Instructional Science (2020) 48:291–312
https://doi.org/10.1007/s11251-020-09511-8

ORIGINAL RESEARCH

Comparing first- and third-person perspectives in early elementary learning of honeybee systems

Kylie Peppler[1] · Naomi Thompson[2] · Joshua Danish[3] · Armin Moczek[4] · Seth Corrigan[5]

Received: 23 August 2018 / Accepted: 23 March 2020 / Published online: 19 April 2020

Abstract

Prior literature has begun to demonstrate 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 such systems thinking in the context of the emergent complexity of honeybee nectar foraging. Specifically, 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 integrated 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.

Keywords Systems thinking · Early elementary · Science learning · Role-play · Technology

Introduction

From food webs and traffic dynamics to social media or the global economy, complex systems are present in every facet of life. Furthermore, understanding how and why complex systems behave the way they do is a critical step toward making accurate predictions and decisions, such as when forecasting disease epidemics or consumer behavior. Yet prior

✉ Kylie Peppler
kpeppler@uci.edu; kpeppler@gmail.com

1 University of California, Irvine, 5206 Bren Hall, Irvine, CA 92697, USA

2 Indiana University, 201 N. Rose Ave., Rm 2054, Bloomington, IN 47405-1006, USA

3 Indiana University, 201 N. Rose Ave., Rm 4040, Bloomington, IN 47405-1006, USA

4 Indiana University, 915 E 3rd St, Rm 102D, Bloomington, IN 47405-1006, USA

5 SNHU, 2500 N. River Road, Manchester, NH 03106, USA

work shows that this systems thinking constitutes a difficult challenge for learners of all ages (Hmelo-Silver and Azevedo 2006; Resnick 1999; Grotzer et al. 2017).

From an educational standpoint, complex systems are of critical importance for multiple reasons: Not only are complex systems ubiquitous in the natural and social world, but systems dynamics are generative and applicable across otherwise diverse content settings and domains. Consequently, despite being challenging for students to initially grasp, systems thinking is requisite for a deep understanding of most any domain of science (Hmelo-Silver and Azevedo 2006; Resnick 1999). Given the obvious value of systems understanding, much effort has focused on improving the teaching, learning, and understanding of why and how complex systems behave the way they do. In particular, a number of studies have proposed to introduce students to systems concepts early in their academic careers, thereby potentially transforming lifelong learning trajectories (Thompson et al. 2017; Danish 2014; Assaraf and Orion 2010; Grotzer and Bell 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 et al. 2014, 2017; Grotzer et al. 2015; Bergan-Roller et al. 2018; Yoon, Goh, & Park, 2018; Wilensky and Reisman 2006; Resnick 1999). A second successful approach has involved participatory simulations through which children physically act as agents within a system (Danish et al. 2011; Colella 2000; Wilensky and Stroup 1999; Stroup and Wilensky 2014; Neulight et al. 2007; Klopfer et al. 2005). While both approaches have led to demonstrable learning gains for young children, few studies have investigated the unique contribution as well as potentially synergistic value of both approaches to learning. Is one approach generally more beneficial to young learners? Does each contribute to slightly different learning outcomes or are these approaches interchangeable? If applied in combination, do they affect learning in a reinforcing, potentially synergistic manner?

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 et al. 2017; Thompson et al. 2017). A recent survey of research on systems thinking education prompted a need for more work that systematically explores the impacts of particular designs for learning about complex systems (Yoon et al. 2018). The present study addresses this need in the field by building on prior established work to explore and compare 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 learning of systems thinking. The current project additionally extends 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 the complexities of honeybee foraging behavior across three conditions: first-person perspective only, third-person perspective only, and integrated (first- and third-person perspectives combined).

Guiding theory of learning: activity theory

Here, we designed for learning by drawing on activity theory (Peppler et al. 2018; Engeström 1987, 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 (Peppler et al. 2018; Greeno 2006). Mediation refers to the process through which different elements of the activity system such as the rules, tools, communities, and divisions of labor transform individuals' experience within activity (Roth 2007). In the context of the current paper, our focus was on designing and then understanding unique mediators of students' experience learning about honeybees from a systems perspective.

We employed an object-identification[1] approach to design in the present study (Danish 2014; DeLiema et al. 2016). From this perspective we begin by identifying the shared motive or object that learners towards as this will shape their participation. Then, we identify the mediators that we believe will support, transform, or hinder learners' experience as they pursue the goal of the participatory simulation. In the current study, students' shared object was to understand how honeybees collect nectar, and this is something we aimed to hold constant across conditions. Young students are naturally curious about honeybees, and so we have found that a combination of asking them how honeybees do collect nectar, and then asking them to resolve challenges to their understanding keeps them motivated to pursue this question with their teacher (Danish 2014). For example, many students assume that a waggle dance might slow the bees down. Helping them see that it is in fact more efficient helps orient them toward a question of how and why it might help honeybees?

