# Designing BioSim: Playfully Encouraging Systems Thinking


Naomi Thompson
Indiana University
1900 E 10th St Eigenmann 531
Bloomington, IN 47406
+ 1 (812) 483-8089
naothomp@indiana.edu

Kylie Peppler
Indiana University
1900 E 10th St Eigenmann 528
Bloomington, IN 47406
+ 1 (812) 856-8381
kpeppler@indiana.edu

Joshua Danish
Indiana University
201 N Rose Ave Wright 4040
Bloomington, IN 47406
+ 1 (812) 856-8330
jdanish@indiana.edu



## ABSTRACT

In this paper, we discuss the design decisions made when creating BioSim, a participatory simulation centered around honey bees and army ants to help young children explore complex systems. We outline some crucial design principles that can help align games and simulations to systems thinking, and conclude that these principles allow young children to engage with complex systems concepts.



## Categories and Subject Descriptors

K.3.1 [Computers and Education]: Computer Uses in Education - *Collaborative learning.*

## General Terms

Design

## Keywords

Systems thinking, design, biology, early elementary


## 1. INTRODUCTION

Recognizing the many, interrelated systems at play in the world around us is difficult. Adults historically have trouble understanding these systems, such as biological processes or even highway traffic, as decentralized and multilayered [10] [16]. These complex systems guide how our world works, yet are rarely fully understood. This has led to several efforts to strengthen education around systems thinking, or systems literacy [2] and make these concepts clearer at earlier ages [1] [6] One promising approach to helping young students learn about systems concepts is to have them engage in games which allow them to take on a new perspective within a system, and thus help them to appreciate the system dynamics at play [14].



In our work, we engaged in iterative design-based research [3] to explore how to support these ideas through gaming in a series under the umbrella *BioSim*. First, BeeSim [15] was created as a "game-like" participatory simulation - a computer supported way to move simulations from the screen to embodied experiences [5] - that provides a first-person look into the life of a honey bee and the complexity of nectar foraging behaviors for young children. In BeeSim, students in grades K-3 wear electronically enhanced bee puppets to "become a honey bee" and work together to collect nectar from a field of electronic "flowers." They also communicate with one another through waggle dances, a real-life phenomenon through which honey bees share locations of known nectar sources. BeeSim stemmed from, and is paired with BeeSign [7] [6], a computer software simulation that provides the third-person view of this honey bee system. Recently, we have expanded this work by designing AntSim; looking at complex systems through army ants gives rise to analogous systems concepts, making transfer an interesting possibility, and both insects offer familiar and fascinating lenses.

Here, we explore the design decisions made when creating these games to help children engage with complex systems. How do we design games to be simultaneously educative and engaging? What tensions arise in the design process when trying to parallel what is known about complex biological systems while essentializing into a simplified model of game play? We use our latest game-based iterations and refinement of BioSim as illustrative examples of the inherent tensions in the design process of creating serious games in science.

## 2. BACKGROUND & GUIDING THEORY

A system is recognized as "complex" when the relationships within it are not obvious or intuitive, and the individual elements of the system give rise to new overall properties that are difficult to see or explain quickly [10]. This is especially true in biological systems where individual organisms may act in ways that seem counterintuitive to the larger pattern. For example, individual honey bees spend a considerable amount of time "dancing" to communicate nectar location to other bees in the hive. However, this behavior gives rise to faster and more efficient nectar collection for the hive as a whole. This is not intuitive for young children - they tend to assume this time spent dancing is wasteful [6]. This surprising interaction between levels [19] in the system is known as emergence; we knew this would be an important concept to cover in our games, which guided the design process. Other important complex systems concepts that guided design include feedback loops, iteration, and constraints.

Much of the work around systems thinking education has been through biological systems, a field well theorized in early school years, and a topic children are familiar with and curious about. For example, Hmelo-Silver has often studied children's understanding of aquatic and respiratory systems e.g., [11] while Wilensky has looked into large ecologies involving wolf, sheep, and grass e.g., [18].

We follow this history of diving into biological systems, while adding in the element of game-like simulation. Games are especially powerful because they allow children to take on new perspectives through play, supporting productive learning. [8] [16]. Games can also allow switching between perspectives - we see both the first-person (seeing as main actor) and third-person (seeing all actors) perspectives as crucial. First-person allows students to understand constraints, while third-person helps them see individual actions add up to aggregate behavior. Understanding the simultaneous differences and connections between these levels is a crucial part of systems thinking [12]. In our activities, we create situations that bring about "double-binds," a mismatch between students' current ways of thinking, their needs, and the possibilities in the environment [4] [8]. The goal of the game is to make constraints in the honey bee system visible, creating a double-bind, then allow children to notice solutions, such as the waggle dance. We needed to create game constraints that mimic the actual constraints the insects face, so the children notice them, and recognize the system mechanisms that overcome them.

## 3. DESIGN PRINCIPLES

Across our multiple design iterations outlined in our process below, some key design principles emerge that can help us align games with systems thinking. These included at least three crucial principles:

1. Choose a central focal point
2. Build on game mechanics typically found in children's play
3. Productively constrain children's play to help them notice certain system elements

These guiding principles helped us hone our focus on the salient parts of the system crucial to complex systems understanding. We also envision that these principles will be useful to others wanting to take up these principles for other games to promote systems thinking among learners of all ages. We outline the utility of these principles here.

## 4. FINDING INSPIRATION IN REAL-LIFE BIOLOGICAL SYSTEMS: SOCIAL INSECTS

With a focus children can relate to, gathering food, in mind, we worked closely with a biologist to find interesting behaviors and constraints in the honey bee and army ant systems.

