EcoGEM: Developing Ecological Systems Thinking Through Interactive Food Web Simulations

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Problem Area

In Ontario's Grade 6 science curriculum, students build on their understanding of biodiversity by analyzing the interrelationships within and between species. In previous grades, students are exposed to food chains and predator-prey relationships that are linear and simple. As students progress through the grades, there is a shift to a dynamic and complex perspective that becomes increasingly difficult for students to grasp. Even as food chains become food webs, students often depict a single example of each organism which reinforces this one-way relationship mental model. As a result, many students are only able to offer linear explanations. When looking at a forest ecosystem a student is more likely to indicate that, "the fox might eat all the rabbits and will have no food left over", rather than considering feedback loops or the stabilizing impact of diversity across the fox's ecosystem. Even when exploring invasive species, many students would typically identify a single direct impact: "it will ruin the native vegetation". Altogether, as these patterns emerge they point to a broader misconception: in middle school, students rely on overly simple, linear mental models of ecosystems and have not yet developed the "systems thinking" that is needed to understand biodiversity as a dynamic, interconnected system. The next sections review key research findings on ecosystem misconceptions and systemic reasoning.

Through a simple set of questions, Webb and Boltt (1990) examined how secondary students (ages 15-17) understood the relationship between food chains and food webs. Their findings demonstrated that even older learners tended to interpret food webs as a series of disconnected, mini food chains rather than as networks of interdependent species. Drawing on the work of Griffiths and Grant (1985, as cited in Webb & Boltt, 1990), they noted several persistent misconceptions: that only predator-prey pairs influence one another, that organisms higher in the web feed on all species below, that changes in prey do not affect predators, and that populations "too far apart" on the web have little or no effect on each other. What makes Webb and Boltt's (1990) findings particularly relevant is that they found no substantial differences across grade levels, suggesting that if systemic biology concepts are not well established in earlier years, these misconceptions can persist as students move through the grades.

A key reason students struggle to move beyond linear models is that systems thinking develops gradually over time. Hokayem and Gotwals (2016) looked to develop a learning progression for systemic reasoning in early elementary students. In interviews with 44 students from grades one through four, they asked them to reason about predator-prey relationships, population changes, and ecological interactions. After coding student responses, they constructed an empirically grounded learning progression (LP) to capture recurring patterns and shifts in how young learners think about ecosystems. Level 1 reasoning is anthropomorphic or concrete, Level 2 reasoning is making simple, localized causal links, and Level 3 reasoning is characterized by beginning the recognition of multiple interactions. Higher levels involve more integrated, dynamic system explanations. Levels 4 and 5 reflect increasingly "integrated" reasoning, where students demonstrate the ability to coordinate multiple causal relationships. They are recognizing ecosystems as dynamic networks in which reciprocal effects and biodiversity interact to shape system behaviour over time. Hokayem and Gotwals (2016) recognize that the LP is not a throughline. They found that students used mixed-level reasoning, where a student might give a Level 1 explanation in one context and a Level 3 explanation in another. This type of complexity aligns with findings by Zohar and Ginossar (as cited in Hokayem & Gotwals, 2016), who showed that even high school students sometimes rely on the anthropomorphic language (categorized as Level 1) because it is easier for communicating emerging ideas - not necessarily because the student has a conceptual misunderstanding.

Finally, to build on the learning progression of systems thinking in the biological context, it is pertinent to examine the work of Eilam (2012) who helps illustrate why understanding ecosystems is so challenging for students. The author focuses specifically on students' understanding of "feeding relations," which extend the familiar food chain and food web representations into a more systemic view of how populations influence one another. Her analysis draws on a yearlong study of grade nine students who investigated a live ecosystem mode of choice (an aquarium, terrarium, or greenhouse) through sustained observation, manipulation, and inquiry activities. Students' written explanations and interview responses were analyzed to trace how their ideas about feeding relations developed and where systemic reasoning continued to break down. Four foundational ideas needed to develop a systemic view of ecosystems were identified: understanding how matter and energy cycle, recognizing dynamic states like equilibrium, coordinating causal interactions across system levels, and applying temporal and spatial reasoning. According to studies reported by Eilam (2012), research across biological domains shows that these ideas are consistently underdeveloped in children and even in both pre-service and even experienced teachers. Eilam's (2012) own findings showed that even after a full year of inquiry with live ecosystem models, students' systemic understanding remained partial and fragmented. A key difficulty she notes is that students rarely recognize feedback loops, which are essential to understanding how ecosystems maintain or lose stability. For example, students don't recognize a "stabilizing negative feedback loop": an increase in rabbits may initially boost the fox population, but as foxes consume more rabbits, the rabbit population drops again, eventually leading to a decline in foxes. Students tend to focus on only the immediate, visible consequences.

Together, these findings reflect a deeper struggle to communicate and understand the complexities of relationships in an ecosystem. For many middle school students, this means they enter the biodiversity unit able to identify organisms and draw feeding relationships, but are still lacking the systemic understanding needed to interpret ecological change, stability, or resilience. These studies show that overcoming linear reasoning requires learning environments that confront students' existing models, make system dynamics visible, and support the development of more integrated explanations.

Design of a Learning Experience

Students' difficulties with understanding ecosystems as dynamic, interdependent systems necessitate the development of learning environments that make hidden processes visible, allow students to test and revise their ideas, and support the movement from linear to systemic reasoning. Late-elementary and early-middle school students' interpretation of linear food webs reveals that static diagrams often hide the depth of relationships in an ecosystem and can contribute to surface-level reasoning (Preston, 2018) which reinforces the need for interactive models. Exploratory work on model-based instruction shows that when students work with dynamic representations of food webs, they begin to recognize indirect effects, population-level changes, and interactions that aren't obvious in static diagrams (Lui & Moher, 2017). Similarly, research on computational food web modelling demonstrates that students also improve computational thinking when they are able to manipulate variables, observe population changes, and evaluate the difference between their predictions and the model's behaviour (Rachmatullah & Wiebe, 2021). A technology-enhanced learning environment (TELE) grounded by the T-GEM pedagogical framework (Khan, 2010) can be used to address common systemic challenges because it affords students the opportunity to speculate, engage directly with the depth and complexity of ecosystem interactions, and then modifying their existing mental models.

