Comparing First- and Third-Person Perspectives in Early Elementary Learning of Honeybee Systems

Kylie Peppler, Naomi Thompson, Joshua Danish, and Armin Moczek,
kpeppler@indiana.edu, naothomp@indiana.edu, jdanish@indiana.edu, armin@indiana.edu
Indiana University

Seth Corrigan, Collective Shift/LRNG, seth@lrng.org

Abstract: While prior literature has demonstrated that even young children can learn about complex systems using participatory simulations, this study disentangles the impacts of third-person perspectives (offered by traditional simulations) and first-person perspectives (offered by participatory simulations) on children's development of systems thinking and biology learning. Through the lens of honeybee nectar collection, we worked with three first-grade classrooms assigned to one of three conditions -- instruction through use of a first-person perspective only, third-person perspective only, and integrated instruction -- to engage ideas of complex systems thinking. In each condition, systems concepts were targeted through instruction and assessment. The combined and third-person classrooms demonstrated significant gains while the first-person classroom showed gains that were not statistically significant, suggesting that third-person perspectives play a critical role in how children learn systems thinking. This work also puts forth a novel assessment design for young children using multiple-choice questions.

Introduction

From food webs to traffic to the respiratory system, complex systems are present in every facet of daily life. It is important to be able to reason and make decisions based on systems phenomena. However, we know systems thinking to be a difficult concept for people at all stages to grasp (Hmelo-Silver & Azevedo, 2006; Resnick, 1999). From an educational standpoint, the importance of these systems is two-fold. First, complex systems are all around us, prevalent in the natural and social world. Second, systems dynamics are quite generative and apply across content settings and domains despite being challenging for students to initially grasp, they are also a set of dynamics that are challenging for students to learn while also being generative and requisite for a deep understanding of most any domain of science (see Hmelo-Silver & Azevedo, 2006; Resnick, 1999). Given the value of systems understanding, researchers have been working to develop new insights into how we can make them more approachable. In particular, a number of researchers have proposed that we introduce students to systems concepts early in their academic careers, potentially transforming lifelong learning trajectories (Thompson, Peppler, & Danish, 2017; Danish, 2014; Assaraf & Orion, 2009; Grotzer & Basca, 2003).

One approach to engaging learners with complex systems concepts has been through computer simulations, where children can interact with visual representations of how systems elements interact (e.g., Danish, 2014; Hmelo-Silver, Eberbach & Jordan, 2014; Grotzer et al., 2015). A second successful approach has involved participatory simulations through which children physically act as agents within a system (Danish, Peppler, Phelps, & Washington, 2011; Colella, 2000). While both approaches have led to demonstrable learning gains for young children, few studies have investigated the unique contribution of each approach to learning. Is one generally more beneficial to young learners? Does each contribute to slightly different learning outcomes or are these approaches interchangeable?

Previously, we demonstrated that when combined within a curriculum, these approaches do provide students with unique opportunities to engage in discussions about the core systems concepts being studied (Danish, Thoroughgood, Thompson & Peppler, 2017; Thompson, Peppler, & Danish, 2017). The present analysis builds on this prior work with a similar aim of exploring how the third-person perspective offered by traditional simulations and the first-person perspective offered by participatory simulations work in different ways to support children's systems thinking learning. The current project moves beyond our prior work by shifting from one integrated classroom to working with three first grade classrooms in a typical Midwestern elementary school to compare how students learned about systems thinking through the lens of honeybees across three conditions: first-person perspective only, third-person perspective only, and integrated (first- and third-person perspectives combined).

Honeybees as a complex system accessible to young children

The term "complex systems" is used to describe collections of inter-dependent and inter-related elements where the collection, or system, has properties that emerge from both the individual elements and their relationship to each other (Jacobson & Wilensky, 2006). In the case of honeybees collecting nectar, the initial topic of the current project, we can view the honeybees within a hive, the hive itself, and the flowers that the bees visit to collect nectar as a system. Honeybees collect nectar from these flowers, converting it into honey within the hive. As scout bees discover good sources of nectar, they return to the hive where they will perform a "bee dance" which indicates the direction and distance to the source of nectar, as well as the quality of the nectar source (Seeley, 1995). Other bees observe this dance and then set out in search of the identified flowers. If they in turn find an abundant supply of nectar, they return and repeat the dance. The result is not only an incredibly efficient nectar collection operation, but also a highly adaptive one with honeybees ceasing to visit flowers that are no-longer effective sources of nectar, and shifting rapidly to new supplies.

