Back to the Future: Embodied Classroom Simulations of Animal Foraging

Alessandro Gnoli, Anthony Perritano, Paulo Guerra, Brenda Lopez, Joel Brown, and Tom Moher
University of Illinois at Chicago
851 S. Morgan (M/C 152), Chicago, IL 60304 USA
{agnoli2; aperri3; pguerra2; brendita; squirrel; moher}@uic.edu

ABSTRACT
This paper describes the design and pilot enactment of an instructional unit for elementary school students, *Hunger Games*, which centers on development of learner understandings of animal foraging behavior. Inspired by traditional teaching practices employing physical simulations, within the unit students engage in an embodied enactment of foraging using stuffed animals (with embedded RFID tags) as tangible avatars to represent their foraging among food patches (with camouflaged RFID readers) distributed around a classroom. Displays situated near the food patches provide students with information regarding the energy gain as the forage in the environment. A two-period pilot enactment of the unit demonstrated the feasibility of the design for classroom use, evidenced the development of affective relationships between learners and avatars, and afforded the emergence of unanticipated behaviors that promoted new questions about the science phenomena. The results suggest provisional support for the effectiveness of the unit as a science learning environment.

Author Keywords
Embodied learning; Foraging; Location-based interaction; Tangible avatars.

ACM Classification Keywords
H.5.3. Group and organization interfaces; K.3.1. Computers uses in education: Collaborative learning.

General Terms
Human Factors; Design; Reliability.

INTRODUCTION
The strategies that animals use to forage among habitats in order to maximize their energy gain and minimize their risk of predation are central concepts in the development of understandings surrounding animal behavior and evolution [17]. Historically, teachers have developed a wide range of ingenious embodied exercises to introduce the topic to learners, situating students as foragers among food patches, using everyday materials to represent food sources, and introducing affordances and constraints designed to mimic those confronted by animals in their natural settings. The practitioner literature is rich with examples of these exercises. One lesson introduces the topics of prey switching and development of search images by using chickpeas augmented with different colored dots to represent food items of varying richness, asking students to transfer them from a source bin to a receptacle using chopsticks [2]. Another situates learners as birds searching for sticky notes of different colors attached to the undersides of classroom chairs and desks to explore the interaction of food distribution on the success of solitary vs. flock foraging [22]. A NASA exercise in exploring penguin foraging behavior positions students as foragers for large (metal washers) and small (candy) krill, Thyanoessa (toothpicks), and salps (marbles) spread around a large field using clothespins to simulate the penguin's bill [16].

Research in the learning sciences and science education offers strong support for the use of these kinds of exercises. Using data obtained from students' own performances leverages students' egocentric interest in and prior knowledge of their own physical activities [14]. These performances in turn can serve as cases that can be compared with theoretical optimal behaviors and empirical data obtained from animals studies, creating opportunities for transfer of learning [19] and understandings of similarities and differences between humans and other species. The exercises situate learners as decision makers in problem-based learning activities [8], affording the development of strategies within direct experiential contexts. Situating students within a social *learning* context leverages the benefits of peer feedback [26] and promotes the development of learning communities [4]. These kinds of activities can also motivate engagement, appealing to many students' desire for variety in learning experiences and, especially among children, physical activity [1]. Finally, they expand opportunities for whole classes of students to simultaneously engage in collective science inquiry [11].

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At the same time, non-digital simulations have some important limitations. The representation of non-depletable food patches would require a (human or mechanical) mechanism for monitoring and replenishing food at patches during enactment of foraging. Modeling predation would require the real-time intervention of the teacher, who would have to simulate random attacks among competitive foragers according to differential patch risk signatures. Even in the simplest case (competition for a depletable resource without predation), enactment of embodied foraging exercises imposes significant tangential demands on teachers and learners, particularly with respect to the representation of food. For teachers, preparation of the materials for these exercises requires their acquisition, preparation (e.g., painting dots on chickpeas), and distribution (in the case of the Penguin activity, for example, spreading 1,200 items around a field). Moreover, these exercises typically require "bookkeeping" phases in which students' harvests must be manually tabulated in order to obtain data for subsequent analysis. These operations can be both time-consuming (discouraging utilization of the exercises, or limiting the ability to change habitat configurations within class periods) and error-prone (resulting in data sets that fail to reflect actual performances).

