

# Learning to Model Ecosystems With Interaction Food Webs in Middle School Classrooms

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**Abstract:** Modeling is an important part of scientific practice that represents phenomenon but also allows for prediction and reasoning about systems. While students typically do not have issues with understanding simple linear relationships, difficulties arise when more complex relationships are introduced. Richer representational diagrams make visible the complexities within ecosystems and can help students better understand interacting forces. We co-designed an instructional sequence with software applications to support middle school students building interaction food webs as models of ecosystems. 48 students participated in the lessons and used the applications in groups of three to four students. 87% of groups were able to successfully produce an interaction food web. Posttests found that over 80% of students gave a completely or partially correct explanation, demonstrating reasonable proficiency in understanding interaction food webs. The results from each step of the instructional sequence are discussed with respect to the curriculum and technology design.

## Introduction

Modeling is increasingly being recognized as an important aspect of scientific literacy and practice. According to the Next Generation Science Standards (NRC, 2012), students can begin developing and using models as early as Kindergarten (at age 4-5). They recommend that by middle school (age 11-12), students progress to constructing, using, and revising conceptual models to communicate their understandings and making predictions about more abstract phenomena. Used to represent real-world phenomena (yet not corresponding completely), models are abstractions that allow scientists and students to test theories and develop a better understanding of complex systems (Schwarz et al., 2009). Expressed models (as opposed to mental models) can take on several different forms, including schematic diagrams, physical replicas, mathematical representations, analogies, and computer simulations (Baek et al., 2011; Gobert & Buckley, 2000). Examples of scientific models include molecular models, weather systems for predicting weather patterns, the water cycle model, and food web models that highlight interactions between organisms. All of these not only represents phenomena but also allows for prediction and reasoning about real-world systems (Schwarz et al., 2009; Soloway et al., 1995). For example, building a food web that models an ecosystem not only demonstrates student understanding about an ecosystem, it can also foster deeper understanding of how different organisms relate to one another during the construction process. Once created, students can use the food web to make predictions about how one species' population can affect others within the model. However, studies have demonstrated difficulties learners encounter with understanding relationships within systems (Gallegos, Jerezano & Flores, 1994; Mandinach & Cline, 1994). While students typically have no trouble understanding single causal and linear connections, relationships within systems pose a bigger challenge (Ben-Zvi Assaraf & Orion, 2005; Grotzer & Basca, 2003; Hmelo-Silver, 2007). In the case of food webs and ecosystems, students generally understand predator-prey food chains quite well but have difficulty interpreting food web dynamics if two populations are indirectly related (Gallegos, Jerezano & Flores, 1994). When examining food webs some students think about species relationships on an individual level rather than on a population level (Griffiths & Grant, 1985).

Richer representational diagrams can make visible the complexities within ecosystems and have potential to help students attend to multiple interacting forces within the system. Some ecologists use interaction food webs to represent relationships amongst species (Hui, 2002). In traditional food webs, arrows between species indicate the direction of energy transfer, whereas in interaction food webs, each set of relationship is depicted by a pair of arrows, with each arrow accompanied by + or - symbol (Figure 1). The symbol denotes the resulting population effect of the species the arrow is pointing *at*, should the population of the species the arrow is pointing *from* increases (e.g., Rabbit  $\text{---}(+)\text{---}$  Wolf may be translated as, if the rabbit population increases, it will have a *positive* effect on the population of wolves). Not only can an interaction food web represent feeding relationships, it can also express competition and mutualistic relationships within ecosystems. Since the semantic meaning of the arrows are tied directly to population effects, the building and using of interaction food webs are coupled tightly to the practice of making predictions. Once students learn how to read and build interaction food webs, the representation has potential for supporting students' reasoning around complex

ecosystems. Along with science teacher partners, we co-designed an instructional sequence and accompanying software applications for middle school students in order to support students' reasoning around interaction food webs. This paper describes the curriculum design, technology design, and the outcomes of student learning.