Once we have identified the object of students' activity, we then focus on the mediators that shape their experience. While we are interested in the core mediators of activity that are identified within activity theory—the tools, rules, community, and division of labor (Engeström 1987; Wertsch 2017)—and thus use those to guide our design thinking, we also find that there is value in ignoring these distinctions to instead focus on how the different mediators influence learners' interaction with the object of activity (Witte and Haas 2005). Therefore, our focus is on both what mediators are transforming learners' experience, and how. In the present study, we viewed students' perspective, whether first- or third-person as the key mediator of interest. That is, we recognize that being able to take each of these perspectives transforms how students see and thus learn about the system they are studying. We then aimed to identify tools that support these different perspectives and to analyze how the different perspectives mediated students' interactions with honeybees as a system.

Within the classroom activities, a number of elements ultimately helped to produce these different perspectives. For example, rules such as "you should communicate without talking", tools including the computer simulation and electronic puppet, and the division of labor such as having some students collect nectar and then notify their peers after the fact, were all part of providing students with a first-person, third-person, or combined perspective on the system being studied. Our analytical goal was then to explore how these different perspectives were produced, and how they mediated students' interactions with the honeybee system.

Honeybees as a complex system accessible to young children

The term "complex systems" describes collections of interdependent and interrelated elements such that the collection has properties that emerge from the individual elements as well as their relationship to each other (Jacobson and Wilensky 2006). Regarding honeybees, we view the relevant system as including the hive, the honeybees within it, and the flowers visited by the honeybees (Peppler et al. 2018). As honeybees collect nectar from

[1] Previously, this was referred to as the object-oriented approach. Here we have changed to the object-directed approach to avoid confusion with the computer science notion of object-orientedness, which is unrelated.

these flowers, they store it in the hive and convert it into honey. As scout bees discover good sources of nectar, they return to the hive to perform a "waggle dance" which indicates the direction and distance.to the source of nectar, as well as the quality of the nectar source (Seeley 1995). Other scout bees observe this dance and then leave to seek the desired flowers. If these bees then also find nectar at the identified flowers, they will also return to the hive and perform a waggle dance for the flowers. This adaptive process results in efficient nectar collection, and naturally builds conditions for bees to stop visiting flowers that become less effective nectar sources over time (Peppler et al. 2018).

Honeybee foraging is seen as a complex system due to its numerous elements (i.e., the bees, the hive, flowers as potential nectar sources), the inter-related nature of these elements, and the multiple different levels at which the system operates (Hmelo-Silver and Azevedo 2006). Understanding these different levels of analysis also highlights distinctions between the abilities of between experts and novices. Novices tend to view complex in terms of their superficial structures and behaviors rather than the *functions* of these behaviors and structures (Hmelo-Silver et al. 2007; Hmelo-Silver and Pfeffer 2004). This could be in part because understanding systems at the functions level requires understanding the system as a whole, involving more than simply identifying local behaviors. Therefore, a goal of this current work was to explore young learners moving from localized systems descriptions to more big-picture understanding of functions (Peppler et al. 2018). To make this transformation visible, we focused on the design and support of the three perspectives (first, third, integrated) as a way of mediating students' engagement with the system. We then aimed to collected data about how those different perspectives did in fact mediate students experience of how systems behave.

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

While previous work has shown that even though 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 and Orion 2010). A recent study found that students as young as kindergarten were able to shift from deterministic to probabilistic reasoning through engaging in games and various biological, social, and mechanical tasks (Grotzer et al. 2017).

While prior work exploring students' learning of complex systems builds on a range of theoretical frameworks, it can often be identified as starting with either a first- or third-person perspective. First-person perspectives such as agent-based modeling (Goldstone and Wilensky 2008; Wilensky and Resnick 1999) focus on how taking the perspective of an individual agent such as a bee can help students to leverage ideas about how individual agents behave to understand the whole system. In a complimentary manner, third-person perspectives, such as those relying on computer simulations (Yoon et al. 2018) or leveraging the SBF framework (Hmelo-Silver et al. 2007) and its more recent incarnation the Component-Mechanism-Phenomena Framework or CMP (Hmelo-Silver et al. 2007), aim to help students explore the system as a whole, as a way to then reason about the role of individual elements of the system (e.g., components or structures) in helping to shape those aspects of the phenomena. Given the complementarity of these two perspectives, our goal was to design a cohesive set of activities that helps students understand a system by viewing it from both the individual and the third-person perspective given that researchers have noted the importance of helping students to move between levels of analysis in order to understand how systems function (Hmelo-Silver and Azevedo 2006; Wilensky and Resnick 1999).