For these reasons, in recent years embodied classroom enactments of foraging have largely been supplanted by the use of screen-based simulations. In many cases, these simulations are presented as opaque mathematical models of optimal performance; they allow learners to rapidly explore model parameter spaces, but do not situate learners as decision makers within the context of foraging. Agent-based (e.g., NetLogo) simulations expose decision-making regimens, but rely on the use of opaque enactment engines for the production of performance data. Neither model- nor agent-based simulations utilize learners' own performances as a component of inquiry. Distributed screen-based simulations (e.g., [12]), in which networked users enact foraging within a shared virtual environment, hold some of the benefits of traditional exercises: they situate learners as foragers in moment-to-moment decision-making, engage multiple participants in real-time collective foraging and, as with manual simulations, use learners' own performances as data for reflective inquiry. However, they afford only relatively impoverished social learning contexts (by mediating interaction through the computer interface) and social foraging contexts (limiting behaviors to the actions afforded through the application). Finally, these kinds of situations necessarily frame activity around interaction with a display, precluding the benefits that might derive from an activity structured around locomotion and physical manipulation of materials.

In this paper, we present the design, implementation, and our initial experiences with a technology-supported activity intended to recapture some of the benefits of traditional embodied, materials-based exercises. In our *Hunger Games* unit, students are situated as ambulatory agents foraging among "food patches" of heterogeneous quality distributed within the physical space of the classroom. The learning goals of the unit entail the development of learner understandings of foraging behaviors under an increasingly complex sequence of habitat configurations that introduce concepts such as patch depletion, patch dilution (competition), and predation. Each "bout" of foraging is followed by an examination of aggregate (the distribution of patch utilization) and individual (patch selection) student performances, which are then compared with theoretical optimal models (e.g., " ideal free distribution" [10]) and data obtained from empirical studies of animal foraging behaviors.

In designing Hunger Games, we sought to preserve the first person, ambulatory, social nature of foraging while at the same time mitigating the preparation and bookkeeping burdens that make them challenging to enact. In our design, students' movements among food patches are automatically detected and recorded, allowing us to compute aggregate patch utilization without the need for manual logging. Rather than requiring students to collect physical tokens representing the products of their foraging, their "harvest" is automatically computed as a function of the time spent in each patch, based on the instantaneous yield of that patch under varying conditions of patch richness and competition. Predation is introduced by assigning differential risk to different patches. In order to keep students involved in the activity, predation is characterized as resulting in injury rather than death, and injured students are required to return to a "den" to recover for a period time during which they cannot forage.

In the remainder of the paper, we present the conceptual framing and design rationale underlying Hunger Games, describe the implementation of the system used to support the activity, and report on our experience during a short pilot study of the unit in a fifth grade classroom. The paper concludes with a discussion of issues raised during the enactment of the unit, and our plans for further development and research.

INTERACTION DESIGN IN HUNGER GAMES

The key technology design challenges in Hunger Games centered on the development of (a) a method for automatically recognizing and logging movement among food patches and (b) representations of patch quality and individual and aggregate foraging performances.

Tracking Foraging Behaviors

At the outset of the project, we anticipated using a proxemic strategy [13] that would allow students with tag-embedded wearables (e.g., bracelets or lanyards) to be detected in the vicinity (within ~0.5 meters) of food patches without requiring them to provide explicit notification of their arrival. We began to experiment with a range-tunable active RFID system (Wavetrend®) that we had available in our laboratory. It soon became clear that this approach was not viable; the signal attenuation and reflection due to the density of human bodies and metal furniture and cabinets common in classrooms, reader separation constraints imposed by classroom space, and variability in tag recognition as a function of tag orientation, reduced the reliability of the system to the point where it would not support the classroom activity we had envisioned.