What makes this a complex system is not just the fact that it consists of different elements (i.e., the bees, the physical hive where they store their nectar, the flowers which may or may not have nectar), but also the inter-relatedness of these elements, and the different levels of analysis at which it operates (Hmelo-Silver & Azevedo, 2006). The different levels of the system are also the first place where we see a clear distinction between experts and novices. Novices tend to view a system such as this in terms of its superficial structures (e.g., the honeybee body parts) and behaviors (e.g., bees do a dance) instead of the functions of these behaviors and structures (e.g., the dance leads to faster nectar collection) (Hmelo-Silver, Marathe, & Liu, 2007; Hmelo-Silver & Pfeffer, 2004). One reason why the functions are so elusive may be that these functions often require an examination of the emergent properties of the system as a whole, rather than the local behaviors. One goal of the current project was, therefore, to help move young students from superficial descriptions of the system of honeybees collecting nectar to a more nuanced understanding of the functions that these different behaviors serve for the hive as a whole.

One successful approach to examining complex systems in education has been to focus on the process through which properties of the system "emerge" from the behaviors or properties of the individual elements or agents (Jacobson & Wilensky, 2006; Wilensky & Resnick, 1999; Wilensky & Stroup, 2000). In the case of honeybees collecting nectar, for example, we want to help children understand the way the hive as a whole is efficient at collecting nectar despite the fact that individual bees engage in behaviors that don't immediately appear to be effective, such as spending time dancing (instead of collecting more nectar) or continuing to look for new flowers when the hive has already found some that represent a good source of nectar. The concept of emergence also pushes against the misconception that the queen bee directs all activity in the hive. Prior research has consistently shown that this kind of emergent property is even challenging for adolescents and adults to understand, particularly because it requires the ability to shift one's perspective back and forth between "levels" of analysis, represented here by the individual bees and the hive as a whole (Hmelo-Silver & Azevedo, 2006; Wilensky & Resnick, 1999).

First- and third-person perspectives on early childhood systems thinking

While previous work has shown that although systems thinking is an advanced and complex topic, young children can begin to learn these concepts through play and embodiment (e.g., Danish, 2014; Assaraf & Orion, 2009). In particular, the concepts of feedback, a process that leads to increase or decrease in an action or behavior (Sweeney, 2012); iteration, a repetition and building up of an action or behavior (Wilensky & Resnick, 1999); and constraints, properties that make work within a system more difficult (Wilenksy & Reisman, 2006) are crucial systems thinking concepts with which learners may struggle. As such, we built our assessment to address these three concepts. Drawing on activity theory (Engeström, 1987), we know that examining how joint activities are mediated is useful in understanding how learning occurs in these contexts and can provide insights into how the organization of activity might support students in engaging with different aspects of a system (Danish, 2014). For example, first person perspectives have proven powerful in helping students to engage with the constraints within a system, whereas a third person perspective has helped them to see the emergent properties more clearly (Danish, 2014; Danish et al., 2017). Capitalizing on these prior findings, the key design differences between the conditions in our current work is the perspective through which the activities are mediated: First- and third-person perspectives on the system. Table 1 summarizes our expectations for how the different perspectives would support students' engagement with different aspects of the system.

The first-person perspective allows learners to take the role of an actor (i.e., a honeybee) in a system (i.e., collecting nectar from flowers and returning it to the hive). With this view, they can experience first-hand individual constraints that might arise for the actors, and see how other factors such as feedback may cause behavior adaptations in response to those constraints. However, patterns on a larger scale may be more difficult to track from this perspective.

We hypothesized that a first-person perspective of nectar collection could better illuminate the complex communication patterns that happen inside the hive and could be particularly important for our target age group, given the need to learn about complex systems from multiple analytic levels at the same time in order to fully understand the relationship between levels (Hmelo-Silver & Azevedo, 2006). While most prior work on participatory simulations has targeted older children, teens, and adults, this body of research fails to take into account the alignment between participatory simulations and the play activities of young children, who are already apt to explore topics of interest through play-acting and games (c.f., Youngquist & Pataray-Ching, 2004). In addition, it has been suggested that an agent-based perspective where students reason about the behaviors of individual agents within the system increases the potential of students to transfer their understanding to other systems (Goldstone & Wilensky, 2008).

