

A Learning Sciences Investigation of Game-Based Structural Debriefing¹

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Abstract. Systems thinking skills have been recognized as part of the core science literacy, and more recently, as critical 21st century skills. While several studies have investigated how games can be used to facilitate students' systems thinking skills, little is known about how teachers can design game-based curriculum. In this study, we investigate a pedagogical framework called Game-Based Structural Debriefing (GBSD) as a means for bridging affordances of games with curriculum activities that teach systems thinking. GBSD adapts standard systems thinking practices that have been established by the Systems Dynamics community. Using the design-based research method from Learning Sciences, we investigate the GBSD framework by working collaboratively with three middle school life science teachers.

Keywords: Game-Based Learning; Systems Thinking; System Dynamics; Curriculum Design; STEM Education

Introduction

Natural, social, and business systems include many elements and stakeholders that interact through complex causal webs (Grotzer, 2012; Perkins & Grotzer, 2005). Such complex systems are difficult to understand due to the presence of these interdependent, dynamic, and often

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latent components (Ferrari & Chi, 1998; Hmelo-Silver & Azevedo, 2006; Jacobson & Wilensky, 2006; Wilensky & Resnick, 1999; Feltovich, Coulson, & Spiro, 2001). Because systems thinking skills are required for understanding complex systems, these skills have been recognized as a core of science literacy education (Jacobson & Wilensky, 2006; National Research Council, 1996; Sabelli, 2006). Moreover, systems thinking was identified as a critical “21st century skill” that young Americans need to live productively in the competitive global society (e.g., New London Group, 1996; Partnership for 21st Century Skills, 2007). The current national standards for science education (NGSS, 2013) reflect this perspective by explicitly infusing concepts and practices of systems thinking across the standards. For example, by applying the crosscutting concepts of “systems and system models,” students learn to define the system being studied by specifying its boundaries and by making explicit the components of that system. While the inclusion of systems thinking elements in the science education standards is a significant step forward, this poses imminent practical challenges for teachers in terms of how to teach systems thinking.

One of the methods that can be used to teach systems thinking skills is video games (e.g., Gee, 2003; Salen, 2011; Shute et al., 2010). Many popular games, such as SimCity and Zoo Tycoon, model the complexity of real-world problems. To advance in such games, players must continuously think about the underlying interrelationships between the rules, goals, limited resources, and character preferences. Computer games are good learning environments for exploring underlying models (Spector, 2000). Playing games gives students many opportunities to apply systems thinking skills (Senge et al., 2012). While ample evidence supports the idea that playing games can facilitate students’ systems thinking skills (Shute et al., 2010; Steinkuehler, & Duncan 2008; Torres, 2009; Peppler, Danish, & Phelps, 2013), little is known about how teachers can use video games in the classroom to support systems thinking (DeVane, Durga, & Squire, 2010). Simply playing a game might not be sufficient because students may view the game as a “black-box” even if they implicitly understand how it works (Größler et al., 2000).

Learning Sciences and Systems Dynamic communities have a productive history of collaborating. For example, the journal called *Simulation & Gaming* published two special issues in 2000 and 2016 that invited researchers from both disciplines to contribute. Many collaborative projects investigated how dynamic model construction and model-based learning can help people understand complex system behaviors. The common interest between the two

communities centers on various pedagogical approaches and instructional support that can be combined with systems dynamic modeling (Davidsen & Spector, 2000). For example, the interaction with simulations and games followed by a debriefing has been recognized as a productive approach to deepen students' understanding of complex systems (Qudrat-Ullah, 2007). Building upon this line of work, *we aim to establish a pedagogical framework for teaching systems thinking skills with video games*. The framework, which we call the Game-Based Structural Debriefing (GBSD), borrows from the literature and practices of both learning sciences and system dynamics communities. While our approach adapts the system dynamic standard method (Lyneis 1999), we utilize the design-based research approach from learning sciences (Collins, Joseph, & Bielaczyc, 2004) for iteratively developing and refining the GBSD framework.