From an activity theory perspective, we attempted to identify those mediators that would help students meaningfully explore the system of honeybees collecting nectar from these two different perspectives. Specifically, we designed the honeybee puppets to help support a first-person perspective of the system, and the BeeSign computer simulation was intended to help students orient towards the third-person perspective. To help students see the connections between these perspectives, we also aimed to have overlapping objects of activity. That is, in the first-person activities, students were aiming to collect more nectar, and in the third-person activities they wanted the hive as a whole to collect more nectar. In both cases, we also hoped to inspire an interest in understanding how bees collect nectar to help them accomplish these goals, and to help orient them towards understanding the underlying mechanisms of how this system works.

To further support student learning, we also aimed during our design work to identify conceptual mediators—those ideas that do not have a physical instantiation but can nonetheless help students to make sense of the world around them (Cole 1996)—that we felt would most productively help students explore the working of the system from these two perspectives. Specifically, we identified the ideas of *constraints*, *iteration*, and *feedback* as target ideas to help students explore the system. What we mean here is that we felt that an understanding of each of these would mediate students' engagement with the system, and help to shed light on how it functions. Thus, our design goal was to help make the need for and benefit of each of these mediators salient to the students so that they might appropriate them into their own thinking. As we will describe below, we identified these three concepts because each has played a central role in prior implementations, and because they each work at a different level of analysis to help students bridge between them (Hmelo-Silver and Azevedo 2006)—constraints are something that individual agents experience directly in the first-person perspective, whereas iteration of behavior is something that bridges the different levels by explaining how the behaviors of individual agents impact the whole system, and finally feedback is a powerful way of explaining the behavior of the system from a third-person perspective where one can see all of the agent's interactions, and their impact upon each other and the system. We chose these ideas because our prior work had demonstrated that they were approachable for students, and also that they helped students to explore the system as a whole. We have also found these concepts to be easier to assess with young children. Other approaches to understanding systems such as a focus on the emergent properties of a system (Jacobson and Wilensky 2006; Wilensky and Resnick 1999) can be quite powerful, and yet we have found them challenging to identify in students' talk, and therefore less productive for integrated assessment. Therefore, we developed assessment items (described below) to mirror our designed mediators and determine whether or not students had changed in their understanding of the system from these perspectives. Given that our design was oriented around the power of the first person perspective—in the form of the bee puppets—and the third person perspective—in the form of the projected BeeSign simulation to mediate learners' engagement with the system, we now briefly elaborate how how each perspective was supported and how we anticipated it would be taken up.

As we noted, the first-person perspective allows learners to take the role of an actor such as the honeybee in a system (Colella 2000; Wilensky and Resnick 1999). 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. We had previously noted that it was important for students to be explicitly introduced to constraints or else they might not recognize the need for solutions that overcome those constraints (Danish 2014). For example, students initially assumed there was no need for bees to communicate about nectar collection because nectar is easy to find. However, helping them appreciate that nectar is challenging to find helps them appreciate the need for a solution such as the waggle dance.

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 and 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 and 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 and Wilensky 2008).

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 and 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.

The integrated perspective, then, is meant to combine the most promising features of both the first-person and third-person experiences. Here, we hypothesized that learners would be able to both experience individual constraints, and watch how those constraints add up to impact larger scale hive behavior. This approach has also been referred to as "bifocal modeling" by others in the field, wherein learners interact with both physical and virtual learning environments at the same time (Blikstein 2016, p. 513). This approach support learners in searching for better and more complete explanations for observed and experienced phenomena (ibid.) We also hypothesized that this integration would build on young learners' natural play practices while also exposing them to computer models that are common to systems thinking education environments.

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, 2014). 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 2004). 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 consulted with practitioners to inform our design and development throughout the process.

We wanted to explore the roles of first- and third-person perspectives in the learning of systems thinking. To do this, we looked to answer the questions: (1) How do children's performances on a systems thinking assessment change before and after engaging in The Honeybee Game curriculum? (2) How do these changes differ between experiencing the curriculum through a first-person lens, a third-person lens, or an integrated lens that combines the two?

Methods

Setting and participants

The project took place in a public elementary school serving about 400 students in a mid-sized, Midwestern city in the U.S. 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. This school was typical for schools in the area, making it a useful and appropriate setting to explore how first grade learners engage with learning about complex systems. Data collection occurred in each of the schools' three first grade classrooms (ages 6–7); one of the teachers worked with the research team as a practitioner-partner on the development of the activities and assessment measures, and recruited the other two first grade teachers to join and participate in the implementations. Each classroom served as one of the three conditions in this comparative study. In this quasi-experimental design, we found the classrooms were not substantially different regarding their classroom makeup or the teachers' styles. Furthermore, a comparative analysis of pre-test scores across classrooms did not show any significant differences. This makes us confident in the claim that these classrooms are similar enough to warrant appropriate comparison. We worked closely with each teacher who led activities and approached the curriculum in ways appropriate for her students. Each classroom had 20–21 students, with the vast majority opting to participate in the study. 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. All three conditions in this study took place over about 12 days, or in about 8 to 9 h of activity.

