NETWORK SCIENCE

Ecology

| NE STEM 4U

Objective

The student will understand that taking away nodes in a network (e.g. wooden block pieces) sometimes means simply changing what the network looks like and other times can lead to a total collapse of the network (breaking all of the links/ties).

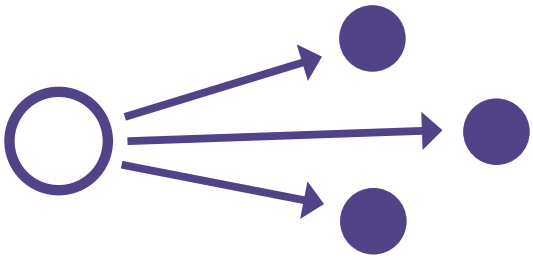
The student will be able to describe how a model (e.g. wooden block tower) gives insights to real world phenomena related to Ecology (e.g. if crickets disappear, what happens to the larger food network?).

The student will engage with NGSS Crosscutting Concept 4. *Systems/System Models.*

Vocabulary

Networks:
1) A set of relationships, 2) which show how things are connected, 3) and reveal hidden information.

Degree:
The number of lines connected to a node. The leftmost vertex (pictured below) has a degree of three:



Robustness:
Refers to the response of a network when pieces are removed. A robust network is one where the remaining network connections still maintain the function of the network when nodes are removed (i.e. pieces taken away).

Cascade (after percolation reaches a threshold):
Small changes to a network might have little to no visible impact on a robust network, until multiple changes accumulate and cause the entire system to change structure (i.e. collapse or become completely connected).

Background

Building a network using wooden blocks demonstrates that some pieces in a network are more important than others. Removing pieces of a network will change the structure, but removing the pieces that are most connected or more foundational to the network will have more significant impacts on the network. In an ecosystem network, the more connected the network, the more robust it is.

Think about ecosystems and food webs as networks with varying degrees of robustness depending upon how many connections and kinds of connections they contain (e.g. if there are “hubs” or “key links” in the chain).

In an ecosystem, one organism may rely on another for energy (e.g. predator-prey) whereas others rely upon each other not for a food source, but for notification of oncoming danger. We can model these relationships with arcs. The arrows represent the directionality of energy when the organisms are eaten. This food chain makes up only a tiny part of a network. Networks help us see the bigger picture.

At the beginning of the “Jenga” game, the wooden block network model is robust. A robust network means that the network does not change much when we take pieces away; it means the network is not as sensitive to losing nodes/vertices. Typically, in robust networks, removing nodes at random will not change the network as much compared to removing pieces with the most connections (high degree). The different impacts of removing more or less connected (higher- or lower-degree nodes) does not just happen in ecosystem networks. Removing pieces with the most connections can have a big impact in any network (e.g. if you have to close an airport hub -versus a small regional airport- because of weather, it has impacts all over the country).

Materials

Per group

- Handout
- Colored wooden block set (e.g. Jenga) with extra blocks
- Six-sided die

Procedure

Introduction

1. Distribute a handout sheet, a wooden block set, and a 6-sided die to each group (ideally 3-4 students per group).
2. Introduce the concept of ecosystems as examples of networks, with **Thinking Prompts and Guiding Questions.**

Activity One: Wildfire

3. For this round, the ecosystem is experiencing a wildfire. Students must each roll the dice to determine the degree of damage. Use the following rules:
    a. If the student rolls an odd number:
        i. Hooray, the firefighters were able to get the fire under control for minimal damage and only a little grass was destroyed! Remove 1 green block.
    b. If the student rolls an even number:
        i. Oh no, the fire is spreading uncontrollably and killing a lot of grass. Remove 2 green blocks.
    c. Every time 3 green blocks are removed:
        i. The loss of grass is hurting the grasshopper population. Remove 1 blue block.
    d. If two consecutive students roll the same number:
        i. Woohoo, the firefighters beat the fire! You won!
4. Proceed to **Activity Two.**

Activity Two: Hunter

5. For this round, hunters have entered the ecosystem. Students must each roll the dice to determine which species were eliminated. Use the following rules:
    a. If the student rolls a 1, 2, or 3: The hunters killed a prairie chicken, which led to more grasshoppers. Remove 1 yellow block. Add 1 extra blue block to the top of the stack.
    b. If the student rolls a 4 or 5: The hunters killed a coyote, which led to more prairie chickens. Remove 1 orange block. Add 1 extra yellow block to the top of the stack.

c. If the student rolls a 6: The hunters killed a mountain lion, which led to more coyotes. Remove 1 red block. Add 1 extra orange block to the top of the stack.