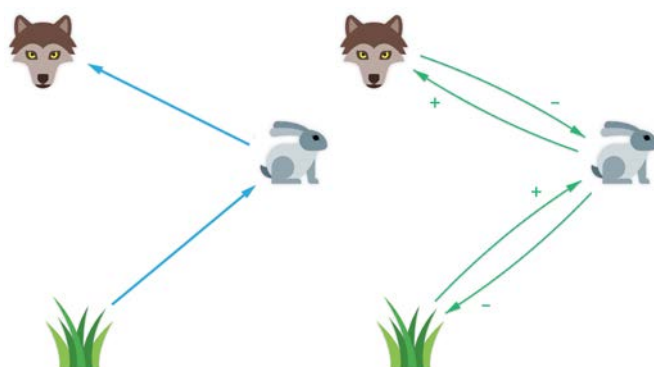


Figure 1. Example of traditional food web (left) and interaction food web (right).

## Related work

A number of prior studies have addressed modeling for students to understand ecosystems. The ScienceWare Model-It is a learning environment that allows high school students to study natural phenomena (such as a stream ecosystem) for building dynamic qualitative and quantitative models (e.g., visualizing relationships between phosphate on stream quality) in planning, building, and testing modes (Jackson et al., 1996). Qualitative results showed that scaffolding within software design supported model construction and that students created models of reasonable complexity and sophistication expected of their grade level. In another study, authors found that most students engaged in cognitive strategies such as analyzing, relational reasoning, synthesizing, testing and debugging, and explaining while using Model-It, however additional support is needed for all students to progress beyond superficial relationships (Stratford, Krajcik, & Soloway, 1998). In Aquatic Ecosystems, a two-week intervention with 311 middle school students, students participated in a technology-supported inquiry unit organized around structure, behavior, and function (SBF; Hmelo-Silver et al., 2014). Modeling technology supports included NetLogo simulations, and an Aquarium Construction Toolkit modeling application. Students significantly improved their understanding of the aquarium ecosystem in terms of structure, behavior, and function, as well as micro and macro relationships. Authors attribute the success of their unit in part to the use of a distinct conceptual representation that allows students to adopt the SBF conceptual framework into their language for expressing complex ideas about ecosystems. While the Model-It studies highlight the need for scaffolding and curricular support around modeling, research on Aquatic Ecosystems demonstrate success with representations that reinforce language for expressing complex ideas. Our instructional sequence and technology design takes the above findings into consideration, and is an example of an additional curricular support designed around providing students with representations and language for model building and reasoning.

## Wallcology

The designs described in this paper are created as part of the Wallcology unit, in response to challenges students encountered in a previous iteration (Slotta, Lui, Cober & Moher, 2017). The larger project centers on a complex phenomenon embedded in the physical classroom environment (e.g., walls), providing an evidentiary base for student inquiry. In the Wallcology phenomenon, simulations of fictitious organisms are “embedded” in the classroom walls. “Wallsopes” (i.e., computer monitors) provide internal views of the walls that reveal different ecosystems of varying abiotic (wood, plaster, and brick) and biotic components (vegetation, herbivores and predators). An underlying computational model developed in consultation with an expert population biologist governs these species and their environmental conditions. Student groups observe and perform investigations on specific ecosystems, with each ecosystem inhabiting a subset of species (e.g., 4-5) that make up a cohesive community of species (e.g., 11 species). Students are guided by collective inquiry activities (Cober et al., 2012) in order to model all of the species' relationships as a class – with the complete set of relationships across all of the species in the community discoverable only by aggregating everyone's observations and investigation finding. In the previous iteration, students had difficulties creating food webs and models, which took curricular time intended for students to actually work with their models.

Building upon prior research on modeling ecosystems and our own past experiences implementing the Wallcology unit, we designed explicit supports for modeling, including tablet applications where students explore feeding relationships, competition and indirect relationships (e.g., effects along a trophic cascade) before they begin engaging with the Wallcology simulation. Understanding that food chains must be taught not as a simple set of isolated organisms, but as an interactive population embedded in an ecological context (Gallegos, Jerezano & Flores, 1994), and that elementary-school students have capability to develop systems thinking skills (Evagorou et al. 2009), we developed an instructional sequence for modeling ecosystems based on an interaction food web representation. This paper describes this curriculum and technology. Our aim is to help students understand complex ecosystems, and to give students the tools to successfully make predictions and reason around food web models. The research questions that drive the current study include: (1) how well can middle school students understand and build interaction food webs? And (2) to what extent can they make predictions and reason around relationships depicted within interaction food webs?

