# Chapter 10

## E-Textiles for Educators: Participatory Simulations with e-Puppetry

Kylie Peppler and Joshua A. Danish

A group of eight young students gather at the front of the room to try on bee puppets in front of a large yellow hive made of fabric. The students quickly discover that these are not just puppets, they are e-puppets; they have special electronic parts with an array of LEDs that light up to help them play an activity called "BeeSim." The teacher explains that when playing BeeSim, the students will be able to fly around to collect nectar from the flowers in the room. Looking around the room, the students see clusters of fabricated flowers hiding behind the bookshelves as well as in plain sight. The students divide into teams and are told to turn on their bee puppets and check-in at the hive. The gatherer bees then have a limited amount of time to fly around the room, collect nectar from the flowers by touching their fingers (the bee's legs) to the tops of the flowers, and then return to the hive before their bee runs out of energy (i.e., before the light on their puppet changes from green to yellow then red). If the bees successfully find nectar, they can pass it to the storer bee at the front of the hive, and the computer will register the amount of nectar the team has collected on an on-screen display. The object of the activity is to be the hive of bees that is able to store the most nectar before the start of winter.

## Introduction

Most of the previous chapters presented examples of how students can develop their own products and programs using the LilyPad Arduino (Buechley and Eisenberg 2008) to learn about topics such as physics, engineering, arts, and crafts. However, it is also possible for educators to incorporate the LilyPad in the classroom without asking students to create e-textile artifacts. One possibility is for teachers to design e-puppets (Pakhchyan 2008) that can be used to enhance students' classroom activities, helping young students in particular to playfully explore ideas that, without computational support, are often challenging if not impossible for them to grasp. This chapter looks at one example where e-textiles were used to develop a set of computationally enhanced puppets designed to help first- and second-grade students explore complex systems-related concepts by playfully inhabiting the role of a honeybee. This approach to developing participatory simulations makes it possible for teachers to engage young students in embodied, dynamic play while also providing some of the structure needed to help students maintain focus upon the concepts being learned.

We describe a first case of e-textile applications in the classroom, a participatory simulation called "BeeSim" that makes use of computationally enhanced puppets (referred to as e-puppets here) and demonstrate how this project engages even young learners in complexity through physical experiences. Participatory simulations are well aligned with young children's role-playing activities. Similar to role-playing games, participants in a participatory simulation reenact the roles of single elements within a system, enabling them to forge personally meaningful understandings of their element's specific behaviors as well as its role in a greater whole (Klopfer, Yoon, and Rivas 2004; Colella, Borovoy, and Resnick 1998). Computationally enhanced puppets are one of many examples of how educators can harness e-textiles to effectively engage learners in the 21st century. Furthermore, playing with such computationally enhanced participatory simulations not only teaches young students about complex systems in science, but they also provide young students with models of what's possible with e-textiles before youth begin to design their own work.

## Why Honeybees?

Honeybees in particular were selected as a topic of exploration in BeeSim because they are familiar to young students and also represent a number of complex-systems related concepts. There are many biological systems that one could explore through e-puppetry approaches, such as ants laying scent trails to find food, termites building mounds through seemingly random behavior, or non-biological systems such as the flow of electricity through a battery or patterns of traffic which emerge from the behaviors of individual drivers. However, honeybees were chosen for our initial explorations because of their close affiliations with kids' culture and their relevance to a number of science standards. Most relevant to the current study is the way that honeybees communicate the location of flower nectar using a form of dance. Students begin with misconceptions such as the belief that the bees search for nectar individually without informing the other bees or that there is some form of central organization in the hive where the queen is aware of the nectar locations and directs the forager bees to them (Danish 2009). This is what Wilensky and Resnick refer to as a "centralized mindset" (1999). The goal of the BeeSim activities was to help students to recognize both the difficulty of finding nectar and the value of communicating nectar sources to other bees. Furthermore, it was shown in a previous study that students as young as kindergarten age could learn to reason about how honeybees collect nectar as a complex system with the support of activities which helped them to see the role of the bee dance in helping bees to collect nectar (Danish 2009). In particular, it was



valuable for the students to have an opportunity to experiment, firsthand, with the effect of the bee dance upon nectar collection. BeeSim was designed specifically to help students garner this kind of experience.