Table 1 Conditions and simulation activities

	Puppet participatory simulation	Computer simulation
First-person condition	×	
Third-person condition		×
Integrated condition	×	×

The honeybee game curriculum designs

We iteratively designed three parallel versions of The Honeybee Game 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 of the three conditions of the curriculum were designed to follow the same progression from simple to more complex topics, introducing more nuanced accounts of systems thinking concepts—feedback, constraints, and iteration—along the way. The activities were primarily whole-group based, with teachers giving instructions or asking questions of the whole group at once. 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 classroom session began with teacher-led recaps and soliciting student predictions, was followed by the planned simulation play, and ended with a teacher-led debrief. See Table 1 for a summary representation of how the curriculum differed across the conditions. The following sections describe each condition in more detail.

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. This participatory simulation is the result of several years of design iterations (see Danish 2010 and Thompson et al. 2017 for more details on this design). The puppets were designed to reflect natural proportions, colors, and other morphological structures as closely as possible, while still appearing inviting and playful for young children. Large swaths of yellow fabric hung from the ceiling, creating "hive" spaces where students waited for their turn in the field. Radio-frequency identification (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. Students were occasionally asked about what an occurrence might mean for "the whole hive" or to think about more than just their individual bees. However, no activities or direct information was given from a third-person perspective. This allowed the teachers and researchers to separate how first-person learning activities impact learning about both first- and third-person perspectives. For example, an important idea in the honeybee system is that the waggle dance produces more efficient outcomes for the hive as a whole, even though it takes time for each individual bee. This concept was discussed in the first-person condition, but was not supplemented with additional simulations, visualizations, or activities. Figure 1 provides a glimpse of this participatory simulation in action.

Fig. 1 Child with bee puppet during first-person simulation activity

In the third-person condition, the planned simulation activity involved students engaging with a computer simulation that represented idealized behaviors of honeybee hives. This computer simulation is the result of several years of design iterations (see Danish 2009, 2014; Danish et al. 2010 for more details on this design). 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 in the simulation settings held constant by the researchers, students could then observe and make predictions regarding possible differences between each hive's collective foraging behavior and nectar acquisition efficiency. Other variables whose impact on nectar foraging were examined 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. This allowed teachers and researchers to separate how third-person learning activities impact learning through both third- and first-person perspectives. For example, constraints such as predators near food sources (i.e., not attacking the hive) tend to impact individual bees more than the whole hive. This concept was discussed in the third-person condition, but was not supplemented with additional simulations, visualizations, or activities. Figure 2 provides a glimpse of this computer simulation in action.

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—first-person or third-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. On the other hand, our experience suggested that students were more likely to see aggregate patterns such as changing behavior despite a lack of negative feedback 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 classroom flowers and the hives to be played back in real or accelerated 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.