Somewhat reluctantly, we turned to more explicit notification methods. We considered several different approaches that had already been used in classrooms. One strategy would be to use computer vision (e.g., using portable QR codes [6] or attaching QR codes to food patches and providing students with portable devices to read those codes upon arrival [25]). A second possibility was to use a contact-based technology (e.g., wearables that could be touched against a contact point to create an identifying circuit [18]). A third possibility was to use very short-range RFID technology (as in [21, 23]) that would allow serial reading of tags. However, we were concerned that such approaches would create interaction bottlenecks as students queued for registration.

We settled on a method that leveraged the multi-read capability of our active RFID system. Instead of embedding tags in wearables, we decided to embed the tags in small plush toy animals that could serve as "avatars": external representatives for the students during foraging (Figure 1). By reducing the range of the readers to 30 cm, requiring that the avatars be placed directly on top of the readers, and location-specific range tuning, our lab studies indicated that we should have been able to effect the necessary reader separation and overcome signal attenuation and orientation issues with sufficient reliability to support simultaneous reads of sufficient numbers of tags to support our activity.

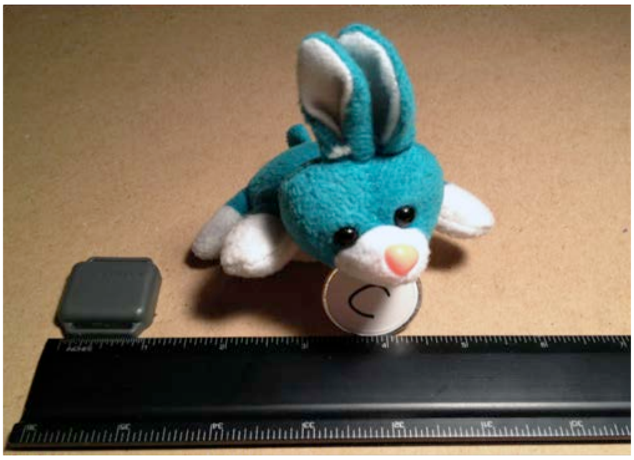

Figure 1. RFID tags (left side of image) are embedded in small plush toys that serve as "avatars" of student foragers.

One limitation of active RFID systems is the constraint that that active tags emit pings no more frequently than once ever 15 seconds when stationary. This problematized the detection of departures from food patches, since the only sure way of knowing that an avatar had been moved was the absence of a signal for a 15-second interval. We settled on the approach of only recognizing avatar arrivals; that is, an avatar was presumed to remain in the patch that it had been foraging until it was recognized as having arrived at a new patch. While was acceptable for our activity (continuous feeding among patches), this would be more problematic in designs where opportunity costs due to inter-patch travel times or energy loss during non-foraging periods was a factor in the energy model.

Representing Foraging Behaviors

Because energy gain is not reflected by the accumulation of physical tokens as in traditional embodied exercises of foraging, we needed to find an alternative method to provide students with formative feedback on the effect of their foraging activity. In addition, because our tests did not result in consistently reliable reads, we deemed it necessary to provide students with visual confirmation that readers had recognized their avatars.

One approach that we considered was to provide students with handheld devices to continuously monitor their energy gains and receive confirmation of patch arrivals. However, we felt that this would encumber students already asked to carry their avatars from patch to patch, and represented an unnecessary additional implementation cost.

We settled instead on the strategy of using public displays to represent this information. At each patch, we installed a small (iPad) display that used a dynamic bar graph to reflect the instantaneous per-forager patch yield (a function of patch richness and dilution due to competition) and the accumulated energy gain of each local forager since their arrival at the patch (Figure 2). We reasoned that students could use this information to evaluate the effectiveness (energy gain) of foraging within that patch.