Theoretical Framework

We propose a pedagogical framework called Game-Based Structural Debriefing (GBSD) as a means for bridging affordances of video games with curriculum activities. GBSD supplements a video game with structural debriefing, which is a number of activities that can help students understand the internal causal structure of a complex system portrayed in a simulation or a video game (Pavlov, Saeed, & Robinson, 2015). GBSD allows students to relate explicit game components (e.g., goals, rules, variable behaviors) to system concepts (e.g., causal relationships, feedback, accumulation and delay). The game does not need to be developed as a system dynamics simulation. Table 1 describes nine elements of the most comprehensive GBSD curriculum unit, as we originally envisioned it. Specific classroom implementations of GBSD may include fewer elements, which might be dictated by practical constraints. During this study, participants also proposed several new elements for GBSD, which we introduce in the Findings section below.

Table 1. Elements of the Game-Based Structural Debriefing (GBSD)

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| <ol style="list-style-type: none"> 1. <i>Gameplay and game analysis</i>: Students play the game and discuss rules and goals of the game. 2. <i>List variables</i>: Students identify and list variables from the game. 3. <i>Draw and discuss reference modes</i>: Reference modes are graphs that show behavior of variables over time. Draw several reference modes for the key variables. |
|---|

4. *Identify momentum strategies*: A momentum strategy refers to a particular strategy that players would try as the “default” strategy.
5. *Construct causal loop diagrams*: Draw conceptual causal loop diagrams to explain the behavior of the underlying system with respect to its structure.
6. *Construct a model*: Using model-building software (e.g., Insight Maker), students build a computational model. Unlike the causal loop diagrams, building a model requires equations.
7. *Validate model*: Students run hypothetical scenarios by using extreme values to test how consistent the model is and revise the model as needed.
8. *Test strategy*: Students use the validated model to explain the momentum strategies and new strategies that can lead to better performance in the game.
9. *Report*: Students communicate the structure of the system within the game, describe their model if they completed building and testing a model, and reflect how their strategies have evolved in comparison to the momentum strategy.

Methods

To refine and test the GBSD framework, we use the design-based research approach (Collins, Joseph, & Bielaczyc, 2004), which, in our study, includes (a) collaborative curriculum design and professional development with three participating teachers, (b) an iterative refinement of the GBSD framework, and (c) a qualitative analysis of teachers’ curriculum implementation. The primary question we address during this phase of the study is: *How do teachers use the GBSD framework to create game-based systems thinking activities?*

We selected Food Fight (<https://www.brainpop.com/games/foodfight/>), a freely available turn-based multiplayer game provided by BrainPop (Figure 1). The goal of the game is for each player to grow the population of a selected animal (e.g., Eagle or Rhino) by carefully adding animals and plants to the biome. Food Fight is a good example of a game that uses complex systems as the core mechanic since the modeled populations compete for limited resources.



Figure 1: Food Fight, a freely available multiplayer game chosen for the study

We recruited three middle school life science teachers and two Master teachers. Many middle school teachers use games like this one in their classrooms when they teach ecosystems, yet they are often not familiar with systems thinking concepts. Three participating teachers worked with the research team and Master teachers to co-design a five-lesson unit that incorporates the elements of the GBSD framework. The research team observed teachers' implementations and followed up with structured interviews to understand fully how the framework was used as a design tool.

Findings

Over several workshops, our research team developed a five-lesson teaching unit, which was later implemented in the classroom by three middle school teachers. This section reports on the findings.

Lesson 1: Ecosystem

During the first lesson, the teachers introduced the concept of an ecosystem and the relevant vocabulary. As pairs, students conducted online research about the African savannah including 6 to 8 living things. The students and the teachers also reviewed examples of a food chain and identified the specific food chains that exist in the African savannah (Figure 2).