## BeeSim

We designed the BeeSim participatory simulation to help students learn about how honeybees collect nectar. Typically, real bees known as forager bees go out in search of flowers. They need to cover a relatively large area, sometimes miles from the hive, in order to find good sources of nectar which will be used to make honey. Once a bee finds a flower with nectar, it carries some of it back to the hive in its stomach. Then, the bee communicates the location of the nectar to other bees in the hive by doing the "waggle dance" which communicates the direction and distance from the hive to the flowers. We have seen that this sequence of events isn't entirely intuitive for young students, who instead tend to assume a centralized explanation (Resnick 1996) for how bees collect nectar. For example, they assume that bees can search indefinitely for nectar, see all of the available nectar sources quite easily, can carry as much nectar as they like back to the hive, and either have no need to communicate the location of nectar to other bees or do so by telling the queen bee, who then organizes the bees to return to the flowers (Danish 2009; Danish et al. 2011). BeeSim was designed to help students understand the inherent difficulty in finding sources of nectar, and the value of communicating the location of nectar to other bees so that nectar collection can proceed efficiently despite the limited capacity of individual bees to carry nectar to the hive. BeeSim was also designed to help introduce students to key environmental variables such as the fact that a flower may be destroyed or have its nectar consumed while a bee is returning to the hive.

The BeeSim play space consists of computationally enhanced bees, flowers, and a hive. Each student wears a bee puppet which communicates how much nectar it has using a series of LED lights. As the student-bees visit flowers in the field, the puppet also communicates to them the amount of nectar that they find in the computationally enhanced flowers. Finally, when the student-bees return to the hive, the computationally enhanced bee transfers the nectar to the hive so that it can be converted into honey (and the score can be calculated). As the youth collect nectar and then transfer it to the hive, they also decide if they want to communicate about the location and amount of the nectar to the other bees on their team, and how to communicate this information. The only limitation we place on the students is that they cannot use words to tell the other bees where the nectar is because real bees cannot speak. In our pilot studies, students initially didn't bother to communicate, thinking it wasn't worth the time it would take to convey directions. However, they quickly realized that it was possible to waste a lot of time visiting flowers that were "known" to not have nectar. At this point, they often resorted to elaborate pointing gestures to help their peers understand the direction and distance to the flowers. The overarching goal of BeeSim is to illuminate the behavior of the individual bees with a focus on the challenge of finding nectar and the benefit of the dance as a form of communication. Once the students master these concepts, the flexibility of the e-textile puppets then allows us to introduce other variables into the participatory simulation setting parameters such as nectar quality, nectar depletion at specific flowers, and the limited flight range of the bees, all of which are important to helping the students develop a rich understanding of the science content.

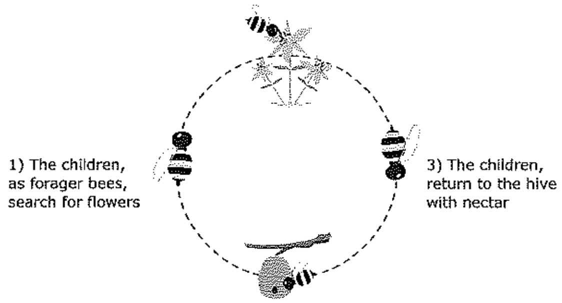


Fig 61 High-level diagram of the flow of activity in BeeSim

The chapter authors were the lead designers of BeeSim, working in conjunction with their team of researchers at the Indiana University Creativity Labs. To design BeeSim, we first completed two pilot iterations of the participatory simulation without the use of computational technologies. For the pilot iterations, we used colored water to represent nectar which the students collected using eyedroppers. To make it challenging for the students to spot the nectar at a distance we utilized construction paper flowers that not only hid the nectar cups but also added some visual realism to the participatory simulation. These pilots helped to verify our belief that this form of gaming activity would help the students to relate personally to the challenges that bees face in finding nectar and by extension to reason through their solutions. However, it also became clear that in the rush of enthusiastic activity, the students were sometimes loath to follow the rules. Furthermore, the teams who collected the most nectar were not necessarily the ones who communicated the best but rather were the teams most physically able to use the materials (e.g., using an eyedropper efficiently) or those that cheated the participatory simulation (e.g., peeking behind the construction paper flowers at the hidden nectar in the Dixie cups). These limitations with the physical materials distorted some of the students' appreciation of the local bee dance in affecting change at the aggregate level—faster nectar collection over time. This, in turn, jeopardized students' understanding of the relationship between the multiple levels within the system of nectar collection. Thus, we designed BeeSim with an eye towards how we might help constrain the students' activity using the affordances of the wearable computers to make visible more aspects of the system.