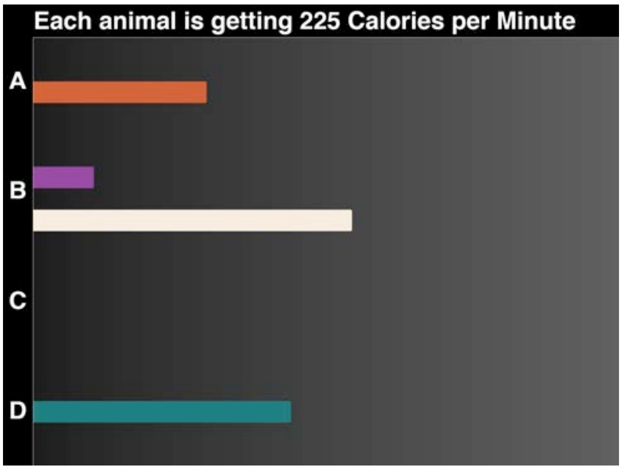

Figure 2. Food patch display. The display shows instantaneous energy gain (top), and how much each forager has accumulated during their current stay at this patch. Students use avatar color and label as index to find their cumulative harvest.

Because the display had to be capable of reflecting this information for all of the students in the class (in the worst case that they all chose to forage at the same patch), we needed to find a compact representation that allowed students to distinguish the representation of the energy gain of their avatar from those of other students. We considered the strategy of using the color of the avatars as an index. This approach was problematic, however, for two reasons. First, there weren't enough distinct colors among our plush toy set to assign a unique color for each student, and second, even if we had enough, we were concerned that it would be difficult for students to accurately distinguish among those variations. We addressed this problem by adopting a two-dimensional representational system, using four easily distinguished colors and attaching a small paper tag to each avatar with an alphabetic "cluster" label (see Figure 1). This allowed us to compactly represent the entire class on a single small display; students found the representation of their avatars by first indexing by cluster, then by color.

In addition to the displays provided at each food patch, we provided an additional display that reflected the real-time cumulative energy gain of individual foragers over all of the patches that they had visited, using a format analogous to that shown in Figure 2.

DESIGN OF LEARNING ACTIVITIES

In fall 2012, we enacted a short pilot of the Hunger Games unit with a group of 11 fifth-grade (age 10 and 11) children enrolled in a Saturday science enrichment program. We had three goals in conducting the pilot. First, we wanted to evaluate the reliability of the system, to see whether food patch arrivals were accurately detected by the RFID readers in a working classroom. Second, we wanted feedback on the feasibility of the activity; we wanted to see how children would engage the activity and materials that we had provided for them. Third, we wanted to develop some preliminary evidence regarding the effectiveness of the unit as a learning activity. Enactment of Hunger Games took place in two 90-minute sessions on consecutive Saturdays, with one of the authors serving as the classroom teacher.

Competitive Foraging among Heterogeneous Patches

The first session focused on issue of how animals choose to forage among food patches of different richness in the face of competition from fellow foragers. To prepare for the unit, we installed six RFID in locations around the classroom. The RFID readers were concealed under butcher paper, which were then decorated with leaves and twigs to resemble a natural environment (Figure 3). No explicit representation of food was used.

Energy gain at each food patch is a function of two variables: the richness of the patch (total rate of yield, expressed in calories per minute) and the number of foragers currently in the patch. Competition (patch dilution) was modeled by reducing instantaneous individual yields by the ratio of the former to the latter. (For example, if a patch had an overall capacity to yield 600 calories per minute, three foragers at that patch would gain energy at the rate of 200 calories per minute.) Three levels of patch richness were used, with two patches yielding 600 calories per minute, two yielding 900 calories per minute, and two yielding 1200 calories per minute.

Figure 3. Students foraging at food patches in Hunger Games. Hidden RFID readers detect tags embedded in stuffed animals, with energy gain reflected on local display.

Each student was given a plush toy ("squirrel") with embedded RFID tag, and the teacher explained rules of the "game" they were to play, establishing the objective of "getting the most calories you can" over a five minute foraging "bout," the mechanism for getting calories (leaving a toy in the patch), and interpreting the displays.