The digital simulation tool chosen for this TELE is the Annenberg Ecology Lab simulation, an interactive food web model that allows students to add or remove species and adjust feeding relationships while observing population changes over time. The tool displays both a field animation view and real-time population graphs which enables students to see interactions unfold across days of simulated time. This environment visualizes the consequences of competition, predation, resource depletion, and possible trophic cascades or "domino effects" as measurable patterns. This TELE is a three-lesson sequence that progressively increases the complexity of ecological relationships students encounter. Before Lesson 1, a brief orientation session allows students to freely explore the simulation interface and identify key features. This aligns with teacher observations reported in Khan (2010), who noted that explicit introduction to a tool's functions would support more focused inquiry during GEM cycles. In Lesson 1, students explore competition and coexistence among producers and a single herbivore. Lesson 2 extends this thinking to multi-trophic relationships by comparing simple food chains to full food webs. Lesson 3 introduces an ecological disturbance, modelling the behavioural signature of invasive species. The sequence is intentionally scaffolded for students to iteratively test ideas, observe unexpected outcomes, and then revise their explanations as their models evolve. As the study of biodiversity involves interactions between living things, a digital simulation also demonstrates a socially responsible way to "experience" detrimental ecological interactions.

The design is informed by the T-GEM (Generate, Evaluate, Modify) pedagogical model proposed by Khan (2010). Each activity is anchored in cycles of prediction, evaluation, and the refinement of hypotheses so that students continuously refine their mental models. By iterating through the GEM cycle, students move from the original linear/static understanding to a dynamic understanding of coexistence and competition. In her 2007 study, Khan noted that student construction and revision of molecular models via a GEM cycle approach contributed to the construction and revision of mental models. The Annenberg Learner simulation, when approached through a GEM framework, explicitly demonstrates a process students wouldn't be able to observe, allowing them to visualize the passage of time and interdependent species relationships that static diagrams cannot convey (Khan, 2010). The T-GEM pedagogical model of inquiry is supported by previous literature on model-based inquiry and digital learning environments. Research by White and Frederiksen (1998) demonstrated that students develop stronger scientific explanations when they iteratively compare predictions with the behaviour of dynamic models. Similarly, knowledge-integration work by Linn, Clark, and Slotta (2003) illustrates that students learn more effectively when their thinking is made visible and revisable. Adding technology and digital simulations can play a central role in this process because they externalize system behaviours that students cannot easily observe, and with proper guidance, they afford the opportunity for learners to notice discrepancies between their mental models and the system's actual dynamics (Khan, 2010). Overall, using the T-GEM pedagogical framework mirrors the systems-thinking skills that this TELE aims to develop. Students will be asked to notice patterns, tracing causal relationships between species, and update their current understanding of how interactions play out on a larger system level.

Finally, there are important caveats to note. First, the study of biodiversity involves more than just biotic factors, but the influence of abiotic factors as well. The simulations in this TELE do not replicate that. It is important to follow up these lessons with an opportunity to experience the relationship between the biotic and abiotic factors, such as a chance to design a fully functioning aquarium. Second, there is a risk that simulations may oversimplify the work researchers do to observe such patterns in nature. As noted by a participant in Khan's (2010) study, students may mistakenly assume that ecological science happens in a neat and predictable way, instead of the often uncertainty that comes with studying nature. This is combined with the added impact of time compression, which is both a benefit of technology and a factor to be aware of. Finally, the simulation used lacks species diversity which can still contribute to an oversimplification of ecological outcomes when compared to the vast amount of interactions that occur naturally.

Pedagogical Goals

The overarching purpose is to help students move from mostly linear and one-directional explanations toward more systemic ecological reasoning. The TELE has three central pedagogical goals that leverage the affordances of digital simulation to support student success with the problems identified. The following is a breakdown of each goal, the specific problem they address, and the criteria used to assess the impact of the experience. The success criteria are guided by the learning progression outlined by Hokayem and Gotwals (2016) which helps distinguish between linear, surface-level explanations and the more integrated, system-level reasoning that the TELE is designed to develop.

Pedagogical Goal 1

Problem. Students rely on one-way, linear descriptions of ecological relationships and often misinterpret competition and simple interactions in food webs.

Learning Goal. Students will be able to accurately describe two-way relationships between species by identifying how the introduction of a consumer changes the competitive balance between producers. (Supported by Hokayem & Gotwals, 2016; Webb & Boltt, 1990; Preston, 2018)

Success Criteria. In lesson 1, students will identify two population-level changes that occur when Herbivore A is added (e.g., “Plant A decreases, then stabilizes,” “Plant B increases once competition changes”). Students will also describe how Herbivore A modifies the competitive relationship between Plant A and Plant B (e.g., “The herbivore keeps Plant A in check, allowing Plant B to survive”). Finally, students will provide a two-step causal chain showing accurate linear reasoning (e.g., “Herbivore A reduces Plant A therefore Plant B grows due to reduced competition”).

Pedagogical Goal 2

Problem. Students struggle to coordinate more than one causal relationship and often focus on only the most immediate, visible effect.

Learning Goal. Students will be able to trace and explain multi-step causal interactions in a food web by predicting and interpreting patterns across multiple trophic levels. (Supported by Hokayem & Gotwals, 2016; Webb & Boltt, 1990; Eilam, 2012)

Success Criteria. By the end of lesson 2, students will identify at least two interactions happening simultaneously when the full food web is activated (e.g., “Herbivore A decreases while Omnivore A increases”). Students will compare their prediction to simulation output and revise their explanation using specific graph-based evidence. Lastly, students will explain a multi-step interaction (e.g., “Plant A drops, so Herbivore A declines. Then, after more time Omnivore A declines), showing Level 3 reasoning (Hokayem & Gotwals, 2016

Pedagogical Goal 3

Problem. Students rarely recognize feedback loops or “cascading” effects in ecosystems which lead to oversimplified mental models of ecological change.