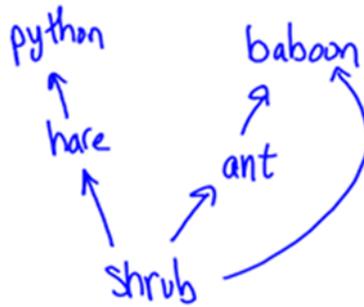


Figure 2: An example of a food chain identified by students and a teacher during Lesson 1

The teachers expressed the need for this pre-game activity to give students the definition and understanding of the food chain in Savannah. It also provided the context for teachers to review with students the science vocabulary. This lesson was an addition to the framework described in Table 1. Based on their experience with this lesson, the teachers suggested that in the future the living things could be grouped as herbivorous, carnivorous and omnivorous to help students see who predate on whom.

Lesson 2: Game play

The primary purpose of this lesson was to introduce the Food Fight game. The teacher started by projecting the game on the screen from his computer and going over the online tutorial with the whole class. Then the students played one round of the game for two competing species that were preselected by the research team. After one round of 14 turns, the teacher and students discussed the variables in the game and strategies used by students (Figure 3). The teacher asked students to list variables that may affect the populations in the Food Fight. The students then played again by choosing any species they wanted.

- | | |
|--|---|
| <ul style="list-style-type: none"> ★ What is a variable?
<i>Something that changes</i> ★ What are the variables in this game?
<i>the turn population, amt of time, organisms, available wild cards (fire, drought, insects), availability of your species, score (pts)</i> ★ What causes the population to increase?
<i>amt of food (prey), decrease in predators, amt of food</i> ★ What causes it to decrease?
<i>shortage of food, amt of predators, wildcards, space</i> ★ Do the rates of increase or decrease change? | <ul style="list-style-type: none"> ★ What is the goal of the game? DAY 2
<i>↑ pop'n → ↑ score</i> <i>Score the most pts</i> ★ What are some strategies?
<i>if ahead, wait it out ⇒ stall</i>
<i>spawn a predator of your opponent's animal</i>
<i>rhino/elephant ⇒ herbivores w/ no predators</i>
<i>add prey that your opponent can't eat</i>
<i>build up your prey and prey for your prey</i> |
|--|---|

Figure 3: Variables and strategies identified by students immediately after the game

When we asked how the first lesson prepared them to play the game, the students indicated that Lesson 1 helped them only very little to play the game during Lesson 2.

Lesson3: Discovering Causation with a Connection Circle

During Lesson 3, students were introduced to the connection circle diagram. They were asked to create a connection circle for the game they played during Lesson 2. Students started by recalling the variables in the game. The teachers stressed the importance of the populations of predators and prey and the space available for plants and animals. To demonstrate how to draw a connection circle, the teachers used a simple food web, such as in Figure 2, to diagram a connection circle, reviewing with the students each connection.

Then the whole class played a Termite vs. Hare game together. The teacher set up the game on the white board and the students watched him as he was adding elements to the ecosystem. For turn 1, the class added grass to the ecosystem. For turn 2, students again added more grass. This brought the population of grass up to 10 units. Then the teacher told the students, that he was going to add zebras. The teacher asked the students to show with their thumbs pointing up or down what they thought was going to happen to the grass population. They predicted a decrease. To their surprise, the population of grass increased to 11 when zebras were added. Several students asked why that happened. All pairs of students recorded the result on their worksheet (Figure 4). Students were then asked to build their own ecosystems with the same organisms, Termite and Hare. The teachers told the students to record data for one organism in the game per turn, to see if the population changed when students added an organism of their choice. Students played for about 10 minutes and most students were able to complete about 15 lines of the worksheet as in Figure 4.

1.	When we added	<u>zebras</u>	,	<u>grass</u>	<u>increased</u>	[increased / decreased / didn't change].
		Species 1		species 2		
2.	When we added	_____	,	_____	[increased / decreased / didn't change].	
		Species 1		species 2		

Figure 4: A worksheet to record changes in variables

Once finished with the game, the students created connection circles based on their observations. The teacher told the students, “Using your data, draw connections and label the arrows as +/- depending on the effect you saw.” This caused a bit of confusion, because in some cases students observed an increase in predators leading to an increase in prey (e.g. when adding zebras appeared to increase grass). This contradicted the connection circle at the start of class that showed that an increase in predators leads to a decrease in prey. Some students stuck to the prompt and created connections that reflected their data even when it went against what they knew about the predator/prey relationships. Others chose to ignore the data sheet, and made connections that made sense to them.