6. Guide classroom discussion with **Thinking Prompts and Guiding Questions.**

Activity Three: Regular

7. This round will be ordinary "Jenga" style. Use the following rules:
    a. Students take turns removing one block and then putting that block at the top of the stack. (Students cannot take pieces from the top three rows.)
8. Guide classroom discussion with **Thinking Prompts and Guiding Questions.**

Activity Four: Insecticide

9. Introduce a scenario in which the use of insecticide to protect farmers' crops is eliminating the grasshopper population.
10. Ask students to consider how this would affect the other parts of the ecosystem and to develop a set of rules for gameplay.

Thinking Prompts and Guiding Questions

Introduction

- In this food web, what is connected and how? *Ensure that students understand that all organisms are connected and interdependent, in both direct (e.g. coyotes eat prairie chickens) and indirect (e.g. if coyotes consume prairie chickens more than usual, the grasshopper population might increase, and the grass might decrease) ways.*
- What would happen if a certain organism disappeared altogether from this food web? *If a species disappeared altogether in this food web, the changes would be severe (e.g. if prairie chickens were eliminated, coyotes would not be able to live off only grasshoppers). In real life, coyotes would likely find a different food source or develop adaptations to digest different organisms over time.*

Activities One and Two – Wildfire and Hunter

- What did you observe?
- Does the removal of blocks from the bottom versus the top of the stack affect the likelihood that the structure will collapse? Does this make sense with what would happen in a real-life ecosystem?

- In the game of Jenga, removing blocks from the bottom is more risky than removing from the top. However, in a real ecosystem, nearly every organism is important (e.g. removing an apex predator would cause dramatic change throughout the ecosystem).
- What happens to the stability of the structure as you take pieces away and change their location? What ultimately causes the stack to crash?
    a. Because the structure is stable ("robust"), it can handle considerable change, until one key piece with important connections is removed, at which point the entire structure collapses ("percolation").
- Besides wildfires and hunters, what other factors could disturb a prairie ecosystem (or other type of ecosystem)?
    b. Insecticides, pesticides, pollution, oil spills, and deforestation are some examples (which are all human-made – i.e. anthropogenic!).

Activity Three – Regular

- What did you observe?
- Which pieces are most important and why? How did you decide which pieces to remove? *Blocks which singlehandedly have the most connections (e.g. the last remaining block in a row) are the most essential. Blocks that are not the sole providers of strong connections (e.g. one wobbly block in a row of three) are more expendable.*

Career/Future Application

Ecologists can use networks to study the relationships between animals in an ecosystem. For example, ecologists are interested in network characteristics such as the level of connectivity within an ecosystem and the robustness and stability of an ecosystem. There are also applications to human ecosystems (e.g. transportation, global food distribution) – people working in logistics work on these systems.

References

Ch. 8 of the book Network Science by Barabási describes the phenome we discuss in this activity as "network robustness":

Houston-Edwards, Kelsey. 2021. "The Mathematics of How Connections Become Global:

Percolation theory illuminates the behavior of many kinds of networks, from cell-phone connections to disease transmission." Scientific American.

Shows a "three-dimensional Square Lattice" (looks like a Jenga) as an illustration of how percolation works.

The concepts in this activity were adapted from the following research article:

Dunne, J. A., Williams, R. J., & Martinez, N. D. (2002). Network structure and biodiversity loss in food webs: robustness increases with connectance. Ecology letters, 5(4), 558-567.

Wildfire Jenga

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The loss of grass is hurting the grasshopper population. Remove 1 blue block.