Learning Goal. Students will be able to identify and explain feedback loops and “cascading” effects by modelling the introduction of an invasive species and interpreting population-level outcomes over time. (Supported by Eilam, 2012; Hokayem & Gotwals, 2016)

Success Criteria. By the end of lesson 3, students will identify at least one stabilizing (negative) feedback loop or amplifying (positive) loop using simulation evidence (e.g., “Herbivore C reduces Herbivore A, and then Omnivore A decreases later”). Students will revise their model or food web to include new relationships revealed by the disturbance. Students will provide a multi-step explanation that references both a graph trend and the food web structure (e.g., “Species C enters which causes X, then Y, resulting in Z”).

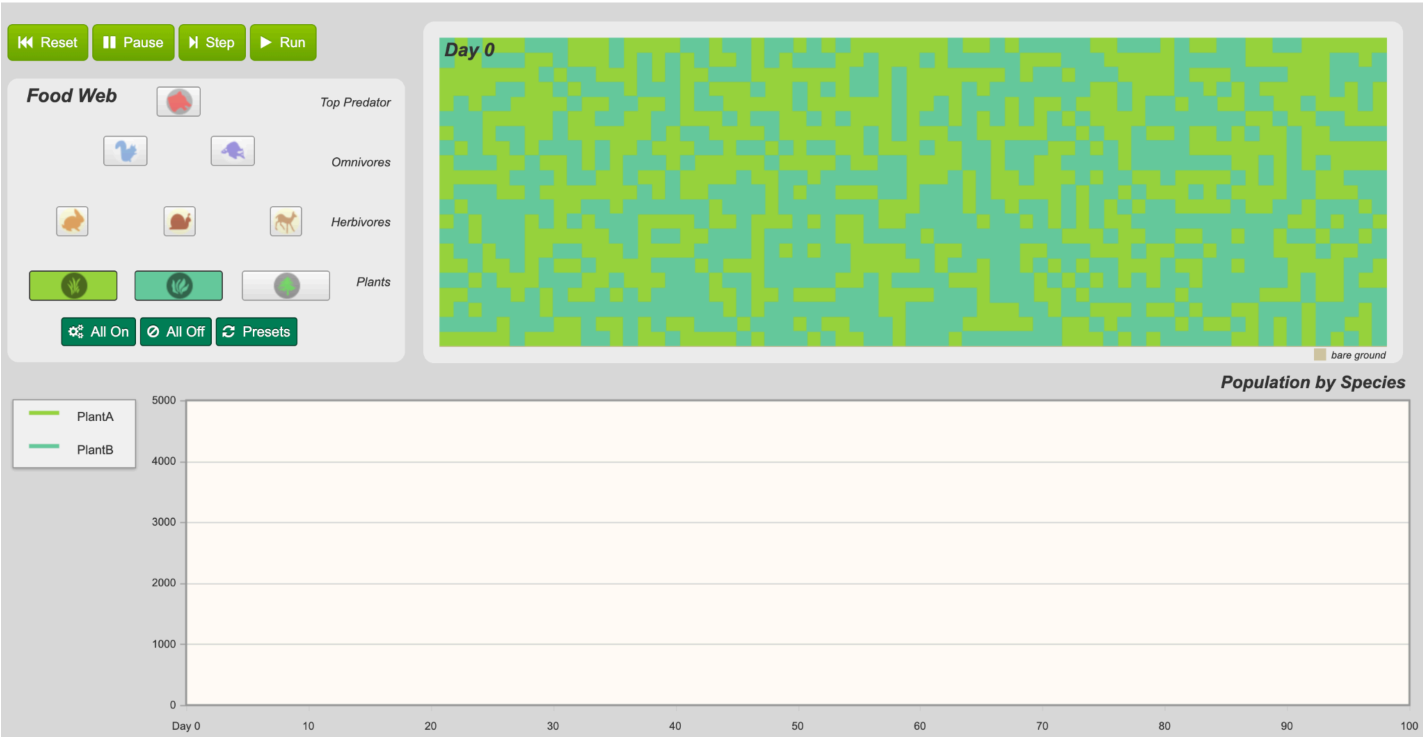
Digital Technology

Annenberg Learner Ecology Lab

The Annenberg Ecology Lab simulation (Figure 1) is an interactive food web model that allows students to add or remove species and adjust feeding relationships while observing population changes over time. The tool displays both a field animation view and real-time population graphs which enable students to see interactions unfold across days of simulated time.

Figure 1

Overview of Ecology Lab Simulation

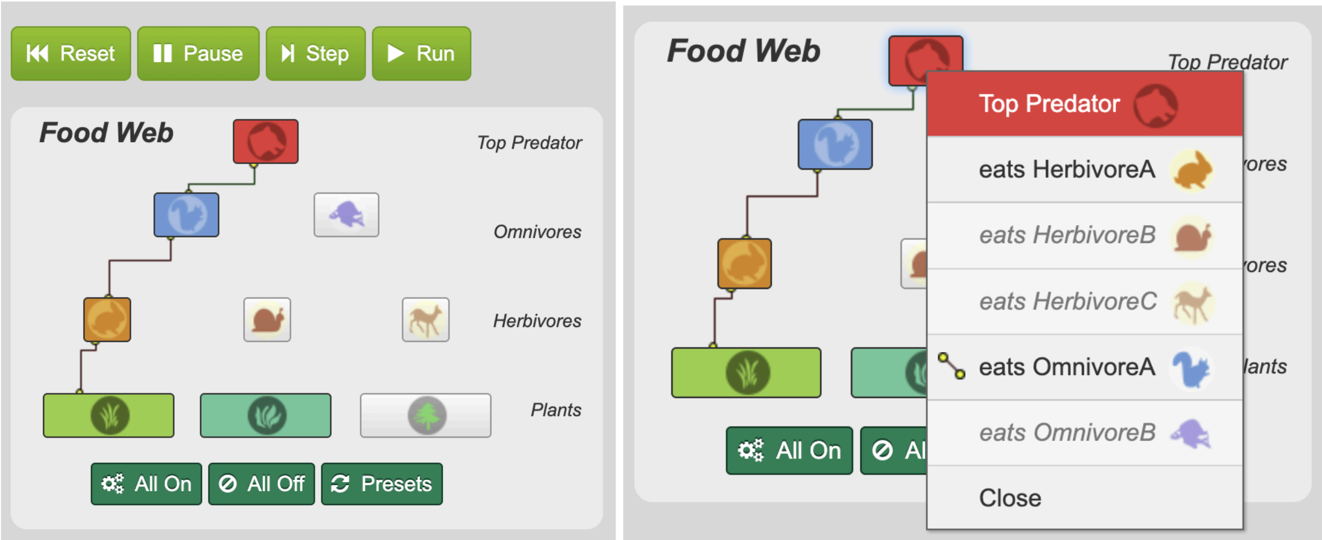


Note: Screenshot from Annenberg Learner. (n.d.). Ecology labs: The producers [Interactive simulation]. https://www.learner.org/wp-content/interactive/envsci/ecology/producers.html