Table 1: Hypothesized strengths of each model/perspective in the context of honeybees

Targeted concepts	**First-person views increases awareness of:**	**Third-person views increases awareness of:**	**Integrated first- and third-person views increases awareness of:**
Honeybee behavior	Reasons behind individual behaviors (e.g., why bees waggle dance)	How the hive as a whole adapts and pursues a single nectar source.	The impact behaviors that overcome challenges in the 1st-person perspective have on patterns in the 3rd person.
Feedback loops	The benefit one's own activities gain from feedback.	How feedback from a few bees can impact many more bees.	How providing feedback helps the hive as a whole, just as receiving feedback helps an individual bee.
Iterative processes	How repeated activities can look different at the individual level, depending on the context (e.g., does a flower still have nectar).	Repetition as a path to better results for the hive as a whole, in contrast to a hive without the same feedback loops and repeated patterns of behavior.	*(No expected difference)*
Constraints	Challenges individual bees face (e.g., finding flowers with nectar is challenging).	Challenges the hive as a whole faces (e.g., gathering enough food to survive through winter).	How individual and group constraints are interrelated.

By contrast, the third-person perspective allows learners to observe the actions of many actors in a system (i.e., all the honeybees that are searching for nectar) from a bird's eye view. Here, rather than experiencing individual constraints, learners can visualize the larger impacts of constraints on the whole system (e.g., falling nectar levels in winter). The build-up of iterative behaviors into emergent patterns is also more salient from this removed viewpoint.

We hypothesized that the third-person perspective would better provide learners with a view of large scale patterns. Much of the previous work on systems thinking with children has focused on third-person computer simulations, often designed by the learners themselves (c.f., Wilensky, 2006; Wilensky & Resnick, 1999). As with the first-person work, this often occurs with older children and adults as complex computer programming is often involved. Previous work with the third-person simulation discussed here has shown success in helping very young children begin engaging with complex systems through the lens of honeybee hives (Danish, 2014). This view from the outside allows learners to track actions and outcomes and make connections to smaller scale behaviors that can be difficult to notice from a first-person perspective. It is also ideal for discussing iteration as students watch actions repeat and build.

Guiding theory of learning: Activity Theory

Here, we designed for learning by drawing on Activity Theory (Engeström, 1987; Engestrom, 2008), a theoretical framework grounded in the work of Vygotsky (1978) that focuses on learning as a mediated, social process where learners move toward a shared goal. Activity theory provides ways to attend to the rules, tools, communities, and divisions of labor that shape the learning process. These mediators shape and define learners' interactions with each other, the technology, and the learning goal. Using this theoretical perspective, we can focus on these intersections and the roles they play as children generate and transform their ideas about how systems work. From this perspective, it is understood that learning is socially mediated (see Vygotsky, 1987; Greeno, 2006). This informs the focus throughout the curriculum on group discussions and debrief. The contributions of individuals in a classroom impact the learning of the group as a whole, as well as individual students. In designing the curriculum, we used activity theory as a guiding theory for the design, paying particular attention to the system elements to build parity across the three conditions. Regardless of condition, the shared goals of each classroom were the same: to collect as much nectar as possible (either themselves or through a computer simulation), and to gain new understandings about honeybees along the way. The main difference across conditions was the perspective through which the activity was mediated.

General design-based research approach and research questions

Our general approach to the overarching work was a Design-Based Research paradigm (The Design-Based Research Collective, 2003) where we iterated on the designs of our intervention and assessments until we were able to conduct the present quasi-experimental study. The current study was designed to further refine our understanding of the differential contributions of first- and third-person perspectives on systems learning as well as the features of our designs that appear to support this learning. In order to accomplish this, we developed conjectures during our design process about what specific features of the tools we are developing we believe led to student exploration of or understanding of particular aspects of the content and then evaluate those conjectures as part of our summative evaluation (Sandoval, 2004). Throughout the design and implementation process, we worked regularly with children and teachers as co-designers, mutually determining the purpose, value, and interpretation of our software prototypes, physical materials, and curricular approach (Nelson, 2000). Application of this iterative process allowed the designs to progressively improve over the course of five iterations of technology and curriculum. To ensure that the proposed activity system effectively complements curricular and practical realities, we consult with practitioners to inform our design and development throughout the process.