## Methods

This research employs a design-based methodology, characterized by iterative cycles of design, evaluation and revision of an intervention for study in authentic classroom settings (Brown, 1992; Design-Based Research Collective, 2003). Researchers and two high school teachers developed curriculum activities, content materials and specialized software using a co-design method (Penuel, Roschelle, & Shechtman, 2007). The study described in the current paper took place in private urban middle school in Chicago across three Grade 6 Science classes, which were taught by one of the co-design teacher partners. A total of 48 students (aged 11-12, with 16 students per class) participated in the lessons in groups of three to four during their regular science class over a period of two days. Each class period ranged from 50 minutes to 1 hour and 50 minutes, depending on the class and day. A posttest was conducted in the class period following day 2. Several data sources were used in the analysis: the models the students constructed, software-generated log files of each group's activities with the application, and audio and videotapes of student discussions and class activity.

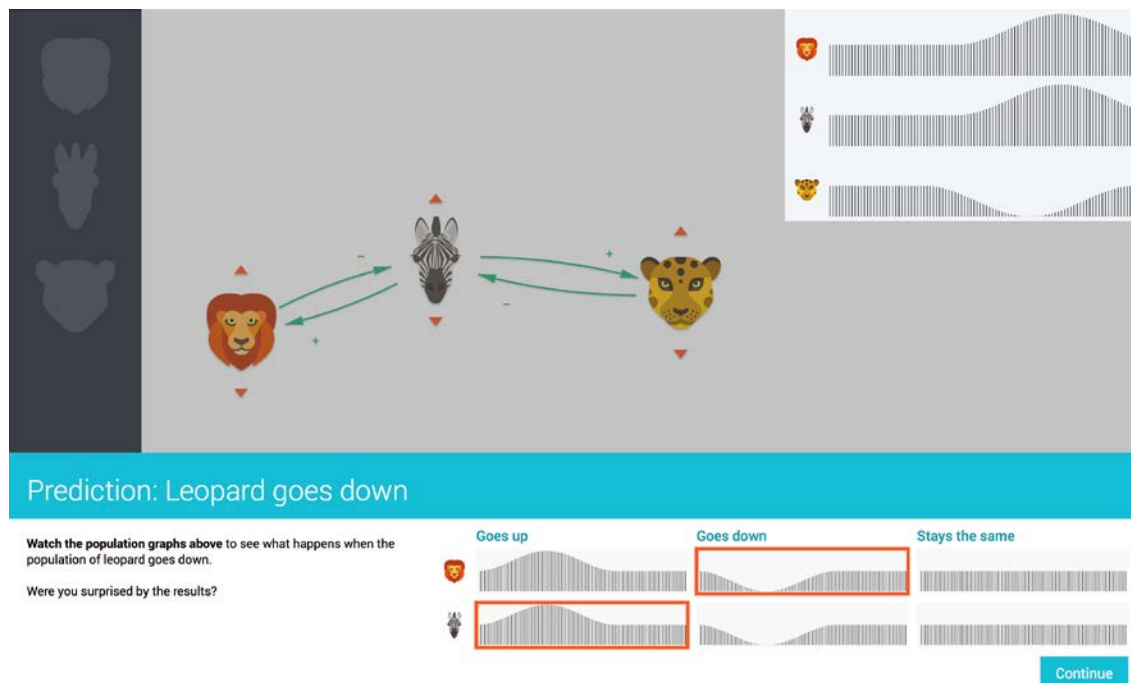
## Design

### Day 1: Introduction to interaction food webs

On day 1, students worked in groups of three to four (five groups per class) to learn about the interaction food web representation using a custom software application. Each group was provided with a laptop computer. There are four stages in the program, taking groups through successively complex relationships (Table 1). The first two stages guided students through with step-by-step instructions, while the latter two stages allowed students more latitude to explore various relationships and meaning of + and - symbols. At each stage, a palette on the left is populated with recognizable species (e.g., lion and zebra). As students dragged species into the work area, a graph depicting its population over time is revealed. When species that are related to one another are placed on the work area, arrows are automatically established. The work of the student then, is to make changes to species populations. Up and down arrows for each species are made available (i.e., increase or decrease populations respectively). When a population manipulation is attempted, students are tasked with making predictions about the population effects on the other species in the work area. Only then will the population graphs reveal the resultant effects (Figure 2).