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Hunter Jenga

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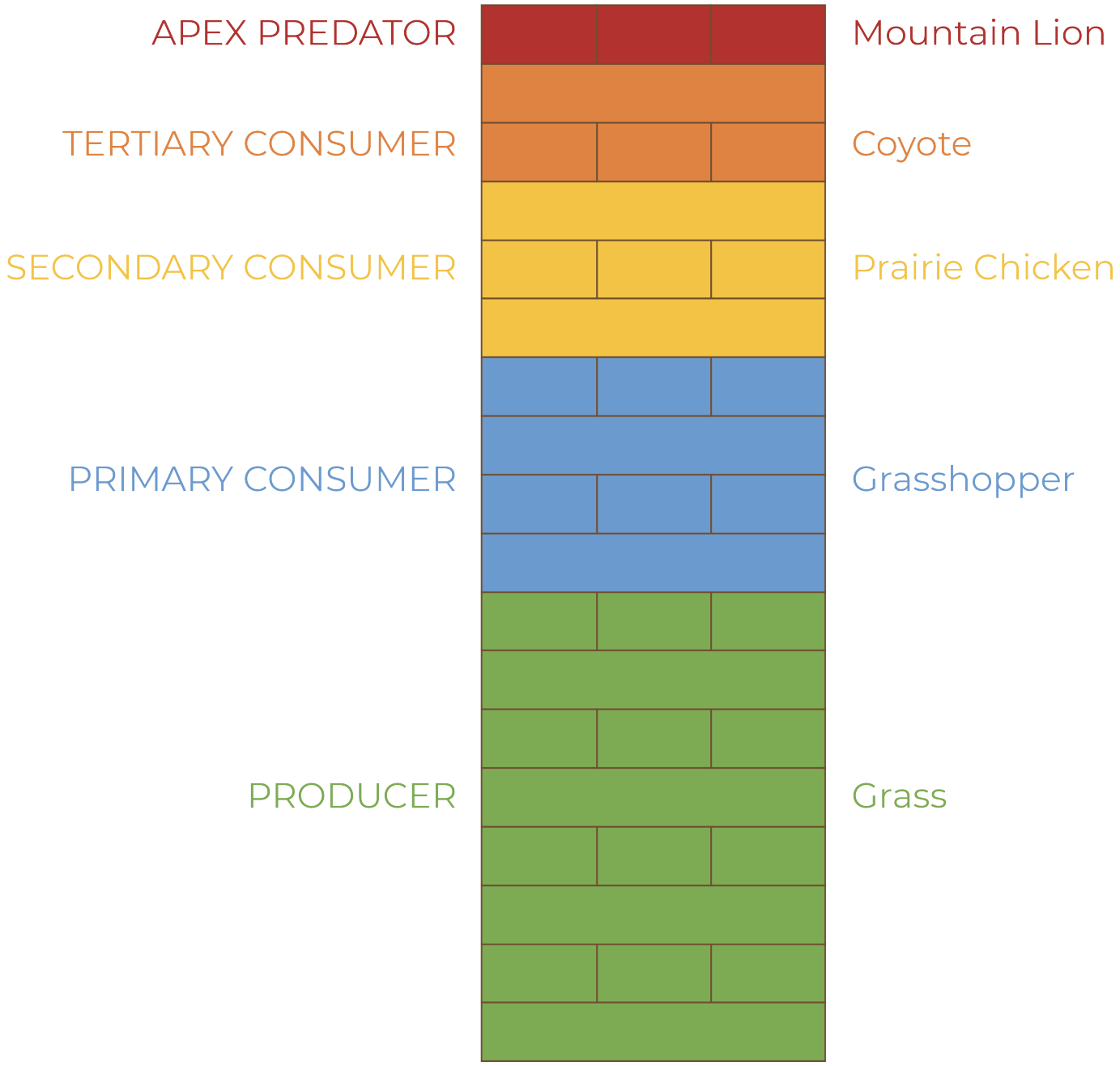
APEX PREDATOR
Mountain Lion
TERTIARY CONSUMER
Coyote
SECONDARY CONSUMER
Prairie Chicken
PRIMARY CONSUMER
Grasshopper
PRODUCER
Grass