The Food Web Controller area of the tool (Figure 2) shows the species in the food web and how they can interact. There are four levels displayed in the controller area: plants (with 3 unique producers), herbivores (3 unique animals), omnivores (2 unique animals), and one tertiary consumer or "top predator". Each species button allows users to add them to the simulation. As users move "up" the food web, the activation of a species gives them the choice of how it will interact with the species below it. For example, if users turn on Plant A and Plant B, and then activate Herbivore A, they will be prompted with the choice to have it consume Plant A or Plant B. Lines will appear between species that are interacting with each other. Animal species survive by eating other species. Herbivores, as the nomenclature suggests, may only eat the plants, while the top predator is a carnivore and may eat any other species other than the plants.

Figure 2

Food Web Controller

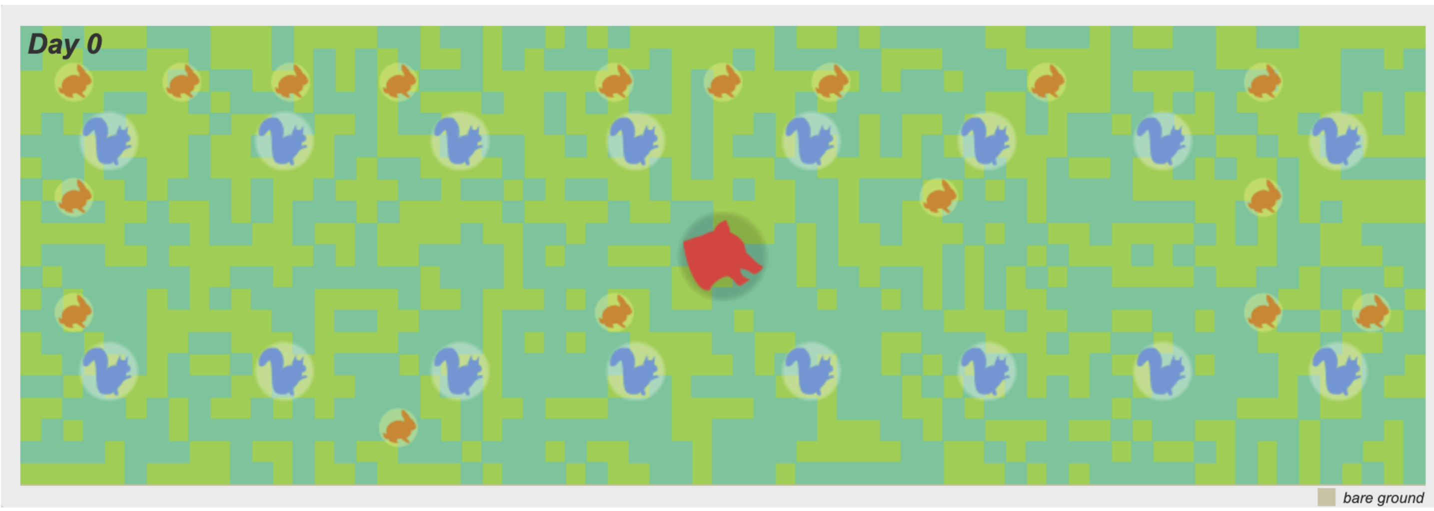


Note: Screenshot from Annenberg Learner. (n.d.). Ecology labs: The producers [Interactive simulation]. https://www.learner.org/wp-content/interactive/envsci/ecology/producers.html

Once users have selected their interactions within the system, they are able to click the Run button to start the simulation. The first time users click "run", the simulation will play out for 100 days. Users can pause the simulation at any time or can click "Step" to initiate the next 100 days. Once the simulation is running, two different views show what is happening in the system. First, there is a field animation view (Figure 3). Plant species are represented by coloured squares and animals are represented by icons. The colours and icons match those used in the population-time graph.

Figure 3

Field Animation View

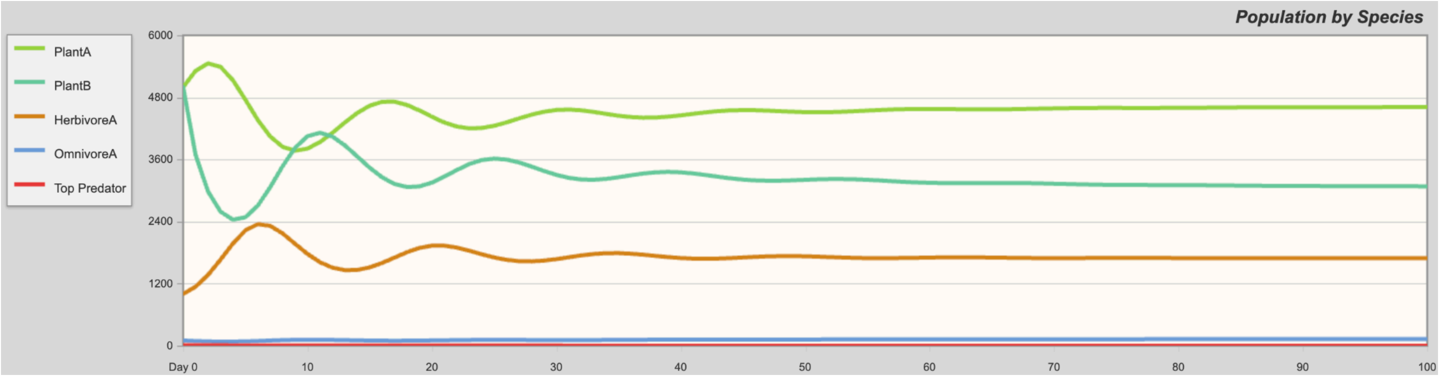


Note: Screenshot from Annenberg Learner. (n.d.). Ecology labs: The producers [Interactive simulation]. https://www.learner.org/wp-content/interactive/envsci/ecology/producers.html

The second visual is a population-time graph (Figure 4) that uses lines to represent the absolute value of populations as time goes on. The y-axis is population and the x-axis is the day. Users can hover over the line to see the exact value at any given point.