We look to answer the questions: (1) How do children's performances on a systems thinking assessment change before and after engaging in the BeeSim curriculum? (2) How do these changes differ between experiencing the curriculum through a first-person lens, a third-person lens, or a combination of the two? (3) How might first- and third-person perspectives work together and separately to support systems thinking learning?

The BeeSim designs

All three conditions in this study took place over about 12 days, or in about 8 to 9 hours of activity. In each classroom, we began by interviewing a sample of the students for a qualitative assessment of learning; this interview was repeated at the end of the implementation. Each implementation also began and ended with a 20-question multiple-choice assessment administered through a clicker system.

We wrote three versions of the BeeSim curriculum corresponding with the three conditions. The participating classroom teachers were involved in the curriculum design process and provided useful insights into classroom appropriateness. Each version of the curriculum followed the same progression from simple to more complex topics, introducing more nuanced accounts of systems thinking concepts -- feedback, constraints, and iteration -- along the way. Each condition began by introducing the basics of the honeybee body, then moved to the basics of bee nectar collection in a single hive, introduced competition by comparing two hives, introduced the waggle dance as the feedback mechanism, explored how feedback and system constraints were related, and considered the role of negative feedback (or the lack thereof). The typical pattern for a session began with teacher-led recaps and soliciting student predictions, was followed by the planned simulation play, and ended with a teacher-led debrief.

In the first-person condition, the planned simulation activity involved students using electronic bee puppets to collect nectar from larger than life flowers placed around a classroom. Large swaths of yellow fabric hung from the ceiling, creating "hive" spaces where students waited for their turn in the field. RFID tags in the flowers could be read by sensors in the bee puppets' heads, allowing information to be transmitted between the bee and a central server. Lights on the bee's body indicated how much nectar it was holding, how much energy it had, and the quality of a flower when checked. The curriculum progressed as indicated above, all framed through the first-person perspective. While students were occasionally asked about what an occurrence might mean for "the whole hive" or to think about more than just their individual bees, no activities or direct information was given from a third-person perspective in order to separate how first-person learning activities impact learning about both first- and third-person perspectives.

In the third-person condition, the planned simulation activity involved students engaging with a computer simulation that represented idealized behaviors of honeybee hives. The interface could show either one or two hives. To compare patterns and the effects of the waggle dance, one hive could be set to "not dance" while the other was set "with dancing." With all other variables held constant, students could observe and make predictions about the hives' differences. Other adjustable variables included flower number, position, and quality. The curriculum progressed as indicated above, all framed through the third-person perspective. While students were occasionally asked about what an occurrence might mean for an individual bee, no activities or direct information was given from a first-person perspective in order to separate how third-person learning activities impact learning about both third and first-person perspectives.

The integrated condition incorporated parts of both the first- and third-person conditions. Students both played with electronic bee puppets and engaged with a computer simulation. We identified the form of simulation -- 1st person or 3rd person -- that we felt, based on prior experience, was most likely to engage students productively with the concept. For example, the first-person bee puppets were chosen to introduce the waggle dance because it would allow students to directly experience the role of the dance, whereas our experience suggested that students were more likely to see aggregate patterns through the third person simulation. Children in this condition also had access to a separate "playback" technology that allowed the movements of the bee puppets between the flowers and the hives to be played back in real time for the students to reflect upon. This provided an experience that was truly a blend of first- and third-person perspectives, as the bees represented the children's individual actions, but were treated as a bird's eye view.

Participants and data sources

The project took place in a public school in a mid-sized, midwestern city. The school population is 86.6% white, with 41.8% receiving free or reduced lunches. The school, and our particular classrooms were evenly split in terms of gender. Data collection occurred in the schools three first grade classrooms; we worked closely with each teacher who led activities and approached the curriculum in ways appropriate for her students. We compared performance and change across two time points for the three conditions: first-person (n=19), third-person (n=21), and integrated (n=20) perspectives. To compare the differences between the three conditions, we collected multiple forms of observation and assessment data. All sessions were video and audio recorded. All students took two pre- and post-assessments before and after the 12 day intervention. The first asked students to draw how bees get food. The second was a 20-question multiple-choice assessment given through a clicker system. Over three design and testing iterations, we created this assessment to ask eight "simple" biology-based questions (e.g.,*This forager bee just came out of the beehive. Its job is to collect nectar. What will it do next?*) and twelve "complex" systems-based questions (e.g.,*This bee saw a waggle dance that said this flower had a lot of great nectar, but all the nectar was gone when it got there! If other bees saw the same waggle dance, what would they do?*). All questions and answer options were read out loud at least twice to alleviate concerns about varying reading levels. It is important to note that due to concerns of test fatigue with young students -- most first grade students do not often take multiple-choice assessments -- we were unable to tease apart some of the more nuanced concepts we hypothesized would differ across conditions. Also, a random sample of 20% from each condition was chosen to participate in pre- and post-interviews to provide qualitative evidence of understanding.