Table 1: Stages in introduction to interaction food web application (day 1)

Level	Aim	Species Available
1	To explore population effects with food chains	Lion, zebra
2	To explore population effects with interaction food webs notation	Lion, zebra
3	To explore population effects with interaction food webs (feeding relationships only)	Lion, zebra, leopard
4	To explore population effects with interaction food webs (feeding and competition relationships)	Lion, zebra, grass, acacia tree



**Figure 2.** Introduction to interaction food webs software interface (level 3). The application shows a prediction panel (which pops up from bottom) when students select a manipulation of species population. In the screen above, the red ‘down’ arrow below the leopard has been selected, indicating that an attempt was made to decrease the leopard population. Once predictions about lion and zebra population have been made, students can compare their answers with the animated population-over-time graphs (top right).

## Day 2: Modeling with interaction food webs

On day 2, students worked in newly formed groups of three to four (five groups per class) to build their own interaction food webs using a modeling application on a tablet computer (Figure 3). The modeling application is based on the software design from day 1, with differences being that: (1) students could choose the relationships they wished to depict and (2) non-specific “species” (i.e., shapes to represent species) were used in place of recognizable species. Similar to the application on day 1, up and down arrows were made available for each species, and when a population manipulation is attempted, students were tasked with making predictions about the population effects of other species in the work area. Once completed, the population graphs reveal the ensuing effects. Students explored the meaning of + and – of relationship arrows through an iterative process of prediction and revision. Each group was assigned four different sets of species examined during their recent field trip to a local ecosystem (e.g., sanderling, Karner blue butterfly, butterfly milk weed) and was asked to create a traditional food web (with energy transfer arrows). Then, using the modeling application, they were to determine the correct relationship representations and expand the basic food web into an interaction food web. The instructional sequence concluded with group presentations of population interaction web and class discussions about population effects of the species.



**Figure 3.** Students working with the modeling application on day 2.

## Results and discussion

### Day 1: Introduction to interaction food webs

As groups (n=15) worked through each level, they made predictions about population effects when they manipulated another species' population. The accuracy of groups' predictions was used to evaluate their performance. The mean prediction accuracy was 81.27% (SD = 13.35%), broken down by level in Table 2.

Table 2: Prediction accuracy on day 1

Level	Performance Accuracy (%)	SD (%)
1	86.71	18.66
2	91.22	16.58
3	79.73	21.68
4	76.06	17.72
Average	81.27	13.35

Given the difficulty of the tasks, taking into consideration the relative young age of the learners, these results are promising. Prior studies noted that the concept of populations of organisms in the wild is established in children older than age 13, but remains challenging for them to reason about how populations depend upon each other and compete with one another (Driver et al., 1997).

Further examination of students' performance pattern over successive levels, reveals that groups with the highest accuracy scores in levels 3 and 4 also attained 100% in the first two levels (top four groups). However for groups with the lowest scores in levels 3 and 4, their averages in levels 1 and 2 ranged from 60% to 100% (bottom four groups). Students' group discussions during the activity suggested that they were using what they know about the species to discuss population changes (e.g., "lions eats zebras, so when there are more lions there are less zebras"). They had to make predictions, and were excited when their population relationships matched what the population graphs showed. There was little evidence of students attending to the arrows or the symbols on day 1, but additional video analysis is underway to understand groups' performance patterns over the course of the activity.

### Day 2: Modeling with interaction food webs

Students presented their final interaction food webs in groups, with each student taking a turn at explaining what would happen to the population of one species if the population of another species increased or decreased. Most students were able to correctly explain population effects. With respect to the interaction food webs that groups presented (Figure 3), 87% of the groups were able to produce a completely correct or partially correct interaction food web, 67% (10 of 15 groups) produced completely correct interaction food webs, 20% (3 groups) had minor errors, 2 groups neglected to include a symbol on one of the arrows but the representation was otherwise correct. 1 group reversed the symbols for one set of relationship, and 13% (2 groups) were unable to produce an interaction food web, instead presenting a traditional food web (Figure 4).