Figure 4

Population-time Graph



Note: Screenshot from Annenberg Learner. (n.d.). Ecology labs: The producers [Interactive simulation]. https://www.learner.org/wp-content/interactive/envsci/ecology/producers.html

The ability to toggle species and their relationships, play out the simulation over multiple periods of time, and gain very specific data from the simulation makes this an excellent opportunity to accomplish our pedagogical goals set out to address the larger problem.

Affordances of The Ecology Lab

The Ecology Lab simulation offers several cognitive and social affordances that support the goals of this TELE. The opportunities afforded include (1) dynamic visualization, (2) real-time feedback, (3) multiple-linked representations, (4) externalized thinking, and (5) collaboration. First, the Ecology Lab allows students to toggle species interactions on and off, changing their links, and even introducing major systemic changes. To ensure deep understanding, students need to be able to test out the interactions, not just read about them. Jackson et al. (1995) emphasize that direct manipulation helps students construct causal explanations because they can act on system components and observe the consequences. Second, this simulation affords real-time feedback to changes with a time-compressed system, allowing students to see population changes over time. Jackson et al. (1995) highlight real-time feedback as crucial for helping students notice patterns and that it led to further exploration of the relationships in the simulation because it could be implemented quickly. Next, Ecology Lab's combination of graphic data, field animation view, and food web controller functions as a set of "multiple linked representations" (Kozma, 2000). As students reconcile the symbols in the field animation view with the legend and lines on the population-time graph, they use common "surface features" (e.g., shared colours and icons) to map one representation onto another. This affords the opportunity to draw on the unique features of each to modify their understanding of population dynamics and system behaviour. Another affordance of the Ecology Lab simulation is that it externalizes student thinking by making their predictions and results visible. When students run scenarios, compare outcomes with their hypotheses, and reflect on population curves, their reasoning becomes observable. They are allowed to iterate on their suspicions with multiple revisions making it explicit. This aligns with knowledge-integration principles from Linn, Clark, and Slotta (2003), who argue that a learner will benefit when their ideas are made visible and can be compared against competing explanations. Finally, this explicit and visible representation of student thinking is exactly what makes this simulation afford social reasoning and interaction between students. White and Frederiksen (1998) argue that when students work with “public representations,” they are better able to compare interpretations, evaluate claims, and negotiate revisions because the results are equally visible to all group members. The shared reference points, visible data that all learners can reference, and discrepancies between predictions and outcomes can prompt discussion and allow students to compare interpretations.

TELE

Implementation Recommendations for Running the TELE

This TELE is a series of GEM-aligned lessons designed to be implemented with the teacher actively facilitating students' use of the Ecology Lab simulation. I believe the most effective structure is for the teacher to project the simulation at the front of the room while students work in pairs on their own Chromebooks or laptops. Working in pairs helps achieve the social affordances set out in the previous section as it allows students to co-construct predictions and compare their interpretations of the graph and field animation. In larger classes, I also believe that pairs may also be combined into groups of four when discussing their results to further support the social comparison that the research highlights as essential for developing more systemic ecological reasoning. This TELE can also be run as a full-class demonstration when device access is limited. The teacher would control and project the simulation while students contribute predictions, observations, and revisions collectively. Each lesson provides multiple GEM cycles so I believe this still preserves the pedagogical intent, provided that the students are properly prompted to justify claims using evidence from simulation. Ultimately whether through pairs or whole-class discussion, the teacher's facilitation role is to pause the simulation at strategic moments to ensure that GEM is being properly applied. The teacher prompts are suggestions based on a trial with one Grade 6 class in Mississauga, Ontario.

To complement the TELE, I also designed a "Technology-Enhanced Learning Experience Companion" using Google AI Studio. This companion functions as an additional organizational and pedagogical support tool for teachers and students, if needed. The companion includes two streamlined views. A teacher view provides quick-access versions of the lesson goals, success criteria, and the GEM-aligned prompts to help facilitate the lesson. The student view is more of a standalone way students can access the simulation and GEM-aligned prompts without any teacher intervention. This is not meant to replace the TELE or the Ecology Lab simulation and it does not introduce new content or pedagogy. The deployed version is available below. Users must have a Google account (free) to access.

Technology-Enhanced Learning Experience Companion for the Ecology Lab Simulation

Lesson 0

Subject: Grade 6 Science, Biodiversity	**Purpose:** Tool fluency, multiple linked representations
Learning Goal: We are learning how to use all parts of the Ecology Lab simulation so we can test ideas about how species interact in an ecosystem.	
Success Criteria: ● I can turn species on and off using the food web controller ● I can see how species appear in the field animation view ● I can read the population graph to tell whether a species increases or decreases over time ● I can connect what I see in the field view to what I see on the graph	

Lesson Body:

Introducing the Three Views (2 minutes)

- Teacher introduces only the interface, not any ecological outcomes
- Sample teacher prompts:
  - Food web controller: “This is where we choose which species appear in the system”
  - Field animation view: “This shows us the organisms moving or appearing in the environment”
  - Population graph: “This shows the number of organisms changing over time”

Activating a Species

- Students turn on only Plant A.
  - *Teacher prompt: “Click Plant A. Notice how it appears in both the field animation and in the legend on the graph.”* **They do not run the simulation yet.**

Reading Graph

- Teacher walks them through how to read the graph with a very controlled, non-ecological use:
- Students click “Run” only once for 100 days (no comparisons, no predictions).
  - *Sample teacher prompt: “Watch how the green line changes as time moves forward”*
- Students hover over one point to see the value
  - *Sample teacher prompt: “When the line goes up, what does that mean? When it goes down, what does that mean?”*

Matching Representations

- *Sample teacher prompt: “Look at the plant squares in the field animation. Now look at the green line on the graph. How can we tell that they represent the same thing?*”
- Students practice identifying: colour match, icon match, species name match, location of the legend

Consolidation (1–2 minutes)

- Students complete a quick readiness check (verbal or on whiteboards): *“Show me on your screen where you would…”*
  - turn a species on, find where the graph shows population, hover to see the exact value

Lesson 1

Subject: Grade 6 Science, Biodiversity	**Purpose:** Build understanding of competition, dominance, coexistence, and simple two-way relationships using multiple GEM cycles

Learning Goal: We are learning to describe how the introduction or removal of a species affects the relationship between producers, and to explain why some species outcompete others.

