Indoor Positioning Technology and Enhanced Engagement in Early Elementary Systems Thinking and Science Learning

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Abstract: Indoor positioning (IP) technology is sought after for applications in gaming, commercial spaces, and education. While several types of IP systems have become available, none offer tracking of multiple agents that balances high accuracy with low cost. This paper highlights new 3D IP technology designed for educational contexts, which coordinates as few as 4 and as many as 80 physical "tags." The tags act both as anchors to delineate the play space and as trackers that send high-accuracy location data to a server in real time that can later be played back. To test the impact of the technology on learning, we compared it to a parallel non-IP environment that approximates locations between two points in classroom settings. Findings demonstrate how the IP technology supports students in engaging deeply with complex systems concepts that require students to look closely at the local behavior of an organism such as an ant.

Introduction

Systems thinking is the ability to recognize and reason about complex systems. This difficult skill is rarely taught explicitly in schools (Hmelo-Silver & Azevedo, 2006; Resnick, 1999), and is rarely taught in early elementary school. While previous work has shown success in teaching early systems thinking concepts related through traditional and participatory simulations (Danish, 2014; Colella, 2000), efforts are ongoing to enhance these learning experiences and make use of young children's play practices.

Participatory simulations (Colella, 2000) based on agent-based modeling simulations have been shown to be useful for helping children think about complex systems from a first-person perspective. Similar to role-playing games, actors in a participatory simulation enact the roles of individuals in a system, enabling them to make personally meaningful connections to the behaviors that make up that system (see Klopfer, Yoon & Rivas, 2004). Work has also shown that young children can deeply explore a variety of scientific concepts when interacting with technologies that leverage physicality and embodiment (see Montemayor et al., 2002). Thus, we have developed two versions of a participatory simulation (Colella, 2000), that offer a first-person look into the complexity of honeybee and army ant colonies. Representing two design iterations, our army ant participatory simulation integrated indoor positioning (IP) technology to further leverage how young children learn from play and embodiment.

Here, we explore the affordances of the IP environment used in a systems-thinking curriculum centered around army ants in relationship to an earlier iteration centered around honeybees. First grade students engaged in 10-day implementations focused on systems thinking through the lens of honeybees or army ants in ways that utilized both first-person and third-person perspective taking. Emergent findings indicate that the IP technology supports new kinds of engagement because of the way it allows students to engage with high-resolution data. This work has implications for designing for increased engagement in systems thinking among early elementary students in ways that utilize technology in making systems elements salient.

Social insects and systems thinking

Both honeybees and army ants are social insects with similar structures, including one egg-laying female and massive numbers of workers that gather food and protect the colony. For bees, this food is gathered from flowers while army ants forage on the forest floor. Both must search to locate plentiful food sources and have developed methods to communicate the location of these food sources to others. Honeybees use the waggle dance, a phenomenon in which bees move their bodies in particular patterns that use the sun as a reference point to communicate direction, distance, and quality of a flower. Army ants leave pheromone trails as they walk. These trails are not directional, and as more ants walk along the trail between the food source and the colony, the trail becomes stronger, encouraging more and more ants to continue following the trail.

Conceptually, both honeybees and army ants represent the systems thinking concept of a *feedback loop* created in the process of food gathering. In both cases, a lack of food is conveyed through the absence of the positive feedback action. Additionally, both insects have physical constraints on how long they can search for food and how much food they can carry. Accurately simulating the ants' non-directional pheromone trail was the main influence of the IP technology and the main difference between the two implementations.

Indoor positioning technology

Indoor positioning (IP) technology is sought after for applications in gaming, commercial, and educational spaces. While several types of IP systems have become available, few are able to track multiple agents in a way that balances high accuracy with low cost - a necessary quality for educational uses. Consequently, we designed a new 3D IP technology (patent pending) for such educational contexts that is capable of coordinating many actors in a space. In this system, "tags" act both as anchors to delineate the play space and as trackers that send high-accuracy location data to a server in real time that can later be played back.