This paper focuses on the results from the pre- and post- multiple-choice questions. We used a latent variable modeling approach (Skrondal and Rabe-Hasketh, 2004), employing the unidimensional Rasch model to estimate impacts of the BeeSim instructional content. Two general rounds of analysis are presented. The first round of analysis groups all students regardless of condition, responding to RQ1. The second round of analysis – treatment specific analysis - disaggregates students into their respective condition groups in order to facilitate a three-way comparison of the mean student growth for each group across the pre-test and post-test, responding to RQ2. Use of the Rasch model employs students' response vectors for the respective assessments in order to estimate student abilities measured in logits, and standard errors. Using students' resulting parameter estimates at pre-test and post-test, and a difference-in-differences, we employed the simple t-test in order to determine the significance of change in performance from the pre- to post-assessments.

Results

Results from a total of 60 students were used in the analysis. A total of three students were dropped from the analysis because they were missing responses to more than half of the test items at pre-test and post-test. A summary of the following results can be found in Table 2 below.

When all three conditions were grouped together (N = 60), the mean student ability estimate at pre-test was -0.472 logits with a standard deviation of 0.657. The mean standard error for the pre-test ability estimates across the sample, is 0.526 logits. By comparison, the mean student ability at post-test was +0.188 logits with a standard deviation of 1.351 logits, and an average standard error of 0.606 logits. Thus, ability estimates at post-test were higher on average and more dispersed (exhibited a larger variability across the sample) than those at pre-test. Use of a paired sample t-test confirms that the difference in ability estimates is significant. The difference in mean ability estimates between pre-test and post-test administrations is more than half of a logit, +0.660 logits, with $t = 3.897$ (Confidence Interval: 0.321, 0.999) and $p < 0.0001$. Using Cohen's d to calculate the associated effect size, this difference in means is associated with an effect size of 0.621 – appropriately categorized as a 'medium' sized effect. These results address RQ1 which asked about general gains across all conditions on the systems thinking pre- and post-measure.

To address RQ2, we also compared the performance of each condition. As a first step, students' ability estimates across the three groups were compared to ensure they were equivalent. In each case the differences in the three groups' mean ability estimates were not statistically significant ($p > 0.05$). This supports the claim that the three groups were equivalent with regard to their ability estimates at pre-test, though we note it does not guarantee that the groups were equivalent with regard to other baseline characteristics.

On average, students in the classroom receiving the first-person condition (n = 19) did not exhibit significantly different abilities between the pre-test and the post-test administrations of the BeeSim assessment. At pre-test, the mean ability estimate of the group was -0.291 logits with a standard deviation of 0.742 and a mean standard error of 0.533 logits. At post-test, the mean ability estimate was -0.103 logits with a standard deviation of 1.479 and a mean standard error of 0.631 logits. Application of the t-test with 18 degrees of freedom resulted in $t = 0.650$ and $p < 0.523$.

In the third-person condition (n = 21) students had significantly higher ability estimates at post-test than at pre-test. At pre-test, the mean ability estimate for this group was -0.457 logits with a standard deviation of 0.695 and a mean standard error of 0.152. The mean ability estimate at post-test was 0.470 logits with a standard deviation of 1.548 and a mean standard error of 0.338 logits. Use of the t-test resulted in $t = 2.706$ with 20 degrees of freedom, and $p < 0.05$. Applying the function for Cohen's d, there was a medium estimated effect size found of 0.77.