Success Criteria:

- I can use the simulation to identify which plant species becomes dominant
- I can explain how competition affects population changes over time
- I can give a two-step causal explanation (e.g., “Plant A increases, so Plant B decreases”)
- I can explain why producers cannot all coexist without a consumer

Lesson Body:

<u>Students paired and grouped with another pair</u>

PART A / GEM 1: Plant A vs Plant B (10 minutes)

Generate (Predictions)

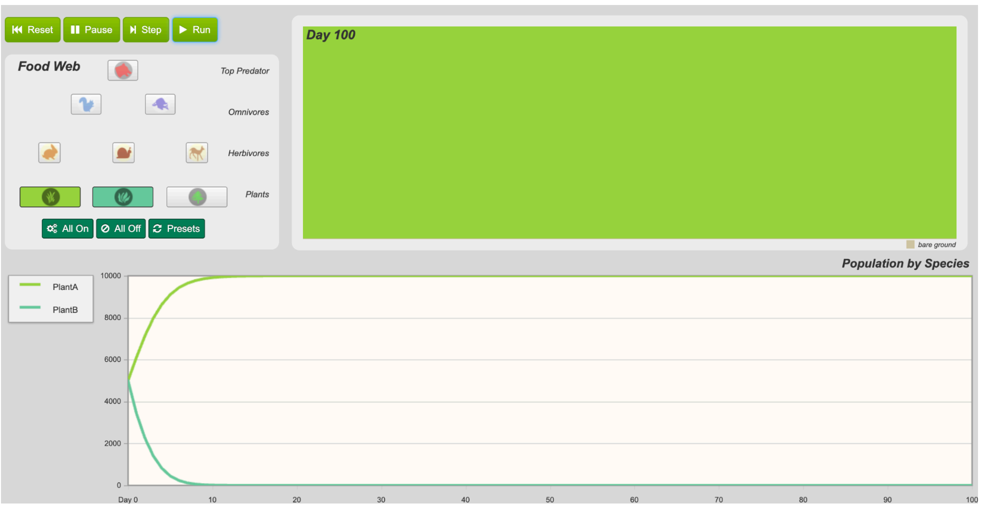
- Teacher prompt: “Do you think Plant A and Plant B can coexist? Why?” and “What might cause one species to win over another?”
- Students record their predictions

Evaluate (Run simulation)

- Turn on Plant A and Plant B. Run for 100 days. Students record: Which plant becomes dominant? What happens to the other?
- Teacher prompts: “Find the turning point on the graph. What is happening at that moment?” and “How do the field animation and the graph tell the same story?”

Modify (Refine thinking)

- Students revise predictions. Teacher prompt: “What did you expect? What actually happened?” and “Why do you think Plant A outcompeted Plant B?”
- Looking for the conceptual outcome of students observing competitive exclusion



PART B / GEM 2: Testing another pair, Plant A vs Plant C OR Plant B vs Plant C (5-10 minutes)

The teacher chooses A+C or B+C based on time. Repeat the same steps as PART A.

Generate

- Teacher prompt: “Do you think the pattern will be the same for this pair? Why or why not?”

Evaluate

- Run the second pair for 100 days.

Modify:

- Teacher prompt: “What stayed the same? What changed?” and “Does this help us see a pattern in plant competition?”
- Looking for this conceptual outcome - can students generalize that one plant consistently dominates?

PART C / GEM 3: The consumer (20 minutes)

Generate

- Teacher prompt: “We saw that plants almost never coexist on their own. What do you predict will happen if we add a herbivore that eats only one of the plants?”, “Will the herbivore help both plants survive, or make the competition worse? Why?”, “Which evidence will help you decide… the field animation view, the graph, or both?”
- Students choose one feeding link (Herbivore A eating Plant A or Plant B)
- Students record predictions about population changes and why they think that will happen

Evaluate

- Students turn on Plant A and Plant B. Add Herbivore A and select its single feeding link. Run to Day 100.
- Teacher prompts should require evidence from both representations: “What did you notice first in the field view? Which species spread? Which shrank?” and “Now check the graph. Which line drops first? Which line rises? How do you know?”
- “Hover at Day 50 or Day 75. What exact values do you see?” and “Do the numbers confirm what you saw happening in the field view?”
- “How do the graph and the field view tell the same story?” and/or “Does one representation show something the other misses?”
- Students record: What changed (using increase/decrease/stabilize language). Evidence from both field view and graph view (population values, line direction, spread of squares/icons).

Modify

- Teacher prompt: “What part of your prediction was supported by the evidence? What needs revision?” and “Use the graph and field view to prove how the herbivore changed the relationship between the plants.”
- Finally: “Describe the cause-and-effect pathway using evidence: What happened first? Then what?”
- Ultimately, looking for students to revise their explanations using a two-step causal chain, grounded in evidence from both representations. This is shown through statements like: “Herbivore A decreases Plant ___. I know this because ___ (graph line drops or fewer squares in field view). That allows Plant ___ to increase. I would see this shown as ____ (graph line rises or more squares).”

