engage with. LPP was designed to support this reflective play using two key components: 1) an augmented reality system that uses computer vision to record students’ physical actions and locations, and 2) software that translates this motion into a physics engine and generates a display and a response based on the sensing data. The LPP system uses commercially available, open source motion tracking and pattern recognition technologies (Kato, 2007) to create an inexpensive alternative to virtual reality within the physical classroom (a 12’ x 12’ carpet at the front of the classroom). Tracked motion is instantly imported into the new LPP computer microworld that allows students to model their understanding of force and motion and compare their predictions to simulated results. Thus their embodied play is enhanced with physics symbols in an effort to provide unique opportunities for reflection about how their play relates to the underlying science.

Our data come from the first LPP study (Enyedy, et al., 2013) in which 43 students (aged 6-8 years) engaged with the LPP learning environment to learn about force and motion. Our findings indicated that 91% of the students (39) demonstrated a significant pre- to post-test learning gain over the course of the 15 week curriculum. In the present analysis our goal is to further explore how the LPP Environment supported students’ efforts at reflecting upon the science content in a manner that ultimately led to these gains. To examine students’ process of reflection, we combine Piaget’s (1983) taxonomy of reflection with that of Davis (2003) to categorize the process through which students talk, gesture, and positioning reveal their reflection upon the underlying content. Piaget suggested three forms of reflection which attend to the physical properties of objects, one’s own actions in the world, and one’s own thinking (metacognition in more recent theories). This can be synthesized with Davis’ (2003) framework, which attends not only to the focus of reflection, but the content of reflection and distinguishes between actions (appropriate ways of behaving, a focus on goals); reflection on activities (the specific tasks assigned to students); reflection on the actual content being studied; and reflection on knowledge (monitoring or improving one’s understanding). The combination of frameworks will support us in examining how students move between these different foci, and how the combination of embodied play and symbolization in the LPP environment supports the process.

Our presentation will include several case studies that demonstrate how students move fluidly between reflecting upon the physical environment, the simulated environment, and their hypotheses about the rules that underlie both. Further, they use both the simulated world, and their embodied action as a method for supporting their ongoing reflection. For example, in one activity students were asked to model what they thought would happen if a ball that was already moving in a straight horizontal line received a force in the vertical direction (a kick) (Figure 9). A common misconception is that the ball will now move in the vertical direction rather than moving diagonally. While several students indicated their predictions, it is particularly illustrative to consider David who indicated his prediction by pretending to be the ball that has received the kick and walking across the space while placing a piece of string upon the ground to indicate his hypothesized pathway. Thus David uses his body and the string to reflect upon the rules he assumes will drive a ball in this situation, suggesting a blurring of the lines between a reflection on the physical world and one's actions. The teacher then runs the computer simulation, which does not trace the same path as David, a point that Sara is quick to point out. She reflects upon the contrast between the two and then indicates her own prediction by walking the same space with a different point in mind. Thus her reflection is made visible to the group through her embodied activity. David pauses while considering both before appearing to realize that the problem was not in his general model, but in his placement of the string that indicated his hypothesis—he had placed it at the edge of where the force was applied to the ball rather than the middle. Thus David's reflection appears to take into account his own thinking, the activity of the computer, the activity of his peers', and his own body in addition to the rules of what it means for a ball to be kicked! This combination ultimately allows him to produce this more accurate depiction, which his peers can then take up and reflect upon in turn.

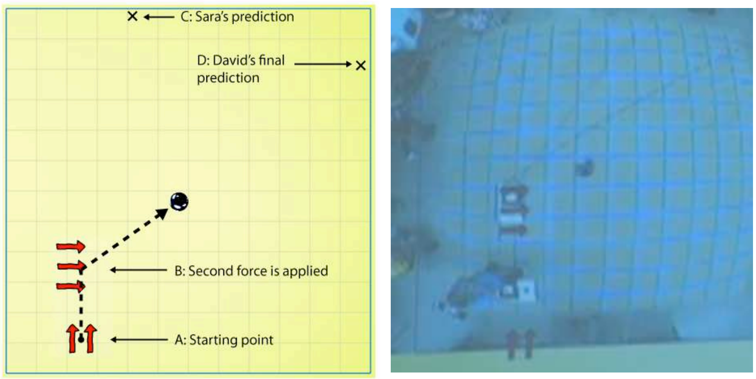

Figure 9. The LPP window on the left depicting 2-dimensional motion. The dashed line depicts the path of the ball's motion once the simulation was begun. The ball was initially placed at point A, on top of a vertical force of 2. Once it began moving, the ball encountered the force of 3 at point B, which altered its trajectory. On the right is the mixed reality version that the students see based on the view of a camera mounted on the ceiling.