We adopted ultra-wideband (UWB) technology for our purposes. UWB can provide highly accurate (Karbownik, et al., 2015) distances through a computation of time-of-flight of the wireless signals. In our approach, at least 3 UWB anchors need to sit at the corners of the tracking area. These physical locations can be predetermined, as we use a trilateration (Cook, et al., 2005) algorithm to compute the tracked positions from the precise distance data provided by the anchors. As an UWB tag device moves within the tracking area or the communication ranges of the anchors, the distances of the tag to all the anchors are reported to a designated computer in real-time for trilateration computation and visualization.

Study design and data sources

Four first-grade classrooms participated in the IP ant implementations (n = 71), while three first-grade classrooms and one mixed first- and second-grade classroom (n = 85) participated in the non-IP bee implementations. All classrooms were located in a mid-sized, midwestern city. Both implementations were based on a previously successful bee curriculum (Danish, Thoroughgood, Thompson, & Peppler, 2017), moving from simple to more complex systems thinking concepts over 10 sessions.

In the bee non-IP implementations, students moved around the room with an electronic bee puppet (see Figure 1) to collect virtual nectar from larger-than-life flowers. The flowers held RFID tags that the puppets could scan; LEDs on the puppet provided information on how much nectar the bee was holding and how much energy it had available. The ant IP implementations proceeded similarly -- the ant push toys (Figure 1) also contained RFID scanners and LEDs. Additionally, each ant puppet contained a UWB tag that allowed the puppet's movements to be tracked in real time. iPads revealed whether a source had food available when an ant puppet approached. Students needed to leave virtual pheromone trails for other ants to follow to food sources through pushing a button on the ant-toy handle when students thought appropriate. The IP system tracked each ant to identify where students left trails. Additional LEDs on the ant provided information about when an ant was close to or following an existing trail. Students could then review their activities using a birds-eye view projected onto a screen. While both approaches visualize information, the specificity and gesture of the movement is maintained in the IP condition (i.e., learners can "see themselves" in the tracking data). This added nuance was introduced to help students explore the nature of the pheromone trails in ways that we felt the earlier technology would not have supported. This shift in designs represents both a shift in conceptual focus (on the movement path instead of the destination) along with the technology needed to support that shift in focus.

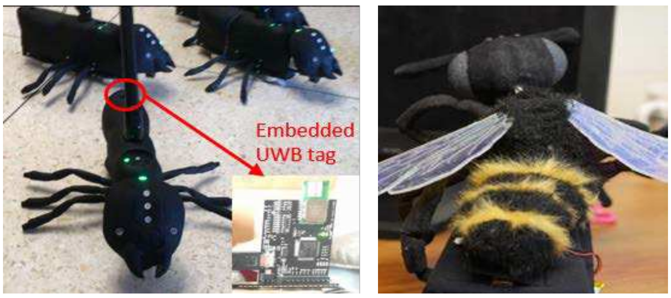

Figure 1. Army ant push toy and bee puppet.

All sessions were video and audio recorded. Here, we look at excerpts from video recorded debriefing discussions where teachers and students reflected upon the game play. As systems thinking is difficult for learners at all stages, we looked for evidence of engagement with complex systems thinking concepts. Rather than assuming students will approach systems thinking in adult ways, we define engagement for early elementary students here as talk about and reflection on how movements and actions have consequences in the system. Here we focus primarily on moments related to the Playback feature that allows participants to rewatch their own prior movements and actions played on a screen in real time. This is a particularly fruitful time for teacher-supported noticing and reasoning, and is where we found that the high resolution information provided by the IP technology added the most value.

Findings

Comparisons of the discussions in the non-IP and the IP versions of Playback indicate that the IP technology affords new and different reasoning about systems thinking concepts by allowing students to explore this new context (pheromone trails) where those nuances are highly relevant. See Table 1 for a representative example of a conversation in the non-IP classroom. Here, the student uses general terms to describe paths and locations. For example, the phrase "around to this side" in line 2 indicates a general area, rather than a specific location. Similarly, "hopping from place to place" in line 1 does not reference specific paths or locations, but does reflect the images on the Playback. The bees do in fact appear to be "hopping" from flower to flower, as there is no data about the paths between flowers. For example, a student with a bee puppet could walk up to a number of flowers before scanning an RFID tag - in this case the Playback would portray the bee as waiting at the first flower until the second tag is scanned.