Lesson 2

Subject: Grade 6 Science, Biodiversity	**Purpose:** Move from linear "chain thinking" to multi-trophic reasoning using multiple, simultaneous interactions in a food web

Learning Goal: We are learning how to explain ecosystem patterns by tracing interactions across multiple trophic levels

Success Criteria:

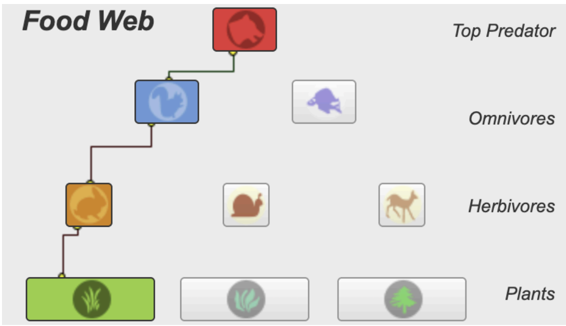
- I can identify more than one interaction happening at the same time
- I can revise my prediction using specific evidence from the graph and field animation
- I can explain a multi-step causal interaction using evidence from the simulation

Lesson Body:

Students paired and grouped with another pair

PART A / GEM 1: Simple Food Chain (10-15 minutes)

The goal is to build the chain, Plant A, Herbivore A, Omnivore A, Top Predator as seen below:



Generate (Predictions)

- Teacher prompts: "If we build a simple food chain, what do you think will happen over time?" and "Which species will increase? Which will decrease? Why?", "What effect do you expect to move through the chain?", or even "Do you think all species will survive, or will someone die out?"
- Students record predictions and share in groups

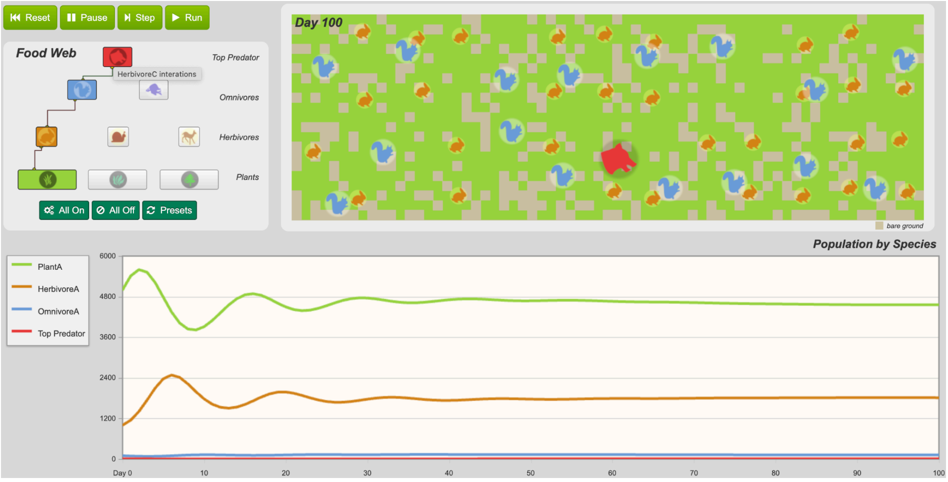
Evaluate (Run simulation)

- Steps: Turn on Plant A. Add Herbivore A (eats Plant A). Add Omnivore A (eats Herbivore A). Add Top Predator (eats Omnivore A). Run simulation to Day 100.
- Teacher prompts requiring evidence: "Which species changed first? What do you see that proves this?", "Hover over Day 40 or Day 60… what population numbers support your explanation?" and "Did anything change that you didn't predict?"
- Students record: Order of species changes (e.g., "Plant A increases first, Herbivore A increases afterward") and population values at several time points.

Modify (Refining thinking)

- Teacher prompts: "What did you predict correctly? What needs revision?"
- "Explain a two-step chain reaction you observed. What do you see that proves it?"
- To show success, we are looking for students to revise their explanation using a multi-step causal chain. Three example responses proving this:
    - "When Plant A's population increased, Herbivore A increased after a short delay. I know because Herbivore A rises around Day 10."

- ○ “Omnivore A population stays low because Herbivore A never gets extremely high.”
- ○ “Top Predator increases slightly after Omnivore A increases, which shows a delayed response



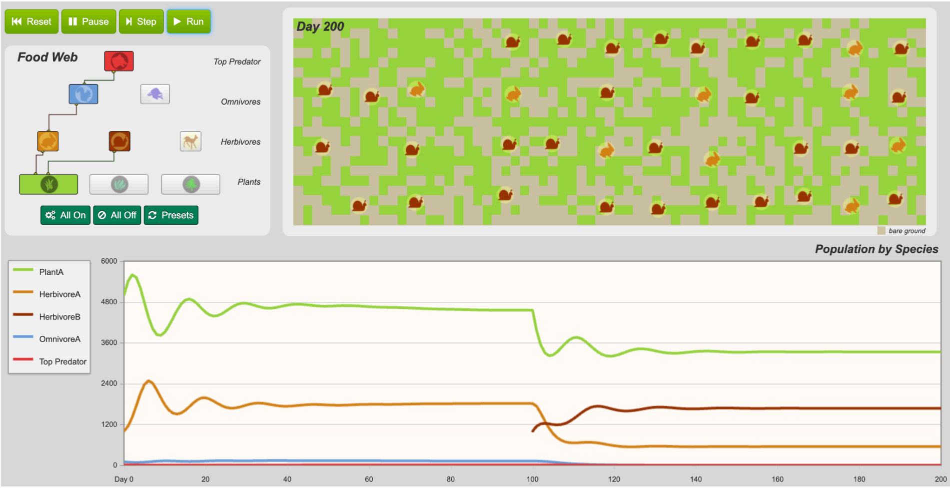
PART B / GEM 2: Adding Herbivore B to consume Plant A (10-15 minutes)

Generate

- Teacher prompts: “What do you think will happen if we add another herbivore that also eats Plant A?” and “How might Herbivore A and Herbivore B affect each other?”
- “Do you think the rest of the food chain will change, even though we didn’t touch those species? Why or why not?”
- Students record predictions and share in groups, ideally naming at least two possible outcomes (e.g., “Both herbivores will increase,” or “One herbivore might win,” or “Plant A might drop faster”)

Evaluate

- Steps: Keep the full chain from Part A. Add Herbivore B and set it to eat Plant A. **CLICK “STEP”** to add another 100 days, and run the simulation from Day 100-200.
- Teacher prompts requiring evidence: “Which species changed first after Herbivore B was added? What do you see that proves this?” and “Hover over Day 120 or Day 140, what numbers show us how Herbivore A and Herbivore B are competing?”
- “Did you notice a species that changed even though it isn’t directly connected to Herbivore B? What shows that?”
- Students record: The order of changes (e.g., “Herbivore B increases first, then Plant A drops quickly”). They should highlight at least one piece of evidence from both the graph and the field view and any unexpected change (e.g., “Omnivore A also changes even though we didn’t touch it”)



Modify

- Teacher prompts groups to discuss:
  - “What did this show you about two species sharing the same resource?”
  - “How did Herbivore B change the chain, even for species that don’t eat it?”
  - “Explain a multi-step interaction you observed. What do you see that proves your explanation?”
- Looking for revision that demonstrates multi-step reasoning, such as:
  - “Herbivore B increased quickly, which caused Plant A to drop. When Plant A dropped, Herbivore A started decreasing.”
  - “Omnivore A changes after the herbivores change even though we didn’t touch it.”
  - “Two herbivores eating the same plant creates competition. Herbivore B wins because its line is higher while Herbivore A drops.”