In this example, students' reflection in an environment such as LPP appears to move between taking multiple aspects of the environment as the object of reflection (the movement of a ball, the simulation of a ball by a computer, and one's peers' embodied predictions) and using these as tools to foster reflection. While at first blush confusing, it appears that it is exactly this synthesis of opportunities that leads students reflections and helps them to develop more normative accounts of the physics concepts. In this short segment we can see the new complexities and affordances that mixed reality provides for reflection. Empirical abstraction is augmented with new virtual objects (e.g., the quantifiable forces that float above the path of the ball) that fuse with the real world to afford new inferences and calculations. Pseudo-empirical abstraction is enhanced both by allowing new actions such as running the simulation and changing the parameters, but more importantly by allowing students to interact with each other and the traces that other people's previous actions have left on the system.

Exhibiting Performances for Data Literacy and Climate Change Education

Leilah Lyons, Priscilla Jimenez, Brenda Lopez, and Brian Slattery, University of Illinois at Chicago

Informal learning institutions are increasingly incorporating full-body interactive experiences in their exhibits. Full-body interaction makes use of the motion and/or position of users' bodies as input to a digital experience, with the output typically presented on large displays mounted on a wall or floor as a projected image. Full-body interaction exhibits are known to be highly engaging for visitors who are directly involved in the interactions (especially younger visitors). Engagement alone does not necessarily translate into learning, however—visitors need opportunities for reflection (Allen, 2004). This is especially true for the many visitors who only peripherally engage in the activity as spectators. They lack the firsthand experience of the interaction, and thus may struggle with understanding the performing visitor's actions (Reeves et al, 2005). In this presentation, we detail the design strategies we employed as we made visitor performances the cornerstone of an educational exhibit for a zoo. This setting allows us to leverage the power of using many visitors' performances to surface data literacy issues, but also introduces reflection challenges.

The Climate Literacy Zoo Education Network (CliZEN), a nationwide group of zoos and aquaria, developed a whole-body interaction exhibit, *A Mile in My Paws*, to address the worrisome trend that despite increasing evidence of climate change, the public has expressed less concern for its impacts. An APA report examining this issue recommends that in addition to exposure to data, learners need a personal or affective connection to the effects of climate change to begin building an understanding of the magnitude of the phenomenon (APA, 2010). One recommendation was that in addition to exposure to data, learners need a personal or affective connection to the effects of climate change to begin building an understanding of the phenomenon (APA, 2010). In our exhibit, a zoo visitor is put in control of a polar bear avatar that must traverse a simulated arctic environment in past, present, and future time periods in search of food. Users control the bear by "swimming" with motion-sensitive gloves (fashioned as plush polar bear paws) and walking in place on a pressure sensitive plate (Figure 10). As polar bears must work harder to swim given the shrinking of sea ice, so too must *Paws* users work harder by swimming more frequently as they play through the maps of 1975, 2010, and a projected 2045 maps (created using satellite data and model, Figure 10).

Figure 10. On the left, *Paws* in use in the Brookfield Zoo. Middle left, a player wears plush gloves containing motion sensors, and stands on a pressure-sensitive plate, to swim and walk, respectively, through three different decades of a simulated arctic environment (maps, middle right). The right image depicts the graphical representation of visitors' performances across the decade, with the most recent two visitors' data highlighted.

Kinesiology research has shown that people are remarkably reliable at judging the relative effort they experience with different physical exertions; we exploited this perception-of-effort as a means of affectively (and hopefully effectively) communicating the magnitude of climate change's impact on polar bears (Lyons et al., 2012). A controlled experiment helped us tune the glove weights (Lyons et al., 2013) so we could induce visitors to perceive later decades (more episodes of swimming) as more effortful for bears than earlier decades.