During class discussions, several students were active in debating the validity of their models. In one scenario, students discussed what would happen if one of two prey populations of a predator suddenly disappeared? One student suggested that the predator population would also decrease which would lead to the remaining prey population to thrive (since their predator population decreased). Another suggested that the predator population would simply make up more of its diet with the remaining prey population, which would result in a decreased population of the remaining prey population. This discussion led to the class discussing issues about the model being a simplified representation of the actual system, and that in reality, there would be other factors involved (such as how prevalent are each of the species' populations? How much of the predator's diet is made of one prey species vs. the other?). These discussions further demonstrated the students' sophistication in understanding interaction food webs as models of ecosystems and their ability to reason around them. Furthermore, the language that students used throughout their presentations and class discussions was indicative of their thinking about ecosystems on a population level rather than on an individual species level.

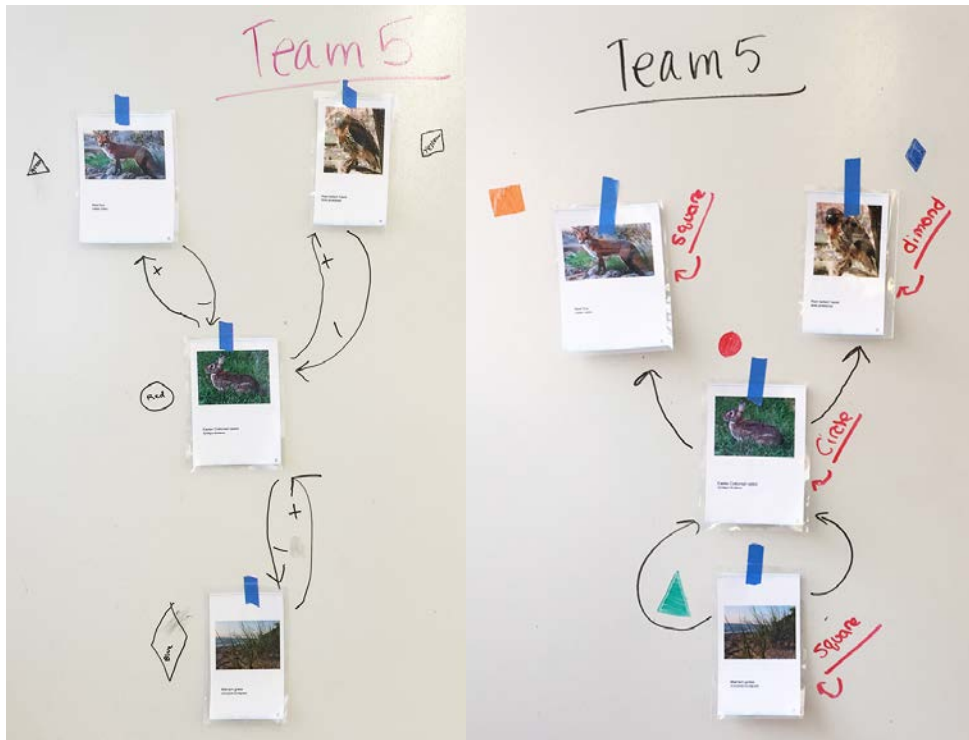


Figure 4. Examples of group interaction food webs. Correct version (left). Incorrect version (right).

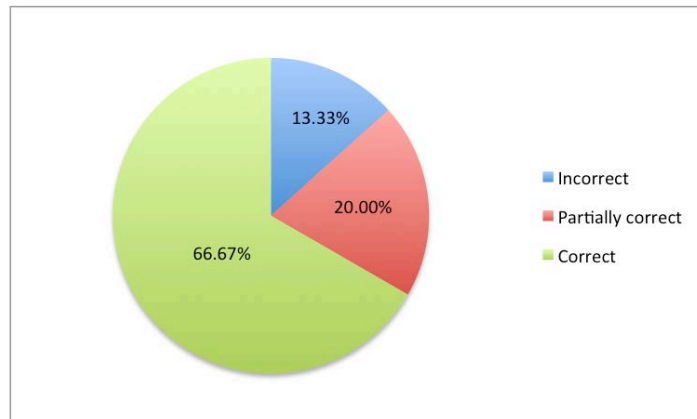


Figure 3. Accuracy performance of group interaction food webs.