The largest change in ability estimates across the three groups was exhibited by students in the integrated condition (n = 20). Among these students, the average ability estimate at pre-test was -0.658 logits. Those estimates have a standard deviation of 0.492 and a mean standard error of 0.110 logits. At post-test, the mean ability score for the group had risen to +0.169 logits with a standard deviation of 0.949 and a mean standard error of 0.212. The t-test results were statistically significant with $t = 3.882$ with 19 degrees of freedom and $p < 0.001$. The magnitude of the effect was large with Cohen's d = 1.09.

Table 2: T-test results for change from pre- to post-assessment

Condition	**N**	**Pre (Logits)**	**Post (Logits)**	**Change (Logits)**	***Cohen's d***
All	60	-0.472	0.188	0.66 (*p* <.001)	0.621
First-Person	19	-0.291	-0.103	0.188 (*p* < .5)	*NA*
Third-Person	21	-0.457	0.470	0.927 (*p* < .05)	0.77
Integrated	20	-0.658	0.169	0.827 (*p* < .01)	1.09

Additionally, we categorized the multiple-choice items into "simple" and "complex." Simple items were those pertaining to non-systems thinking content, such as honeybee biology (e.g., honeybees have a head, thorax and abdomen) or behaviors (e.g., honeybees take on different jobs and responsibilities throughout their lifecycle). Complex questions addressed the systems thinking concepts feedback, constraints, and iteration. We calculated the average percentage of correct answers for each category and compared the three conditions. The integrated condition had the largest gain on the simple items, moving from 43.55% correct to 63.29% correct.

The Simulation condition had the largest gain on the complex items, moving from 46.67% correct to 59.34% correct. See Table 3 for a summary of these results.

Table 3: Change in average percent correct from pre- to post-

	Simple Pre	Simple Post	Gain	Complex Pre	Complex Post	Gain
First- Person	48.61%	49.47%	0.86%	42.59%	49.62%	7.03%
Third- Person	46.67%	59.34%	12.68%	36.90%	55.20%	18.29%
Integrated	43.55%	63.29%	19.74%	30.76%	46.29%	15.53%

Conclusion and discussion

These findings suggest the third-person and integrated conditions provided better systems thinking learning outcomes, although all three conditions made gains from the pre- to post-assessment. Students in the third-person condition also performed best on the complex items, although the gain was only slightly more than the integrated condition. While this suggests the third-person perspective might be the most important, our ongoing qualitative analyses are beginning to indicate that the first-person perspective supports some important conversations and thus learning gains that are not yet measured through this multiple-choice assessment that may continue to complexify these early findings.

In addition to these results on the multiple-choice assessment, we hypothesize that moving back and forth between first- and third-person perspectives, as in the integrated condition, provides some additional insight and experiences not reflected in the multiple-choice scores. In our presentation, we will also share further analyses of the other assessment items as well as the classroom video data to reveal the nuances provided by the three conditions.

Scholarly significance

This work suggests three main outcomes and implications for systems thinking education research. First, early elementary students are capable of learning systems thinking concepts, particularly through third-person perspectives. This is particularly compelling given the costs and easy scalability of digital simulations such as these. It may seem intuitive that children in this age range would have difficulty reasoning about systems from an outside perspective, but our work demonstrates that this viewpoint was especially beneficial for learning outcomes. This is important for early childhood educators in particular, as freely-available curriculum and tools developed for the third-person perspective could help educators begin to introduce systems thinking earlier and more often, through embodied, playful techniques and familiar, high-quality biology content.

Second, there seem to be additional benefits to engaging in a system through multiple perspectives. Students in the integrated condition did significantly better on the post-assessment than the pre- with an effect size larger than the third-person condition. This suggests that further research and design iterations may more fully utilize the affordances of moving back and forth between first- and third-person perspectives. That said, the current research seems to locate the driving factor for these gains, particularly in learning about complexity, are fueled by third person perspectives. As a result, future iterations of the BeeSim platform is working to investigate real-time data visualizations of first-person player activity through our work in a new system, called AntSim, through a uniquely developed indoor positioning system. This work is the focal point of our future research and publications. One hypothesis that we have around why third person perspectives may be driving these learning outcomes is that is to quicker to watch multiple rounds of bees foraging for nectar and to see the emerging behaviors via a computer simulations (and can even be played in a fast forward fashion) than to play the participatory simulation bee puppet game with a group and develop the sufficient expertise in the game so that the emergent patterns can be seen in the same way. Consequently, the third-person perspective condition may have had more time to debrief more fully and deeply engage the content across more cycles of play than in-person groups. Future studies may wish to design comparisons between first and third person perspectives with this limitation of the group comparisons in mind. Integrated maybe didn't get to dive as deep into simulation as would have been necessary for better results

Lastly, further research should continue to tease apart complex and simple concepts in systems thinking and additional types of systems thinking content as it may be that emergence is particularly well suited for third person perspectives while other systems thinking concepts may be more well-suited for first-person perspectives. The differences in performance between the conditions on these simple and complex measures suggests that first- and third-person perspectives may impact levels of systems thinking differently. Defining these differing impacts more fully may have implications for the design and progression of systems thinking curriculum in the future.