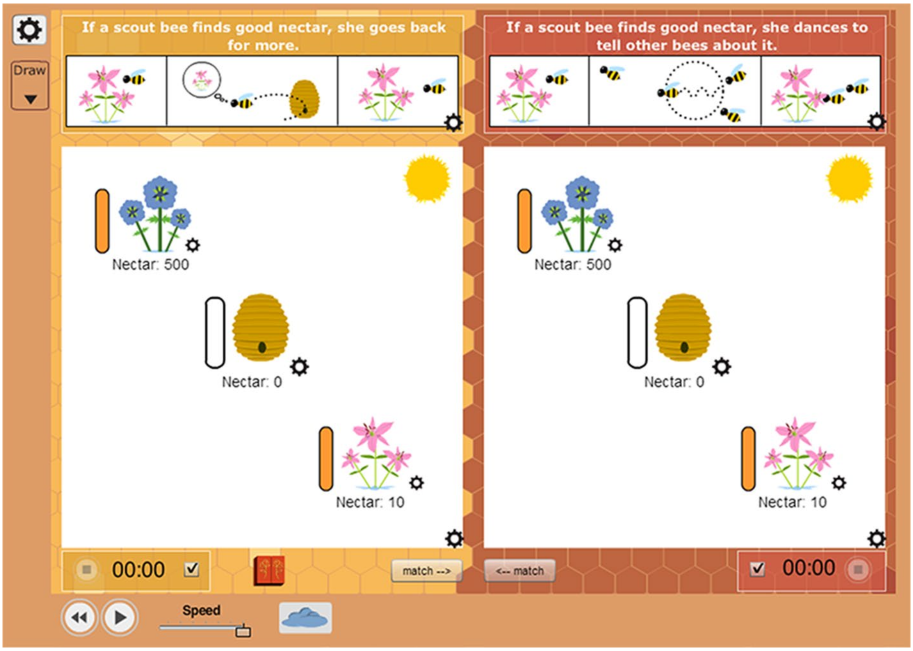

Fig. 2 Screenshot of two hives in the third-person simulation activity

Data sources and analytical techniques

Multiple choice assessment

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 a pre- and post-assessment before and after the 12-day intervention: a 20-question multiple-choice assessment given through a clicker system. Each question was written to have one correct answer. Over several 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?*). Questions designated "simple" covered foundations of bee behavior while questions designated "complex" went further by relating to crucial systems concepts of iteration, feedback, and constraints. 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.

The assessment (see "Appendix") went through several rounds of iteration and validation before use in this study. Initially, practitioner-partners, including one of the teachers whose class participated in this study, assisted the research team over several rounds in crafting multiple-choice questions that were developmentally-appropriate. After a full assessment was drafted, we conducted a pilot study with 65 students to inform refinement of the simulation activities as well as the assessment. Upon gathering the results from the pilot, the authors, including a statistician, closely examined each item to determine items and response options that appeared misleading, too difficult or too easy. Using p-values and descriptive statistics of each item, we reworded some troublesome questions, added items to reach a total of 20—a number we deemed necessary for more robust statistical analyses—and reduced the response options from four per question to three per question to be more developmentally appropriate for first graders. This resulted in the full assessment used in the current study (see "Appendix"). Such assessment development was necessary for this project due to the need to assess at a larger scale than in previous efforts and to provide a robust mix of quantitative and qualitative data.

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. We used a latent variable modeling approach (Skrondal and Rabe-Hasketh 2004), employing Rasch model and a 'difference in differences approach' to allow for instances where the treatment groups' pretest scores are different from one another. This strategy allows us to estimate impacts of The Honeybee Game instructional content across multiple classrooms and timepoints. 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. The Rasch model employs students' response vectors for the respective assessments as inputs in order to estimate student abilities measured in logits, and their associated standard errors. The term "logit" has been used in the field of statistics since Berkson's (1994) introduction of logistic regression, and has been employed in measurement in educational and psychological testing since the 1960's. Our use of logits as the unit of measurement reflects the fact that the Rasch model utilizes the same link function employed in logistic regression. Importantly, the logit scale also has the benefit of being 'additive'—that is, a student ability[2] estimate of four logits is twice as much as a student ability estimate of two logits. Raw test scores are not additive in this manner (Wilson 2004). Using students' resulting ability estimates at pre-test and post-test, and a difference-in-differences approach, we applied the simple t-test in order to determine the significance of change in performance from the pre- to post-assessments. Effect sizes were calculated using Cohen's d (Cohen 1988).

Illustrative interviews

A sample of 20% from each condition was selected randomly to participate in pre- and post-interviews to provide qualitative evidence of understanding (n = 17). Each interview lasted between 10 and 15 min, and consisted of 11 questions. The interview questions were designed to elicit responses related to the complex systems concepts of constraints,

[2] We use the term "ability" here as part of a statistical term known as an "ability estimate" that allows the assessment results of individuals to be compared. This is not used as a reference to students' dis/ability, and we take for granted that multiple choice scores are only one small factor in understanding an individual's learning.

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 ($p=.523$)	Not sig
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

feedback, and iteration. The questions were modeled on the interview used in Danish (2014). Excerpts from these interviews provide illustrative examples of the kind of talk common in each condition. The excerpts discussed below were chosen as particularly clear examples of common responses and trends from the three conditions.

Results

Multiple choice assessment results

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—there was significant growth from pre- to post- across all conditions. A summary of the full results can be found in Table 2 below.

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.

First-person perspective

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 The Honeybee Game 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 $p = 0.523$.

Third-person perspective

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.

Integrated

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 $d = 1.09$.

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. A nonparametric Wilcoxon signed ranks test showed this difference to be significant at the level of $p = 0.015$. This aligns with one of our hypotheses that an integrated perspective would provide an understanding of the relationships between the behavior of individuals and larger-scale impacts. This level of knowledge about honeybee behavior translates to the "simple" questions on the multiple choice test. The third-person condition had the largest gain on the complex items, moving from 46.67% correct to 59.34% correct. A nonparametric Wilcoxon signed ranks test showed this difference to be significant at the level of $p = 0.002$. We hypothesized that a third-person perspective would provide strong understanding of aggregate impacts of feedback, constraints, and iteration. It did strike us that this seemed to translate into higher scores on the "complex" items on the multiple choice test. See Table 3 for a summary of these results.

