The Tree Game Puzzle:
The Shape of Change

The text of
Lesson 7: The Tree Game Puzzle
From the books

The Shape of Change
and
The Shape of Change: Stocks and Flows

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Published by the Creative Learning Exchange

Prepared with the Support of
The Gordon Stanley Brown Fund

Based on work supported by
The Waters Foundation

The Shape of Change

Presenting eleven attractively illustrated and
formatted classroom activities.
Available from
The Creative Learning Exchange
Acton, Massachusetts
(978) 635-9797

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Introduction

This puzzle is an extension of the Tree Game (see Lesson 6). After playing the Tree Game, students explore what happens to the number of trees in a forest following a variety of planting and harvesting policies. Math skills include computation, making and interpreting graphs, problem solving, and communication.

How It Works

As teams of students experiment with their simulated forests, they invent their own planting and harvesting rules, collect data based on those rules, graph the results, and see what those graphs reveal about the rules. All of the rules and graphs are posted separately. Students match them up, explain their reasoning, and think about the long-term consequences of various resource management policies.

Materials

- Approximately 150 wooden craft sticks (Popsicle® sticks) for each team of students
- One container to hold the sticks for each team
- One copy of three worksheets for each team
    1. *Tree Puzzle Rules* (page 6)
    2. *Tree Puzzle Inventory* (page 7)
    3. *Tree Puzzle Graph* (page 8)

Procedure

1. Review the Tree Game. In the previous game, teams of students started with:
    - 120 trees in the original forest
    - An "In" rule of 4 (the planting rate for new trees each year)
    - An "Out" rule that followed the pattern 1, 2, 4, 8, etc.(a cutting rate that doubled each year)

2. This time, teams will make up their own rules and see if other students can guess the rules from the graphs. They will be changing the planting and cutting rates.
   (After playing the Tree Game, students are ready for the Tree Game Puzzle. In Grade 5, we usually do both lessons in about and hour.)

3. Give each team one copy of the *Tree Puzzle Rules* worksheet (page 6) and explain the rules as outlined on the next page. Remind students that accuracy is important.
   (Give students the option of using sticks to count their trees. If they have just played the Tree Game, some students may not need this concrete step.)

Tree Puzzle – Rules of the Game

1. Decide how many trees are in your forest to start and write that on your *Tree Puzzle Rules* worksheet in LARGE numbers.
2. Make up a rule for the number of trees planted each year. Write the rule on the worksheet. Write LARGE.
3. Make up a rule for the number of trees cut each year and write it on the worksheet. Write LARGE.
4. The rules can be stated in words, with formulas, or by listing numbers to describe a pattern. For example:
    - "Start by cutting one tree, then double the number of trees cut each year."
    - "Cut 1, 2, 4, 8, …"
    - "Newly cut trees = 2 * old number of cut trees"
5. Use your rules to complete the table on the *Tree Puzzle Inventory* worksheet.
6. After you have completed the table, use it to make a graph of the number of trees in the forest over time on the *Tree Puzzle Graph* (page 7) worksheet.
7. When you are done, hand in all worksheets to the teacher.

Note: The rules are easier to guess if different teams are starting with a different number of trees, so you may want to require that each team start with the same number of trees. If you leave the starting number of trees somewhat ambiguous, most teams will start with 120 trees, because that is what happened in the previous game.

4. As teams finish, collect their two worksheets.
    - Take the *Tree Puzzle Rules* and *Inventory* worksheets and write a large numeral "1" on each sheet.
    - Take the same team's *Tree Puzzle Graph* and write a large letter on that sheet.
    - Once all groups have handed in their worksheets, the students will be asked to match the rules with the graphs, so make sure not to match the labels in an obvious manner – instead, assign random letters to the graphs. It is helpful if you keep a list of the matching sheets: 1-J, 2-A, 3-Y, etc.
    - Keep the inventory table worksheets aside for reference or checking if necessary.

5. Different teams of students will be working at different rates. If some of the teams finish early, ask them to produce another set of rules. Perhaps give these groups a challenge, such as, “Can you come up with a set of rules that produce a graph that goes up and down over time?”