We then set out to prototype a solution using the LilyPad Arduino toolkit that would monitor and model elements of the system more closely. This version built upon prior successes where eight students are split into two teams of dueling "hives," requiring teammates to work collaboratively to collect "nectar." The communication between computationally enhanced textile bee puppets, flowers, and a hive, heightens the realism of bee behaviors and helped students attend to the rules of the system. In this version, we also strove to overcome the challenges we had encountered in earlier activities that did not utilize technology. For example, in the pilot studies, the honeybees' range (how far they could fly before returning to the hive) had to be monitored by a research assistant with a stop-watch who notified the students that they had to return—something that they often ignored or resisted by looking at "just one more" flower. Because of this, the participants often failed to consider the range to be a real constraint for bees, because it was not a real constraint for them. In fact, several students even believed it would be beneficial to navigate to more distant flowers to avoid having the other team spy on them despite the increased time required to collect nectar. In contrast, the computational textile bees embedded the bees' energy into the participatory simulation in a natural and familiar manner such that the students in the role of the bees had to attend very carefully to it or suffer the consequences (lost nectar). This resulted in far more attention to details important to understanding the system. As an added bonus, it was much easier for one instructor to facilitate the participatory simulation without the need for additional research assistants to help "police" the rules. We see this as particularly important in elementary school classrooms where teachers rarely have a surplus of adult assistance.

Fig 62 Pilot users using the ForagerBee puppets to collect nectar from flowers and deposit it at the BeeHive

As the example above illustrates, we designed the BeeSim activity to capitalize upon the potential of the BeeSim e-puppets for helping students to explore the science content. During the BeeSim activity, students are given a limited amount of time (45 seconds) to collect nectar from the flowers and deposit it back at the hive. The students also have a limit on how much nectar they can carry (3 units). During the allotted time, a child runs from flower to flower and tries to collect nectar (Figure 62). A child can collect one unit of nectar from any given flower (if the flower is not empty) and will also be informed as to how much nectar remains inside the flower. A child may collect nectar from the same flower more than once. Once the child's nectar stomach (represented via a LED array) has been filled, he or she returns to the hive and deposits the stored nectar. If time runs out prior to depositing nectar, the nectar is lost and not counted. When a child's turn is over, marked either by running out of time or by making a successful deposit, the glove is passed to a teammate. (Ultimately, we hope to provide each child with a glove in future implementations.) As the child relinquishes the glove, the child may attempt to inform the next bee, through nonverbal language of the location of any high-yield flowers. After all students have had a turn, the team with the most nectar wins, as they are most prepared for winter. These constraints were all designed to help the students reflect upon the constraints that real bees face as they collect nectar as well as the benefits of the solutions that honeybees have evolved to these constraints (e.g., the bee dance to convey nectar sources). Through participating and playing with the e-puppets, students learn more about complex systems through play. For example, after engaging in the BeeSim activity, students were more likely to note that the bees really benefited from communicating about the source of nectar, a key realization in the process of helping them to understand the overall behavior of the hive.