Interview illustrative examples

In order to further describe the differences in each classroom, we provide illustrative examples of the kind of talk common in each condition. This helps us understand how the various perspectives mediated students' activity and consider how the interactions might be related to differences in learning outcomes as measured by the multiple-choice tests. These

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% SD = 26.18%	49.47% SD = 20.18%	0.86% p = .594	42.59% SD = 11.19%	49.62% SD = 17.28%	7.03% p = .391
Third-person	46.67% SD = 29.78%	59.34% SD = 19.47%	**12.68%** **p = .034**	36.90% SD = 26.85%	55.20% SD = 14.39%	**18.29%** **p = .002**
Integrated	43.55% SD = 32.72%	63.29% SD = 23.25%	**19.74%** **p = .015**	30.76% SD = 24.10%	46.29% SD = 23.84%	**15.53%** **p = .007**

Bold items demonstrate significant differences with $p < .05$

excerpts come from the sample of students that were interviewed in each classroom and were chosen to demonstrate how the students tended to talk about systems concepts, and to describe varying strengths in understanding of the concepts reflected in the multiple-choice results. A different interview question is discussed here for each condition to demonstrate how various systems concepts were made visible in each condition. We begin discussion with the third-person perspective classroom as the multiple-choice outcomes were strongest here.

Third-person perspective

This excerpt comes from an interview with a student after completing the full implementation in the third-person condition classroom. On the multiple-choice assessments, we saw statistically significant gains from pre- to post-, and particularly interesting gains on assessment items classified as "complex."

Interviewer	… Cool. So pretend you are a bee and you found out about nectar from another bee's dance. Let's say you went to that flower and also got lots of great nectar. Would you also dance when you got back to the hive?
Jacob	Yeah.
Interviewer	Yeah? Why is that?
Jacob	Because then the bees would go and get more and more and more and more.

This exchange showcases a typical way we saw the concept of iteration taken up in talk, particularly in the third-person condition. The suggestion here is that each individual bee needs to repeat the waggle dance so increasing numbers of bees continue to go to a particular flower and bring nectar to the hive. This demonstrates some reasoning between the individual and aggregate levels. Such early understanding of this nuance likely contributed to the promising gains on the multiple-choice exam in this classroom. While this class did not participate in the first-person puppet play, the third-person simulation was especially useful for helping learners see the aggregate patterns that emerged from individual actions. About 66% of the interviews from the third-person classroom reflected similar ideas. From our theoretical perspective, we see evidence that the third-person perspective helped to mediate students' experience by making the aggregate gains of the system as a whole salient to them. As we will see below, this is less salient in the first-person perspective which appears to mediate students' experiences differently, orienting them toward individual impressions of the process.

Integrated

This excerpt comes from an interview with a student after completing the full implementation in the integrated condition classroom. On the multiple-choice assessments, we saw statistically significant gains from pre- to post- with the highest effect size of the three classrooms. We also saw particularly interesting gains on assessment items classified as "simple."

Interviewer	Awesome! What will the bee do with the nectar it finds?
Dante	Take it back to the hive and go out again to find more nectar.
Interviewer	Ok! Take it back and go out again to find more nectar, and how come?
Dante	Because if they don't have enough nectar for the hive, umm some bees will die.

This is an example of a promising answer to a "simple" question. Here, simple does not mean easy, but foundational. The student is demonstrating a strong understanding of bee behavior and its implications. It is not necessarily intuitive that a bee would need to continue finding nectar rather than stopping to eat or rest. While this answer does not include the waggle dance that would generally take place after finding a high-quality food, this student is making an important connection between one bee's actions and the overall hive outcomes. About 50% of the interviews in the integrated classroom reflected a similar pattern. It is not surprising, but is valuable to confirm that this integrated perspective appears, therefore, to combine the benefits of mediating students' experience from both the first- and third-person perspective. Specifically, aggregate gains were made salient for the students, and they also attended to how the individual experience of the bees helped make this possible. Thus it appears that the two perspectives both play a role in mediating student learning when combined, and that this is somewhat synergistic.

First-person perspective

The following excerpt comes from an interview with a student after completing the full implementation in the first-person condition classroom. On the multiple-choice assessment, we saw gains in this classroom that were not statistically significant.

Interviewer	Okay, cool! So now let's say you're a bee and when you get close to a flower where you got nectar before, you notice a predator nearby. You get away before you get too close, what do you do next?
Fawn	Ummm tell the other bees not to go there.
Interviewer	Mhmm tell the other bees not to go there? Do you dance?
Fawn	No.