The display of cumulative harvests across the entire session was deployed in a separate portion of the room called the "den" (inspired by the Savannah project [9]) that students could consult during the activity (Figure 4).

Figure 4. Students checking on their total energy gain over the course of a foraging bout.

Within the 90-minute period, children engaged in three 5-minute foraging bouts. Each bout was followed by a reflective session in the den that focused on both individual and collective foraging behaviors. The teacher first engaged the children in a discussion of individual foraging strategies, using the aggregate display to identify individuals who had enacted the most successful strategies, and encouraging them to share those strategies with their classmates. Attention was then turned to their collective behavior, represented by a frequency distribution (the pie chart in Figure 5 that showed how the class had collectively apportioned their foraging time among the six patches). The distributions were then compared with an optimal ("ideal free") distribution, leading to a discussion of strategies that might yield better performance during the next bout.

Figure 5. Teacher leading discussion of collective foraging behavior. The pie chart shows the relative amount of time the class spent in the six food patches.

Predation

The second session focused on the ways that risk of predation impacted animals' foraging strategies. Orthogonal to patch richness, we introduced two levels of (random) predation risk: low risk patches (one predation event per forager for every two minutes in a patch) and high-risk patches (one predation event per forager for every 80 seconds in a patch). Because we did not want to exclude learners from the foraging activities, predation was modeled as injury rather than death. Students who had been attacked were required to return to the den to recover for a 30-second period before their avatar would again be able to receive energy from any of the food patches in the room.

Several changes were made to the patch displays for the second session (Figure 6). We had observed that students were confusing their aggregate energy gain (represented in the den) with their local gains during a foraging session at individual food patches. At the same time, noting that their performance indicated they were not attending to patch richness, we wanted to increase the salience of the instantaneous individual patch yield that they could expect to obtain by visiting patches. We also need to provide students for a notification of predation events.

Figure 6 depicts the revised version of the patch display, which was moved to eye level and which included a much more prominent display of individual instantaneous yield and removal of energy gain bars. Avatar status is indicated at the bottom of the display, using the same color coding as during the first session, with animated ("PacMan"-style) graphics reflecting the presence of an avatar foraging at the patch, "sick" avatars representing avatars that have been attacked, are not eating, and need to go to the den, and empty circles reflecting avatars who are not currently located at the patch. In addition to the graphic display, predation was signaled using an audio recording of an attacking hawk.

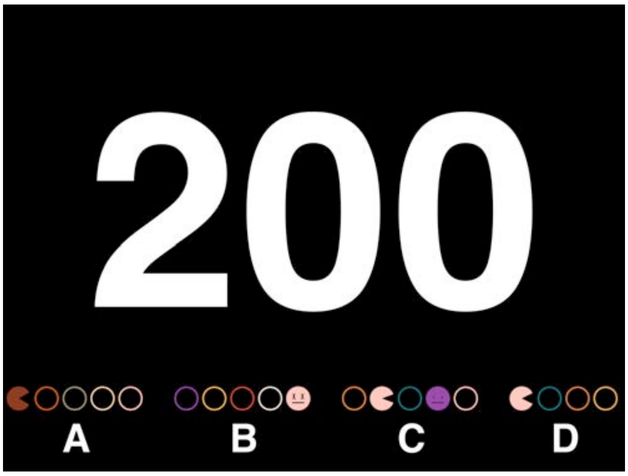

Figure 6. Revised version of the patch display used in the second session of Hunger Games. Circles at the bottom of the display represent avatar state (present, absent, injured). Large numbers reflect instantaneous patch yield for individual foragers. Local energy gain bars were eliminated.

The instructional design of the second session followed the method used in the previous session: three bouts of foraging followed by reflective discussions of strategy.

ENACTING HUNGER GAMES IN THE CLASSROOM

Reliability of tracking

To test the reliability of the tracking system, we compared RFID arrival events with video recordings of student activity at one of the six food patches during the second session. We considered as an arrival to be any instance in which a student placed his or her avatar within a 30 cm radius from the center of the patch; departure events were defined analogously. Over the six bouts, a total of 103 events were counted through video analysis while 110 were detected by the RFID system. In each case, the false positives detected by the RFID readers were caused by transient events in in which students moved through the range of observed patch on their way to another destination.