Users, especially young users, would notice but not realize the import of the increased effort unless it is pointed out to them. For this reason, the users' motions were logged by the system, and the calories they burned estimated and plotted on a graphical representation that zoo interpreters could use to emphasize the exhibit's educational message (Figure 10). This representation was displayed on either an iPad or a large monitor near the exhibit. The graphical representation of performance illustrates the magnitude of climate change impact on polar bears over time, and it helps demonstrate that variability in data does not invalidate trends. (Climate change skeptics often use variability in climate change data representations, like disagreements between tree ring and ice core temperature estimates, to dismiss the validity of warming). Visitors see their own data juxtaposed against the recorded performances of other, allowing interpreters to directly address the issue of variability-in-data. We leverage the large numbers of zoo visitors to make connections between the easily understood performance data variability and the variability in large climate change data sets. With this reflection-on-action (Schön, 1983), we expose visitors to the "core of statistics": "the task of understanding the world from incomplete or imperfect data," often missing from more traditional data literacy approaches (Rubin, 2005).

The post-performance reflection activity clearly offers potential educational benefits to both performers and spectators, but there was still the question of what educational benefit spectators would get during the performances (which last around 2 minutes). Moreover, spectators arrive and leave sporadically – there is no guarantee that they would stay for the post-performance debriefing. We were interested in making the performance more than just a shared anchor for discussion (Diamond et al., 1995) or a means of attracting visitors (Meisner et al., 2007) – because the performance itself is the subject of the exhibit, there was a need to support reflection-in-action (during performances) for spectators (Schön, 1983). The link between user actions and the effects these actions produce should be maximally "expressive, to enable the spectator to fully appreciate the performer's interaction" (Reeves et al., 2005). User actions in *Paws* were intentionally designed to be as obvious and expressive to spectators as possible – to draw spectator attention to the swimming and walking motions performing visitors wear large plush gloves and slippers that look like polar bear paws (see Figure 10). Nonetheless, a special challenge comes with exhibiting effort – kinesiology research shows that spectators are notoriously bad at judging the effort (Lyons, 2012). Therefore, we needed to create a live representation of the performer's exertion (Figure 11) that depicts both the player's path across the arctic map and a running graph of how many calories they have burned.

A pilot study performed *in situ* at the zoo showed that interpreters could and did make use of the live performance data to engage spectators in reflection-in-action (Figure 11), as illustrated by this transcript:

> [01:03:03.07] Visitor-Child: So where is he trying to go?
> [01:03:04.15] Interpreter: He's trying to … go to this red star which is a seal, so if the polar bear were to smell a seal, like up to like three feet of ice they can smell a seal underneath, they'd have to chase and follow it to where they could actually get it, so that's what he's simulating here
> [01:03:23.03] Interpreter: And as he goes we can kind of watch based on how far he's going, how many calories he's burning, and you're gonna see this go way up, especially when he gets to these swimming areas, 'cuz its a lot harder for the polar bear to swim than it is to walk.

Figure 11. Left, screen shot of live performance data, with a depiction of where on the map the performer is currently located and a graph of how many calories the player has burned over time (note the steeper slopes for periods where the player was swimming). Right, photograph of an interpreter (in green shirt, far left) using an iPad to engage spectators in reflection-in-action while another visitor performs.

During this exchange the interpreter gestured to the higher-slope regions of the graph, shown on the iPad device, corresponding to times when the performer had been swimming. We found that gesture was critical to the interpreters' ability to engage spectators in reflection-in-action. Other trials, where the live graph was shown primarily on a large shared display, drew the attention of more spectators, but interpreters seldom highlighted any components of the data representations. By contrast, interpreters using the iPad used gestures to explicitly connect regions of the evolving graph to the live performance, and to the map. Ongoing work extends the "reach" of mediation to more spectators by supporting finger-based annotation and mirroring of the annotated iPad screen on large displays. A separate paper in this volume contains details on the iPads' mediative roles.

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