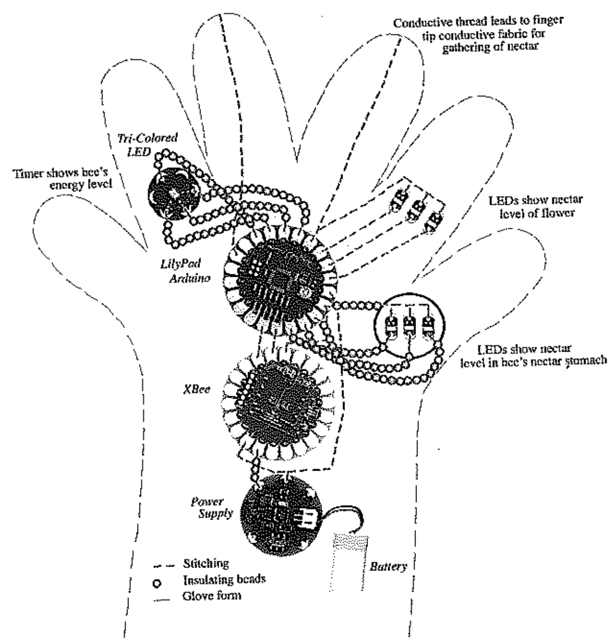


**Fig 63** Layout of the ForagerBee Glove

We have pilot-tested the electronics-based version of BeeSim with first and second grade students as part of a 16-week curriculum unit where the students were learning about honeybees through BeeSim, computer simulations (see Danish, 2009 or http://www.joshuadanish.com/beesign) and traditional classroom activities such as reading, drawing, and play-acting (see Danish, Peppler, Phelps and Washington, 2011). We found that the computationally enhanced BeeSim participatory simulation gives the teacher more freedom and better access to data than in previous incarnations. Furthermore, the students' interactions were both more natural and more authentic. For example, when foraging for nectar, students didn't need to be coerced into limiting their range by the instructor, instead monitoring it carefully on their e-puppet as they ran around frantically searching for nectar.

In addition to the bee range, the e-textiles also helped to model limited amounts of nectar collection, flower variables such as random nectar depletion, the difficulty of determining if a flower has nectar without visiting it, and supporting easier tracking of how much nectar was collected. In the prior iterations, for example, students were sometimes distracted by their efforts to fill an eyedropper with nectar rather than focusing on the importance of communicating the flower location so that other bees could then find it. With these new computational limits, however, ideas such as the value of completing the bee dance to communicate the nectar location to one's peers took on new import for the students.

## The BeeSim Design

In designing the BeeSim e-puppet, we started by first conceptualizing the students' activities as described above, pilot-testing them without technology to better understand the likely behavior of the students. Then, our goal was to develop a tool that would accomplish two competing aims: 1) helping to constrain and extend students' natural activities where appropriate (e.g., helping them focus on the limited range of the bee) while 2) leaving the students the opportunity to engage in more natural activities when those activities might promote learning (e.g., having the students design their own communication patterns regarding the nectar location). The BeeSim puppet was, therefore, designed primarily to track and limit the bees' flight, and nectar collection, while effectively and effortlessly communicating this information to the students.

The BeeSim e-puppet, called the "ForagerBee," consists of one LilyPad Arduino microcontroller, one XBee 2.5 2mW Wireless Module and LilyPad XBee Breakout Board, two sets of 3 LEDs, one Tri-Colored LED, one regulated power supply, one resistor, and two pieces of conductive fabric shaped into a child-sized glove (Figure 63). The XBee Wireless Module allows for wireless communication between the glove and another XBee attached to a computer embedded within a giant cloth BeeHive. During gameplay, students wearing the bee puppets can monitor through a set of three LEDs the amount of nectar currently stored on the glove, while an accompanying set of LEDs displayed the amount of nectar in each flower. To represent the finite energy levels of bees as they travel between the hive and a flower, a Tri-Colored LED was used as a timer, moving from green to red to indicate to students when they needed to return to the hive. As this model continues to progress, we hope to model other aspects of nectar collection including nectar quality and predators that make it difficult for bees to collect vast amounts of nectar.

To simulate a field of flowers, a unique resistor was embedded to each of eight fabric flowers (Figure 65) with two pieces of conductive fabric attached to the ends of the resistor. An additional resistor was placed at the BeeHive. When the fabric from the glove comes into contact with the fabric of the flower, the LilyPad on the glove measures the voltage across the resistor. Each flower has a unique resistor and therefore a unique voltage. This voltage was used in our software to identify which flower the glove was touching. As the child collected nectar, the computer noted the time and flower ID of the collection. If the child returned to the hive before time ran out, the total amount of nectar for the team increased by the amount of nectar currently stored on the bee. As the amount of total nectar increased, a webpage running on a laptop next to the hive displayed the new nectar amounts (Figure 64).

Finally, it is important to note that it would have been quite easy, from a technical standpoint, for the ForagerBee to automatically communicate the location of flowers with nectar in them to the other ForagerBee puppets. This is where our second design goal, noted above, helped us to note the conflict between our technical capabilities and our learning goals. We decided to leave this part of the interaction to the students because it was both fun and an important part of the interaction that we wanted them to both experience and design. In this way, we were able to put the burden of tracking the "rules" of the participatory simulation on the e-textile puppets and then leave the important "work" of playing and communicating to the students so that they could most effectively learn from their experiences.