The error introduced by these events had no significant impact on our application. The average duration of these quick entry-quick exit events was 3.2 seconds, over five minute bout, this introduced only about a 1% error in energy gain computation per instance, and very negligible impact on collective performance. Because the children-in-transit did not stop at the food patch, they did not notice that they had been "picked up" by the system, instead continuing on to their intended destination where they saw that their arrival had been recognized. Because these are much shorter than any actual foraging instance (average 33 seconds), we have now introduced a filter that allows us to ignore these transients.

Engagement

Enactment of the foraging activities resulted in a competitive, game-like atmosphere in the classroom. The students quickly grasped the mechanics of game play. Upon entering patches, they would place their avatars on the patch and quickly look to the local display to confirm that they had been recognized, using the color and label codes that identified their stuffed animal. Students were very interested in their emergent "score," and consulted the den display frequently during the early bouts. That behavior changed after a while, though, as they realized that they were missing valuable foraging time when they went to the den to check their scores.

Students appeared to form close relationships with their avatars, often exhibiting explicit affection (hugging and kissing) or protective behaviors (covering an avatar with leaves to keep it warm) as in toy play. There was a strong sense of ownership, with students speaking of "my" avatar, and a dispensation toward animation, with students attributing behaviors and dispositions ("Mine goes fast, it could jump," "That's me!," "Mine's going to eat yours" and growling at another avatar) to their stuffed animals.

An interesting outcome of the enactments was the emergence of behaviors mimicking natural animal behaviors. Population ecologists report how dominant individuals alter the perception of a habitat's quality by excluding subordinate individuals from exploiting a resource that could in fact, support both individuals. This phenomenon is called the *despotic effect* [10]. We observed several verbal and physical instances of this effect during our enactment of Hunger Games. Most notably, oral deception became very common among some students as a technique to maintain exclusive control over a food patch. Deception went both ways, with some episodes referring to the patch which student was in (e.g. "this patch is no good") and some other instances referring to other patches (e.g. "that patch over there is better"). We also observed several instances of physical despotism in which students tried to use their bodies, arms, and legs to prevent other students from entering the food patch where they were foraging.

Learning

The limited availability of the students precluded the application of formal independent measures of learning. However, we find tentative evidentiary support for claims of learning in student discourse and behavior.

There was evidence of students attending to both patch richness ("I got a full load over there, in a snap") and competition from other foragers ("If there is less persons you might be getting a higher food rate"), the two variables that controlled instantaneous energy gain. The students seemed able to interpret the pie chart representation of patch utilization and relate that to behavior in the patches ("This one was better", "Nobody went to number three"). Students also distinguished effective and ineffective foraging strategies; for example, one student's strategy ("I follow him around") was challenged as ineffective by another student, "Because they might go to the same place and if you go in the same patch it will be crowded."

Another indicator of student learning would be evidence of improvement in their foraging behavior over multiple bouts relative to optimal performance. In an ideal free distribution, the collective time spent in the food patches should be directly proportional to patch richness. As they learn more effective foraging strategies, students should distribute themselves more closely in the ratio 2:3:4 among the patches representing the three different richness levels used in the exercise.

No such improvement was found during the first session. However, we did see an improvement trend during the second session (Figure 7), as students moved progressively from over-utilization of rich patches to near optimal performance over the course of their three bouts.

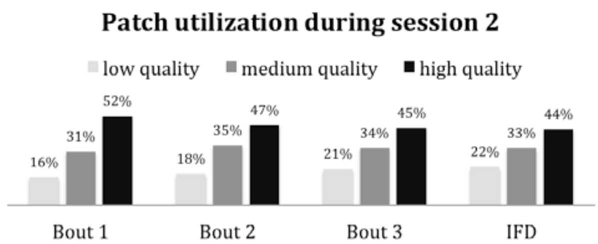

Figure 7. Patch utilization during session 2 of Hunger Games pilot enactment. Over three successive bouts of foraging, patch utilization approached optimal distribution predicted by Ideal Free Distribution (IFD).