Feedback loops, especially where negative feedback is not present, are difficult to comprehend for learners at all stages. This interview response seems to suggest partial understanding; the student seems to understand that the waggle dance does not communicate negative information, but maintains that some other kind of communication must be necessary to warn others away from the predator. Perhaps with additional prompting, the student may have modified her response, but such initial misconceptions may have partially contributed to the less exciting outcomes in this classroom. In this condition in particular, as hypothesized, the focus on the first-person experiences may have made it more difficult to grasp systems behaviors at a higher level, such as that the loss of a few individual bees would have little effect on the hive's overall functioning. About 60% of the interviews from the first-person classroom reflected a similar pattern. Unfortunately, this suggests that while students did learn, the first-person perspective does orient students toward their individual experience as a single honeybee, making those challenges quite salient and potentially obscuring the view of the system as a whole that is brought to the fore in the third-person and integrated perspectives.

Summary

In summary, our results suggest that the integrated and third-person perspective conditions demonstrated significant gains on the multiple-choice pre- and post-assessments. Additionally, the illustrative interviews corroborate the quantitative results, with students beginning to demonstrate increasingly sophisticated reasoning about honeybee behaviors and relationships between levels of the honeybee system. While students in the third-person perspective performed well across the board, the unique strengths seen in the integrated condition suggest that there is particular power in taking a first-person view of a complex system, especially when paired with an aggregate view as well. The integrated condition showed particularly promising gains on assessment items categorized as simple, and also significant gains on the complex items. This suggests that something powerful does exist in the combination of these perspectives.

Discussion

These findings show the third-person and integrated conditions provided significant systems thinking learning outcomes, although all three conditions made gains from pre- to post-assessment. This suggests that systems thinking curriculum designed through first-person perspectives may be supported by some inclusion of additional perspectives such as through high-quality data visualizations that provide opportunities for reflection. This could be facilitated through classroom discussions and activities in ways that allow for movement between aggregate patterns and individual, first-hand experiences. This makes it possible for experiences through each perspective to inform understanding through the other.

In addition to these results on the multiple-choice assessment, we hypothesized 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. This condition included the Playback technology, which we see as a particularly interesting area for exploration. Here, learners re-watch their prior actions in a way that seems to be a hybrid space in-between first- and third-person perspectives. This technology was not included in either of the other conditions for this reason. However, we are in the early stages of a new line of analysis that is beginning to suggest Playback allows learners to see themselves in the data, prompting rich reflection and discussion. Our ongoing work on The Honeybee Game and a parallel set of activities called AntSim will explore this in more depth.

This work suggests three main outcomes and implications for systems thinking education research. First, this study strengthened our understanding that early elementary students are capable of learning about complexity and other systems thinking concepts, particularly through third-person perspectives (cf., Danish et al. 2010; Peppler et al. 2010; Danish 2014). This is especially 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 (cf., Blikstein et al. 2016). 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 Honeybee Game platform are working to investigate real-time data visualizations of first-person player activity through our work on a uniquely developed indoor positioning system. This work is the focal point of our future research and publications. Our hypothesis around why third-person perspectives may be driving these learning outcomes is that it is quicker to watch multiple rounds of bees foraging for nectar and to see the emerging behaviors via 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, while the integrated condition may not have had the opportunity to debrief as deeply. Future studies may wish to design comparisons between first- and third-person perspectives with this limitation of the group comparisons in mind.

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.

Limitations

Although the findings here are exciting and provide directions for productive future research, we note that there are limitations to the study presented. First, each classroom in the study aligned with one curriculum condition. As such, the participants in each condition were not randomly assigned. We do not see this as an issue that invalidates our results as we do not frame the current study as a true experiment. Here, the classroom delineations are authentic to the ways curriculum is often taken up and slightly modified by individual classroom teachers. Further research could compare groups of students who were randomly assigned to the conditions to continue to explore the roles of perspective taking on learning of systems thinking in non-classroom settings.

Next, we note that 20 items on a multiple choice assessment may be a relatively small number for determining pre-post changes across three conditions. More items on this assessment may have provided more robust data, but we were dedicated to keeping the assessment brief based on the age of the participants, the limited experiences first grade students have with multiple choice tests, and the amount of time we were willing to ask the students to sit silently in their seats. We endeavored to ensure that the majority of our time together would be interactive and playful, aligning with our understanding that young children need to play to learn and communicate. Despite the relatively small number of items, we were able to see clear upward trends overall and within conditions.

Last, we note that the results in the first-person condition were not as strong as we had expected. The third-person and integrated conditions showed significant gains from before to after the curriculum while gains in the first-person condition seemed marginal. Some may see this as an argument against the importance of a first-person perspective in learning about complex systems. However, we see this result as a testament to the importance of providing an aggregate perspective on personal experiences for young children. Students in the integrated perspective showed higher gains on items pertaining to honeybee behavior, suggesting that the combination of first- and third-person focused activities gave learners a better grasp of these concepts. There is also potential that first-person activities could lead to increased enjoyment or engagement with complex science concepts, signaling more positive outcomes over time. Further research should continue to explore the strengths of first-person perspectives for science learning with this age group, and the particular balances of first- and third-person perspectives that best support learning.