## Future Possibilities

Building a wearable, fabric-based computational device works well for students running throughout an indoor space and interacting with other electrical components. By sewing the device onto something wearable, the object then becomes tactile and part of the students' play space. It should be noted that BeeSim was developed by educational researchers with a good amount of pre-existing technical expertise, including familiarity with computer programming. While the issues that teachers have historically faced when developing their own technology have been documented elsewhere we envision that future iterations of commercially available e-textile toolkits, including those that replace needle and thread mechanisms with reusable snap connections, will facilitate easier e-textile construction for classroom instructors, including those with little advanced knowledge of electronics. Coupled with the kinds of success in teaching young students about systems thinking that we have seen with these tools, our hope is that wearable devices will become central in helping to bring participatory simulations into more classrooms in an effort to support youths' understandings of complex systems.

In plans for future iterations of BeeSim, we have devised a way of easily reusing the wearable computers in the bee costume by reprogramming and adding a new skin to explore other complex systems that would be attractive for this target group (e.g., the bees can easily become ants or termites, or even cars). In this way, this work can lead to "patterns" of wearable experiences that can be reused and adapted in similar contexts. Our hope is that this will help to foster general practices and conceptual building blocks that students can leverage to understand a large number of complex systems, including other natural biological systems such as ants and termites, as well as other systems in a host of curriculum domains. These efforts would also help teachers in justifying the investment required to build their own e-puppets both in terms of time and materials. By helping educators to design, build, develop, and potentially



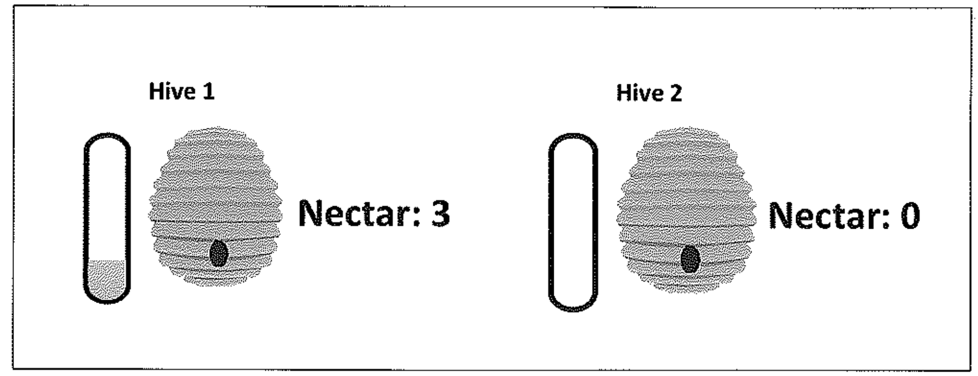


Fig 64 (T) Partial screenshot from the BeeHive Interface
Fig 65 (B) The BeeSim flower

share re-purposeable e-puppet technologies, our hope is that we can increase the likelihood of their useful and meaningful adoption across the curriculum.

In describing BeeSim, we have also tried to illustrate that e-puppets have a potential that is far greater than simply adding entertainment value to classroom activities. Rather, the real strength of e-textiles lies in how they can be used to help shape, guide, and constrain student activities in productive ways. In a sense, the BeeSim puppets were powerful tools for student learning not just because they added possibilities, but also because they removed others (e.g., cheating, running endlessly around the yard, etc.).

While the case presented here is the first of this line of work, we hope to illustrate how educators can capitalize on these new materials to build novel experiences for youth that transform the schooling curriculum even without asking the students to participate in programming the devices directly. Other examples of where educators could adopt e-textiles in the classroom include enhancing puppet shows for special effects to enrich the language arts curriculum, using e-textile displays to depict the water cycle in science, e-textiles could also be used for geographical mapping in math, science, and social studies, and computationally enhanced gloves can display in real time to track things like speed and motion for the study of physics. While these are just a few potential ideas, e-textiles can be useful anywhere in the curriculum where teachers seek to transition from a curriculum focused on fact-based learning to a more experiential and tactile approach.

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# Textile Messages

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To Seymour Papert, the grandfather of this work

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