References

Assaraf, O. B.-Z., & Orion, N. (2010). System thinking skills at the elementary school level. *Journal of Research in Science Teaching*, 47(5), 540–563.

Colella, V. (2000). Participatory Simulations: Building Collaborative Understanding Through Immersive Dynamic Modeling. *Journal of the Learning Sciences*, 9(4), 471–500.

Danish, J. A. (2014). Applying an activity theory lens to designing instruction for learning about the structure, behavior, and function of a honeybee system. *Journal of the Learning Sciences*, 23(2), 100-148.

Danish, J. A., Peppler, K., Phelps, D., & Washington, D. (2011). Life in the hive: Supporting inquiry into complexity within the zone of proximal development. *Journal of science education and technology*, 20(5), 454-467.

Danish, J., Thoroughgood, L., Thompson, N., Peppler, K. (2017, April). BeeSim: Re-Mediating Students' Engagement with Honeybees Collecting Nectar from a First and Third-Person Perspective. Presentation at 2017 Annual Meeting of AERA, San Antonio, TX.

Engestrom, Y. (1987). *Learning by expanding: An activity-theoretical approach to developmental research*. Helsinki: Orienta-Konsultit Oy.

Grotzer, T. A., & Bell Basca, B. (2003). How does grasping the underlying causal structures of ecosystems impact students' understanding? *Journal of Biological Education*, 38, 16–29. doi:10.1080/00219266.2003.9655891

Grotzer, T. A., Powell, M. M., Derbiszewska, K. M., Courter, C. J., Kamarainen, A. M., Metcalf, S. J., & Dede, C. J. (2015). Turning transfer inside out: The affordances of virtual worlds and mobile devices in real world contexts for teaching about causality across time and distance in ecosystems. *Technology, Knowledge and Learning*, 20(1), 43-69.

Hmelo-Silver, C. E., & Azevedo, R. (2006). Understanding complex systems: Some core challenges. *Journal of the Learning Sciences*, 15, 53–62.

Hmelo-Silver, C. E., Eberbach, C., & Jordan, R. (2014). Technology-Supported Inquiry for Learning about Aquatic Ecosystems. *Eurasia Journal of Mathematics, Science & Technology Education*, 10(5), 405-413.

Resnick, M. (1999). Decentralized modeling and decentralized thinking. In W. Feurzeig & N. Roberts (Eds.), *Modeling and simulation in precollege science and mathematics* (pp. 114–137). New York, NY: Springer.

Seeley, T. D. (1995). *The wisdom of the hive: The social physiology of honey bee colonies*. Cambridge, MA: Harvard University Press.

Sweeney, L. B. (2012). Learning to Connect the Dots: Developing Children's Systems Literacy. *Solutions*, 5(3), 55–62.

Thompson, N., Peppler, K., & Danish, J. (2017). Designing BioSim: Playfully encouraging systems thinking in young children. In Zheng, R. & Gardner, M. (Eds.), *Handbook of research on serious games for educational applications*, Ch.7 (pp. 149-167). Hershey, PA: IGI Global.

Wilensky, U., & Reisman, K. (2006). Thinking Like a Wolf, a Sheep, or a Firefly: Learning Biology Through Constructing and Testing Computational Theories—An Embodied Modeling Approach. *Cognition and Instruction*, 24(2), 171-209.

Wilensky, U., & Resnick, M. (1999). Thinking in levels: A dynamic systems approach to making sense of the world. *Journal of Science Education and Technology*, 8(1), 3–19.

Acknowledgments

This material is based upon work supported by the National Science Foundation under Grant No. 1324047 awarded to Kylie Peppler, Joshua Danish, and Armin Moczek. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation. Thank you to Janis Watson and the many teachers and students who made this work possible.