Table 1: Noticing Bee Actions on Playback, non-IP

1	Ms. Kay	They came out, and look at them hop all around. So at the beginning, they went to a flower and went back in. Now, they're coming out and hopping around and around and around. Why do you think it would have changed like that? Ezekiel, why?
2	Ezekiel	I know that, that, that my side, like two, after a little while, every flower didn't have any nectar in it, so people were going around to this side to get nectar, and people were just hopping around from place to place everywhere because they couldn't find any.
3	Ms. Kay	Oh! So the way the bees are behaving changed because of how much nectar there was out in the field.

It is important to note that this is considered a high quality interaction in the bee implementation. In the honeybee system, concepts such as feedback and emergence are not necessarily embedded in the exact movements and locations of the individual actors. This exchange demonstrates exciting evidence of emerging understanding of relationships between systems elements and actor behaviors.

Table 2: Noticing Ant Pathways on Playback, IP

1	Mrs. Arrow	So I noticed this ant was doing a good job of leaving a trail and then it stopped
2	Stanley	And started going all over the place
3	Mrs. Arrow	And started going all over the place. I think that it was at that good food source and then came over here and was checking another food source. Is that what it should have done?
4	Class	No!
5	Mrs. Arrow	What should it have done?
6	Stanley	Followed its own trail
7	Mrs. Arrow	It should have left a trail straight back to the...
8	Class	Hive!
9	Mrs. Arrow	Colony, yeah.

Table 2 shows a discussion about ants in the IP version of Playback. Here, the teachers and students are able to discuss in much more detail where the ants went in the room, and make judgments about the usefulness or efficiency of those paths. Here, "all over the place" line 2 refers to real time, on the ground movements rather than "hopping from place to place." The students are also able to talk about, visualize, and reflect on the importance of following a trail as a more efficient strategy for food collection, which is not possible in the non-IP version. With the IP technology, children can notice when their path was inefficient, when they missed a fruitful food source, or did not pick up on a nearby pheromone trail.

The differences between these two exchanges may be subtle, but are highly consequential. The discussion in Table 2 sets the students in this classroom up to make additional conjectures about the consequences of "going all over the place." They can make predictions about why the ant acted in that way, and what might have been different had the path been more efficient. With the previous technology used in the bee implementations, this type of discussion would not have been possible. While the interaction in Table 1 is promising as related to the honeybee system, it would not be enough to highlight the specific phenomena of the pheromone trails present in the army ant system where movement and location are key. Here, the unique blend of consequential system elements and technology leads to new support for classroom reasoning.

Discussion

The early evidence seen here suggests new affordances for using indoor positioning technology to explore systems concepts that are tied to a nuanced understanding of where students move throughout a physical space. Participatory simulations have long made use of technology to enhance learning environments through new affordances and productive constraints (e.g., Colella, 2000). Here, it seems that specific types of reflection are possible by this unique combination of IP technology and the Playback feature. It has been noted that both first-person and third-person perspectives play important and complementary roles in systems thinking education for young learners (Danish et al., 2017). The Playback feature provides an intersection of these perspectives, wherein learners can see themselves and their actions reflected in the data, while also viewing the simulation from a detached, bird's eye view. The IP technology deepens this interaction where movement and location was particularly consequential, making the first-person perspective more accurate and realistic.

While approximations of actor location in a classroom were useful when location was not a key component of the system, the addition of the indoor positioning technology allowed us to explore a different physical phenomenon that required a more nuanced understanding of the movement around the classroom. The IP technology discussed here has potential for use in educational spaces, and more research is needed as we continue to consider how technology can be used in systems thinking education to highlight system elements and phenomena. It will be important for researchers to continue to explore what information needs to be made visible across systems as we build and utilize technologies that support learning through embodied interaction.

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