## Posttest

41 students completed the posttest, in which students were asked to build a model of an interaction food web consisting of square, triangle, circle and diamond "species" and explain population effects from changes in two different populations. For example, if the population of triangles suddenly disappeared, what would happen to the square population?

A composite scoring was assigned based on whether both answers were correct, incorrect, or incomplete. The test was scored as correct if both explanations were correct, partially correct if one of the answers was correct, incomplete if explanations were not provided in both answers, incorrect if both explanations were incorrect. Results showed that over 80% of students gave a completely or partially correct explanation, demonstrating some level of understanding. Further breaking down results, 60.98% offered correct explanations, 19.51% offered partially correct explanations, 9.76% of the explanations were incomplete, and another 9.76% of explanations were incorrect (Figure 5).

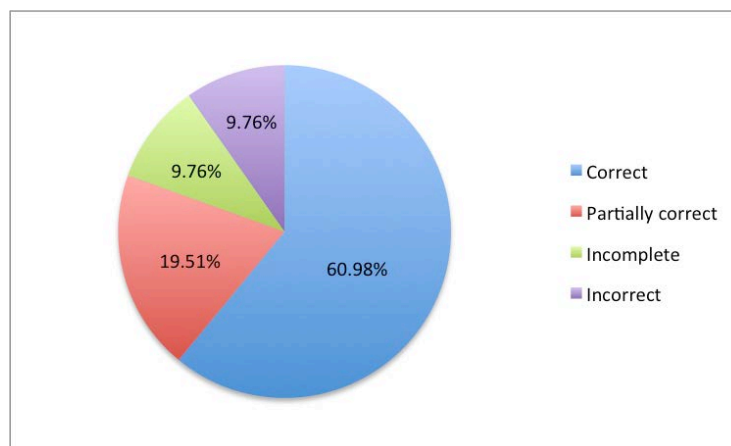


Figure 5. Frequency of explanation performance of posttest questions (n=41).

Of the students who produced incorrect or incomplete explanations (n=8), only one belonged in low performing groups on both day 1 and day 2 (defined as groups with lower than average performance scores on day 1, and groups who were unable to complete an interaction food web on day 2). Three students belonged in low performing groups on day 1, and the remaining students in this cohort belonged in high or average performing groups on both days. This suggests that these students may have missed core concepts learned on day 1.

Of the students who produced partially correct explanations (n=8), three students belonged in average performing groups on day 1, with the remaining students belonged in high performing groups on both days, echoing possibility that these students may have missed core concepts learned on day 1. Of the students who produced correct explanations (n=25), the majority 76% (n=19) belonged to high or average performing groups on both days. More than half (56%) belonged in high performing groups, however there were still some students who belonged to low performing groups, including: 3 (12%) who belonged in low performing groups on day 1 and 3 (12%) who belonged in low performing groups on day 2. It is possible that these students gleaned important information from the discussions that occurred during presentations, but further analysis will be conducted in order to understand these students' learning progressions.

## Conclusions

The majority of groups were able to successfully produce an interaction food web and analysis of posttest explanations found that over 80% of students were able to give completely or partially correct explanations about population effects along a trophic cascade. These results demonstrate that middle school students were able to attain reasonable proficiency in understanding and building interaction food webs. Students adopted appropriate language in discussing their interaction food webs, highlighting their predictions of population change throughout their presentations and class discussions. Given the complexity and abstract nature of the symbols at the heart of interaction food webs, these results suggest that, with proper scaffolding, middle school students may be capable of even more sophisticated systems thinking. A follow-up study of the Wallcology unit will reveal if students were successful in translating what they learned with the instructional sequence and technology applications described in the current study – to effectively build models and make predictions about much more complex ecosystems.

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