At the end of class, the students and the teacher discussed some of the “unexpected” results, such as the zebra/grass example. The students came up with several explanations for the zebra/grass puzzle. In one explanation, students hypothesized that zebras fertilize the grass (Figure 5). That would lead to a reinforcing loop, as indicated by the letter R.

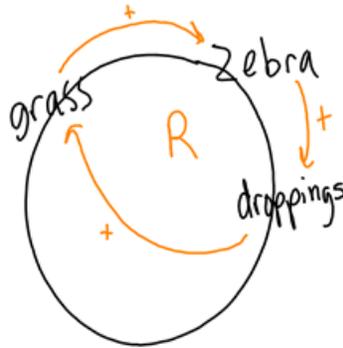


Figure 5: A connection circle to explain the zebra/grass puzzle

The teacher explained that the Food Fight game did not include fertilization, and therefore students had to look for alternative explanations. A student proposed that the answer to the puzzle had to do with the relative amount of grazing. He said: “Maybe zebras eat grass slower than it grows.” The teacher followed up on this explanation by drawing an analogy with caterpillars and trees. Trees feed the population of caterpillars and caterpillars reduce the population of trees by eating them. These relationships are shown in Figure 6 with positive and negative arrows respectively. Small self-loops show the reproduction reinforcing loops of caterpillars and trees. The teacher suggested that a small number of caterpillars in a large forest would not have a significant effect on the trees. That point was clear to students.

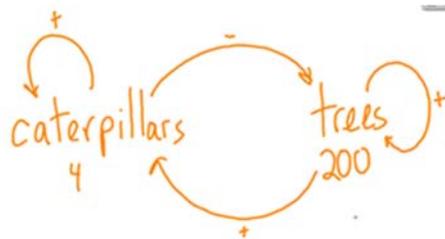


Figure 6: A connection circle created during Lesson 3

Lesson 4: Causal Loop Diagrams

During Lesson 4, the teacher first introduced the concept of causal loop diagrams. Causal loop diagrams explain system behavior in terms of the *system structure* by implying elements of the system (variables), causal relationships between them (arrows, positive and negative relationships), and feedback loops. Students continued by playing a physical activity called *Living Loops* (Figure 7). For this activity, the teacher attached strings to notecards that had

either a “+” or a “-” written on them. Students stood in a circle, holding hands. To experience a reinforcing loop, all students wore the “+” notecards, which meant that they had to match the signal they received from the other student. For a balancing loop, one student wore a “-” notecard, which meant that he had to flip the signal.