### 4.1 Bees as Systems

Honey bees are divided into multiple classes, the queen lays eggs and drones engage in keeping the bees alive. The bees that search for nectar are scout bees. We focus on the phenomena of honey bees quickly and efficiently collecting nectar to turn into honey. They search for flowers with good sources of nectar, then fly back to the hive and share the flower's location through the waggle dance. The waggle dance in the hive, conveying only positive information, creates a positive feedback loop, a crucial concept in systems thinking. They are constrained by bad weather, predators, fluctuating nectar levels, and limited distance capabilities.

### 4.2 Ants as Systems

Ants create an analogous positive feedback loop, although the system looks quite different from the outside. The forager ants move around in forests and jungles looking under rocks and leaves for food to bring back to the nest. As they move, they leave trails of pheromones behind them. If an ant finds a food source that is too big to carry alone, it will follow its own trail back to the nest to recruit help, reinforcing the pheromones. The more these trails are reinforced, the more ants continue to follow them, creating the positive feedback loop. Trails that result in no food are not reinforced and fade away. Ants also have a remarkable way of spreading out their search areas by relocating their nests every few weeks.

To build the game rules, we asked of these systems: What are the insects' main needs, and why? What issues do they face in pursuit of meeting these needs? What roles do various members of the system play?

## 5. KEY DESIGN CONSIDERATOINS IN BIOSIM FIRST-PERSON GAMES

While biological systems provide a fruitful starting point for design, it can also be challenging as we design games based on complex systems to choose a central focal point since there are a number of feedback loops within each of these systems as well as nested systems at play (e.g., bees collecting nectar are simultaneously pollinating flowers). In this case, we chose to focus on nectar collection because we felt it could be more meaningful and more easily aligned with young children's perspectives, to help students think about the needs of the bees and what drives their actions.

In addition, we wanted to build upon game mechanics that are typically part of children's play. For example, with bees we drew upon puppetry play and perspective taking along with movement around the room in playful ways. Similarly, since army ants forage for food in dense forests and jungles, traveling long distances under and around large obstacles, it seemed appropriate to give children a similar constraint by asking them to crawl or crouch to move from place to place.

Other design decisions were based on trying to constrain children's play in productive ways to help them understand the mechanisms of the system. Since both insects are small, they must be economic with how long and how far they go in search of food. However, children (especially distracted children) have a tendency to search indefinitely, causing the game to lose momentum and the science to be difficult to understand [13]. To mirror this, we needed ways to alert the players to their waning energy levels that can only be restored by resting at the hive or nest.

These are a few examples of what we chose to include in the design and the rules to push students' thinking about the reasons and motivations behind the actions these organisms take (see Table 1).

**Table 1. BeeSim and AntSim Rules of Play**

| | BeeSim | AntSim |
|---|---|---|
| **Need to gather food** | You are a forager honey bee, search for nectar to bring back to the hive. | You are a forager army ant, search for food to bring back to the nest. |
| **Search necessary to find food** | The flowers are scattered around the field, some have nectar and some do not. | Piles of leaves are scattered around the area, some have food underneath, and some do not. |
| **Communication and collaboration** | Bees cannot talk with words, they use a special dance to communicate to other bees about nectar location. | Ants cannot talk with words, they leave trails of pheromones leading to food sources for other ants to follow. |
| **Energy constraints** | You only have a certain amount of energy. To restore low energy, rest at the hive a while. | You only have a certain amount of energy. To restore low energy, rest at the nest a while. |

# 6. RULES OF PLAY: THE CASES OF BEESIM AND ANTSIM

As part of the iterative design process, we started with no/low-tech playtest sessions before eventually moving to integrate the technology in the BioSim project. This allowed us to see how the game rules worked, where technology would or would not enhance the activity, and whether or not children seemed motivated to participate.

## 6.1 BeeSim

Several iterations of BeeSim took place, beginning with a version where children collected pieces of cork hidden around the space as nectar [7]. This gave way to using eyedroppers to collect liquid, limiting how much could be collected at one time [15]. To play BeeSim, children walk around the play space checking “flowers” for nectar. An area of the room is blocked off to serve as the hive, such that the players cannot see the room, and must communicate through the waggle dance to convey nectar location. This mirrors the real-life phenomena wherein bees communicate inside the hive in the dark. The children may also encounter flowers with poor or no nectar, and they must decide what information to share, just like real honey bees.

## 6.2 AntSim

This version has also been through two smaller iterations, with a third version in the works. Through multiple iterations of playtesting with both groups of graduate students and children at an after-school club, our designs settled on actors taking the role of army ants. To simulate this part of the system, we gave players brightly colored game chips (similar to those found in Bingo) to leave on the ground as they crawled around searching for food, and hid paper food sources under fake leaves, just as ant must look under brush for food. Chips on the ground can be easily moved around or challenging to pick up, reinforcing that advanced technology such as indoor real-time positioning could enhance this portion of game play in future iterations. Players also must recruit help to carry food pieces, as ants are highly collaborative and work together to bring large finds back to the nest.

# 7. CONCLUSIONS

Through this work we realized that some constraints need to be made salient to fully bring across the concepts we have identified as crucial, meaning there is exciting space to leverage technological affordances. The game space provides interesting opportunities to make salient those constraints that create productive double-binds. By choosing a central focal point, building on children’s common play mechanics, and productively constraining play, we were able to build games that engage young children with complex systems concepts in interesting ways.


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