Lesson 3

Subject: Grade 6 Science, Biodiversity

Purpose: Model ecosystem disturbance and discover multi-level, system-wide effects of adding an "invasive species"

Learning Goal: We are learning how to explain ecosystem changes by identifying feedback loops and cascading effects when a new species enters a stable food web

Success Criteria:
- I can identify what changed first, next, and later in the food web
- I can describe an indirect effect using evidence from the graph and field animation
- I can revise my explanation using a multi-step causal chain (e.g., "X changes, which causes Y, which causes Z")

Lesson Body:

Students paired and grouped with another pair

PART A / GEM 1: Establishing a Stable Food Web (10-12 minutes)

Students should initiate setup:
- Turn ON: Plant B, Plant C
- Turn ON: Herbivore A (eats Plant B)
- Turn ON: Herbivore C (eats Plant B and Plant C)
- Turn ON: Omnivore A (eats Herbivore A)
- Turn ON: Omnivore B (eats Herbivore C)
- Leave Top Predator off

Generate (Predictions)
- Teacher prompts: "Looking at our food web, what do you predict the populations will do over time? Will all species survive? Will anyone go extinct? Which species do you expect to change first? Why?"
- Students record predictions.

Evaluate (Run Simulation)
- Steps: Run the simulation to Day 100 (until stable oscillations form like seen above).
- Students observe the graph and field view.

- Teacher should use evidence-focused prompts: “Which species changed first? What do you see that proves it? How do Plant B and Plant C behave over time? What pattern do you notice?
- “Hover over a peak and a valley. How far apart are they?”
- Students record:
    - A description of stability (“All species populations change a bit, but none go extinct”)
    - One piece of evidence to prove it, e.g., a hovered value or specific graph moment
    - The order in which species rise and fall

Modify (Refining Thinking)
- Teacher prompts: “What part of your prediction matched the results? What do you need to revise now that you’ve seen the data?”
- Students update their explanations using at least one pair of representations.

PART B / GEM 2: Introducing the “invasive species” (10-12 minutes)

Click “Step” to add another 100 days. Turn ON Herbivore B to eat Plant B. It should look like below.

Generate
- Teacher prompts: “We now have a stable system. What do you predict will happen if we introduce Herbivore B, which also eats Plant B? Which species do you think will change first? Why? Who might be affected even though they are NOT directly connected to Herbivore B?”
- Interesting to note if students understand this is simulating an “invasive species” without prompting
- Students record predictions and share with peers

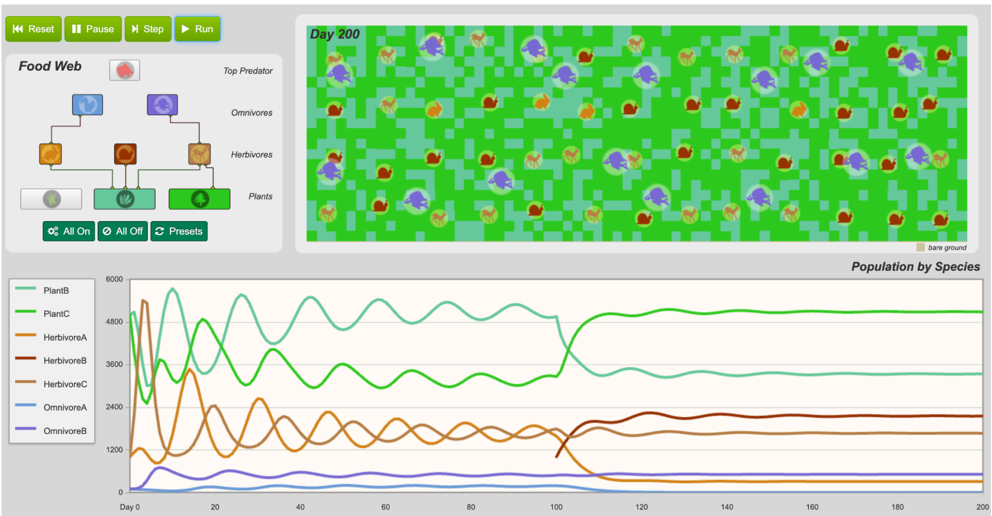
Evaluate (Run Disturbance Simulation)
- Steps: At Day 100, turn ON Herbivore B and set it to eat Plant B. Run the simulation to Day 200
- Teacher prompts requiring references to specific visual evidence: “Which species reacts first? What do you see on the graph that proves it? What happens to Herbivore A after Plant B declines? Point to the moment on the graph. What do you notice about Omnivore A later on? How do you know this from the field view or graph?”
- Students observe and record the three major impacts, discussing with the group. Examples:
    - Plant B population declines sharply (direct effect)
    - Herbivore A population declines because its food source is reduced (indirect effect)

    - Omnivore A population collapses to zero because Herbivore A population collapses (delayed "cascade")
- Students must reference:
    - One exact graph moment
    - One observation from the field animation (e.g., disappearance of icons)

Modify

- Teacher prompts: "Which part of your prediction was accurate? What needs revision? "Explain a multi-step causal chain that you observed. What evidence supports each step? Who was affected even though they were not directly linked to the new species?"
- Success in this step looks like students explaining at least one three-step interaction, e.g.:

"Herbivore B reduces Plant B population, then Herbivore A population decreases so Omnivore A eventually goes extinct in this area. I know this because Plant B's line drops right after Day 100, Herbivore A's line drops after Day 120, and Omnivore A's line reaches zero at around Day 160."



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