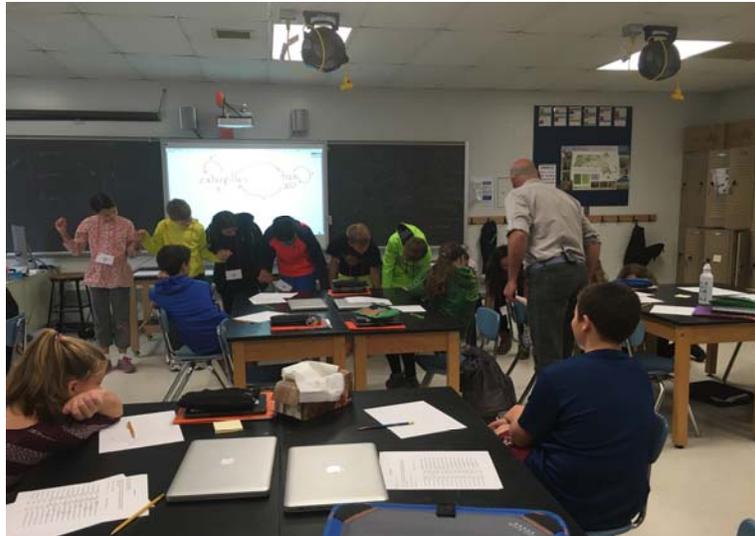


Figure 7: Students play the activity Living Loops during Lesson 4

After the Living Loops activity, the teacher asked if students could identify the feedbacks and reinforcing loops in the ecosystem of the Food Fight game. Most of the students were able to connect feedback loops to the ecosystem but others were having a tough time with it. Students especially had difficulty with identifying reinforcing loops. The teacher explained that many ecosystems are able to naturally balance themselves out, and balancing loops were generally easier to find. The teacher asked the students to identify balancing and reinforcing loops from their connection circles. After the students identified balancing loops from the connection circle, the teacher asked, “Did any of you find reinforcing loops?” Because there were no explicit reinforcing loops visible, the teacher explained possible reinforcing loops that can explain different behaviors of the game. For example, the teacher explained how the increase of the termite population could negatively influence the praying mantis population by decreasing their habitat, which can cause decrease in the dove population, which will decrease growth of grass, as there is less fertilization by dove droppings. While this relationship was not explicitly observable from the game, the teacher was able to describe possible reinforcing relationships in

the game in this manner. After running through examples in the small ecosystem, most of the class was able to understand what each loop entailed. However, a great number of students were still confused, indicating that it might be helpful to spend some additional time on feedback loops.

Lesson 5: Putting It All Together

Students played the game as pairs one more time. After the gameplay, the teacher asked the whole class, “Can you share some strategies for the game that you used, which included any of the things you learned about systems?” Students described different strategies that demonstrate their understanding of how to keep the ecosystem sustainable. For example, a group of students responded, “We came up with the strategy where we introduced enough plants to feed all other animals, so they don’t die out.” “We made sure all the animals have sufficient population, so they don’t die out.” Students suggested that some species, such as Ostrich, have fewer predators. Students noticed that bigger omnivores, such as Ostrich, Rhino, and Elephant, usually could get more points because nobody can eat them. Students used the scientific language of the ecosystem to describe the strategies they used. Examples of student expressions were: “I introduced predators that ate the other person’s species.” “When I first started I didn’t know how to play, but this time I am paying attention to predators and prey.”

Students also explicitly explained how they tried to use systems thinking tools that they had learned in order to win the game. For instance, a student said, “Mack and I are competitive, and back in my mind, I used the connection circle, and I imagined what would be negative for him. His species was the elephant and I knew that it was herbivore and I added another herbivore to decrease amount of food available to the elephant.” Another student said, “I tried to do a reinforcing loop with termite and grass, but praying mantis died too much. It was working otherwise.”

Implications and Future Work

From this implementation, both teachers and researchers recognized that the Food Fight game might require some modifications to incorporate fully all the elements initially specified for the framework. Because games often hide the underlying model (or do not allow users to interact with the model directly), they can limit users’ experience of manipulating different aspects of the model to fully understand systems behaviors. For example, for Food Fight, loops were not

directly observable; therefore, teacher had to explicitly explain feedback in the game. Overall, although the lesson accomplishes the goal of introducing connection circles and the connection circles led to some very interesting discussions, it was difficult for students to see how the connection circle relates to the game. Also some students wanted to know if their connection circles were right or wrong, particularly with respect to the mysterious “when zebras increase, grass increases” kinds of scenarios. It became clear that it is necessary to spend more time on the meaning of connection polarity. For example, we noticed that many students see the “+” sign and think addition. The idea that “Variable A --- (+) ----> Variable B” can mean “a decrease A causes a decrease in B” was not obvious to the students. In the future, this may need to be addressed explicitly. Similarly, we believe that the students may benefit from additional time and exercises to practice using the systems thinking language. In conclusion, from this implementation of a game-based curriculum that was guided by the GBSD framework, we could address the question of how systems dynamics practices could be used by teachers as a design tool. Overall, while teachers found the framework useful, many of the standard practices, such as Constructing Models, was difficult for teachers to fully incorporate in K-12 curriculum, because either it takes some time for teachers to become fluent with or it requires too much time for teachers to implement in their curriculum.

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