DISCUSSION

While continuous tracking of student locations throughout an interior space has enormous potential as a tool for supporting embodied learning activities [3, 7], existing technologies for continuous tracking lack the reliability, ease of installation, and price points which would make them viable candidates for incorporation in school classrooms [5]. Designing activities around proximity to discrete locations, even when requiring explicit notification, appears more promising in the near term as a strategy for affording simple ambulatory location-based activities for classroom learners. In this paper, we showed that a relatively inexpensive commercial RFID system could be reliably configured to support activities supporting large groups of concurrent users in the classroom. While the initial configuration of the classroom to accommodate Hunger Games was non-trivial, once in place the ability to rapidly re-configure and re-use the simulated environment offer significant timesaving over non-digital analogues. The advent of new location sensing technologies such as Bluetooth 4 promises to further reduce the cost and initial set-up time for similar designs.

The avatars played an unusual role as boundary objects in the activity, serving as physical "representatives" of the children and at the same time as entities capable of engaging in independent behavior in a virtual space. While these behaviors were admittedly simple (i.e., gaining energy while stationary), they introduce a tangible analog to the kind of "cloning" used in multiplayer video games such as Ultima, World of Warcraft, and OGame.

While still requiring explicit notification of arrival, a fortuitous side effect of using the avatars was that students were able to enact foraging without having to maintain their own spatial position in close proximity to the RFID readers. This solved an important problem—the potential for overcrowding in areas adjacent to readers—that could have been problematic in certain classroom deployments (e.g., corner locations). It also opened the door to enactment scenarios that allowed students to engage in other activities concurrent while their avatars were busy gathering calories at food patches. At a minimum, this approach relaxes constraints on discourse during the activity, but, importantly, it also enables instructional designs in which foraging can be framed as a "background" activity thread that runs concurrently with reflection, in the style of embedded phenomena [15].

While a distributed, screen-based application could presumably provide mechanisms that would support deception and exclusion, they would have to be anticipated *a priori*, and could never support the full range of despotic behaviors that we observed. The appearance of those in our enactments behaviors highlights one of the important benefits of embodied social learning activities: the potential for the *emergence* of unanticipated phenomena that can become a source for the development of new understandings. In our case, the use of these strategies led to discussions not only of what was "fair," but also to questions about whether animals engaged in the same kinds of behaviors—authentic questions that we had not anticipated but that were of genuine interest to the children.

Our claims with respect to the development of understandings regarding animal foraging behaviors are intentionally couched in conditional terms, and will require deeper probes in future enactments to more fully support. Ultimately, assertions of deep understandings would require evidence that students are able to use their knowledge to predict optimal strategies in novel ecological contexts, and we are developing an extended Hunger Games unit that will provide students with those opportunities. At the same time, students did improve their performance, at least during the second session when they were more intentional in their foraging, reflecting the potential for using improvements in foraging skills as a "stealth assessment" similar to those used in exploratory virtual environments and "smart games" [24].

CONCLUSION

We began this project with the motivation of designing technologies that would make an effective, traditional embodied learning activity richer, more flexible, and easier to use. We selected the theme of "back to the future" not simply nostalgia for traditional practices, but as recognition of their potential as a source of inspiration for new designs. It is ironic that researchers who advocate embodied learning activities often feel compelled to demonstrate their superiority over screen-based alternatives; is wasn't that long ago that the reverse was the case.

We are continuing our development of both the Hunger Games curriculum and technologies. On the technology side, we are developing tools that will allow teachers to configure a large multidimensional space of simulated habitats that allow learners to engage issues of dilution, depletion, predation, species differentiation, and other variables that impact animal foraging behaviors. On the instructional side, we are developing technology supports designed to support teachers and learners in the collaborative construction of knowledge around the science concepts and practices that students are modeling through their embodied activity [20].

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