This research provides us with exciting paths to recognizing and supporting the intellectual work of young elementary students. Strengthening learning about complex systems for children has potential to create a population more able to solve problems at large and small scales in the future, and to answer questions in a rapidly changing world that have not yet been asked.

Acknowledgements 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 as well as the many teachers and students who made this work possible. An earlier version of this paper was published in the 2018 International Conference of the Learning Sciences Proceedings.

Compliance with ethical standards

Conflict of interest The authors have no financial or other conflicts of interest involved in this study.

Ethical approval This study was approved by the Institutional Review Board at Indiana University. Informed consent was received from all parents and informed assent was received from all youth participants included in this manuscript.

Appendix

Multiple-choice items and simple/complex categories

Item	Category
1. This forager bee just came out of the beehive. Its job is to collect nectar. What will it do next? a. Fly behind another bee b. *Look for a flower with nectar* c. Visit a nearby picnic	Simple
2. Why would bees go to this flower? a. It's pretty b. *They saw a waggle dance to this flower* c. The queen told them to go there	Simple
3. What will the bee do with the nectar it finds? a. *Store it away* b. Eat it c. Put it in another flower	Simple
4. How does a bee know where to find nectar? a. The queen tells them b. *By watching a waggle dance* c. They have to guess every time	Simple
5. This bee just found nectar at this flower! No other bees have found nectar. What will the bee do next? a. Take the nectar to the hive and come back for more b. *Bring the nectar to the hive and tell the others where she found it* c. Eat the nectar and look for more	Complex
6. This bee visited a flower that doesn't have nectar any more, then returned to the hive. What would the bee do? a. Tell others the flower is empty b. *Watch a waggle dance* c. Ask the queen	Simple
7. This bee went to this flower, but there's a spider nearby! The bee got away, what will the bee do next? a. *Leave and find another flower* b. Make up a new "don't go there" signal c. Fly as far away as possible	Complex
8. There are two flowers with nectar: Pink and Orange. This bee visited the orange flower, got nectar, and returned to the hive. Which flower will more bees go to over time? a. Pink, because it's closer b. Orange, because it has better nectar c. *Orange, because this bee will tell others about this flower*	Complex
9. 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? a. Another bee will stop them and tell them where a new flower is b. Go wherever the queen tells them to go c. *Come to this flower because of the waggle dance. Then they'll need to find a new one*	Complex
10. Why is it important for bees to collect nectar quickly? a. It's actually not important to be fast b. *The more nectar they collect, the more food they will have for the whole hive* c. They need to keep the nectar away from other insects and animals	Complex
11. What can make it hard for bees to find nectar? a. Predators might eat them b.They have to search all over c. *All of the above*	Simple

Item	Category
12. This bee went to this flower, but there's a spider nearby! The bee got away, will other bees go to this same flower with the spider nearby? a. No, the other bee signaled not to go there b. Yes, because they will fight the spider c. *Maybe, but only if they had seen a waggle dance for that flower earlier*	Complex
13. This bee followed a waggle dance and got lots of great nectar! Would it also waggle dance when it got back to the hive? a. *Yes! More waggle dances means more bees find the flower* b. No! Only the first bee should waggle dance c. No! It would just go back to the flower by itself	Complex
14. Which of these things in a bee's surroundings might make it harder for a bee to find nectar? a. Trees and grass b. Butterflies and hummingbirds c. *Strong winds and spiders*	Simple
15. Which of these things on a bee's body might make it harder for a bee to find nectar? a. *Breakable wings and small bodies* b. Big head and long antennae c. Full thorax and heavy abdomen	Simple
16. What is one thing we can tell by looking at patterns of lots of bees flying around? a. Their favorite colors b. *When bees keep or stop waggle dancing for certain flowers* c. If bees are trying to get away from predators	Complex
17. What is one thing we can tell by watching one individual forager bee? a. *Challenges the bee has to deal with* b. How much nectar the bee has found in its lifetime c. Which other bees it spends time with	Complex
18. Why would bees that are flying all over the place all start going to the same flower? a. They each decided on their own that flower looked the best b. *More and more bees started waggle dancing for that flower* c. All the other flowers died	Complex
19. Which of these is a way we can tell a waggle-dancing honey beehive apart from a hive with bees that don't waggle dance? a. *Bees from a waggle dancing hive would collect more nectar, faster* b. A waggle dancing hive would be bigger c. Bees from a not-dancing hive would have more energy	Complex
20. Why is it important to learn about systems? a. Because bees are very interesting b. Because scientists told us that we should c. *Because systems are everywhere, so it is important to explore how they work*	Complex

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