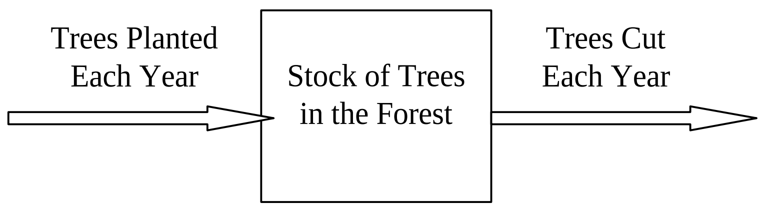
6. Post all the rule sheets on one section of a wall and all the graphs on another section. Give teams a few minutes to examine the sheets and challenge them to match the rules with their graphs.

Bringing the Lesson Home

Ask each team to explain how a rule could be matched with a graph. (Teams are not allowed to match their own rule and graph.)

? **How did your team determine the match?**
If students have difficulties explaining their thinking, have them focus on the simultaneous effect of the inflow and outflow on the stock of trees.

Students have to predict how the quantity of trees in the forest changes over time when trees are continuously planted and cut at certain rates. This game is a natural way for students to think about the effect of **inflow**s and **outflows** on the **stock** of trees.



Once a team has proposed a match, ask other students to verify the logic and assumptions of the presenting team. As students present different arguments, the class will come to a consensus on the matches in a non-threatening manner. This open-ended approach is easier than it may seem. Students actually enjoy making guesses, explaining their reasoning and defending their team’s arguments before the class.

After all the graphs and rules have been matched, expand the debriefing to an economic context.

? **What stories do these graphs tell? What was happening from the forester's point of view? Is the graph realistic?**

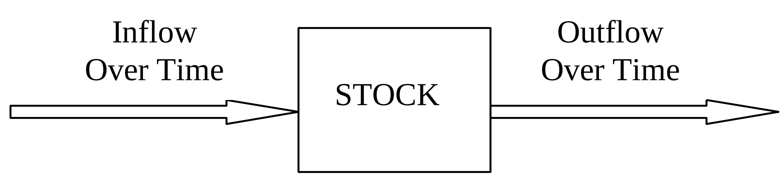
- *Select a few graphs for class discussion. What do the graphs tell us?*
- *For example, an "out" rule of 8 could mean that there is only a demand for 8 trees per year, or that there has been a restriction on cutting trees for some reason.*
- *An increased planting rate may suggest that the forester expects a rise in house building because the economy is improving or the population is growing.*
- *Some graphs my show a depletion of the forest; others may show growth. What could be the causes and implications?*

? **Does the Tree Game remind you of other real world situations?**

- *Renewable resource management for sustainability*
- *Agricultural planning for planting and harvesting to meet demand*
- *Money management to balance income and spending*

Stocks and Flows

The change in any stock depends on what flows in and what flows out over time, usually simultaneously and following different rules.



TREE PUZZLE RULES

Write LARGE

Starting number of trees:

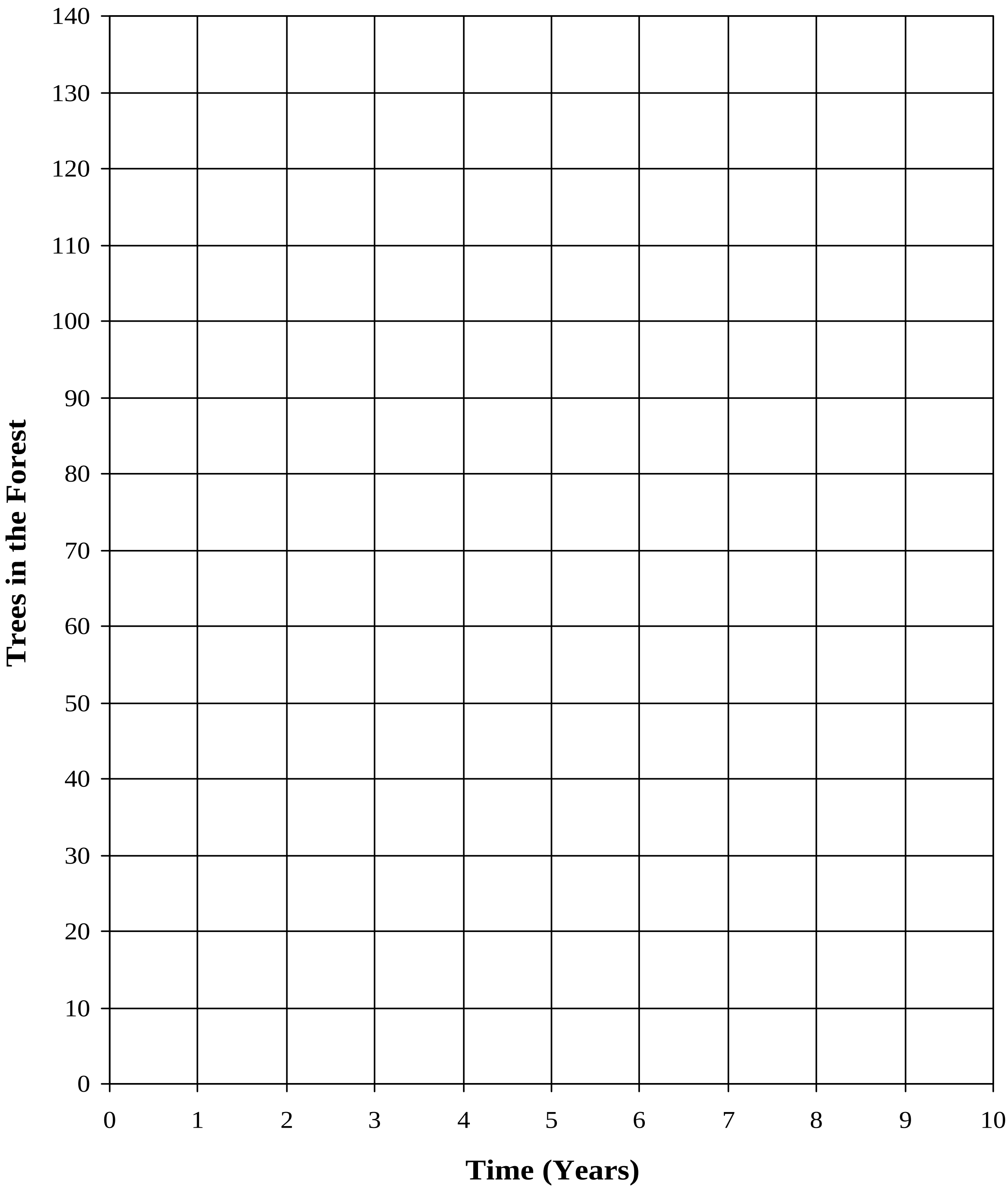
Rule for planting trees:

Rule for cutting trees:

TREE PUZZLE INVENTORY

Year	Number of Trees in the Forest	Number of Trees Planted	Number of Trees Cut Down
Start			
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			

TREE PUZZLE GRAPH



All of the lessons in ***The Shape of Change, Stocks and Flows*** *build directly on classroom activities and lessons presented in* ***The Shape of Change****, also by Quaden, Ticotsky and Lyneis (2004), available from The Creative Learning Exchange. These lessons also build on one another sequentially*

The Shape of Change

In Lesson 7 of ***The Shape of Change***, students extended the Tree Game lesson by implementing their own planting and harvesting policies and graphing the results. All the policies and graphs were posted on the wall, and students matched them up. See Pages 73-80 in ***The Shape of Change*** for the complete lesson.

Overview

Developing stock/flow maps for the students' Tree Game puzzles poses a dilemma for the teacher. On one hand, there is a great degree of uncertainty: students come up with all kinds of rules and these rules will require unique maps. On the other hand, this is a great opportunity for students to clarify their own thinking and to experience the power of making stock/flow maps. Students usually are willing to try their hands at this as long as they are given the opportunity to do so in a non-threatening way.

Students will find this exercise easier if they have had more exposure and practice with stocks and flows, so you may want to save this lesson for later. Yet, the best way to get that exposure and practice is to just do it. It is a good way to learn from our own mistakes.

Does This Make Sense?

To help students get started, remind them to always recount the story of their stock/flow maps as they build them.

For example:

- " An increase in this causes a decrease in that."
- "This inflow makes the stock grow because…"
- "Tracing the story, this loop causes the stock to grow faster and faster, or decline more and more slowly."

Each link needs to make practical sense and relate directly to what the policies actually *do* in the game, on the graph and in the real world.

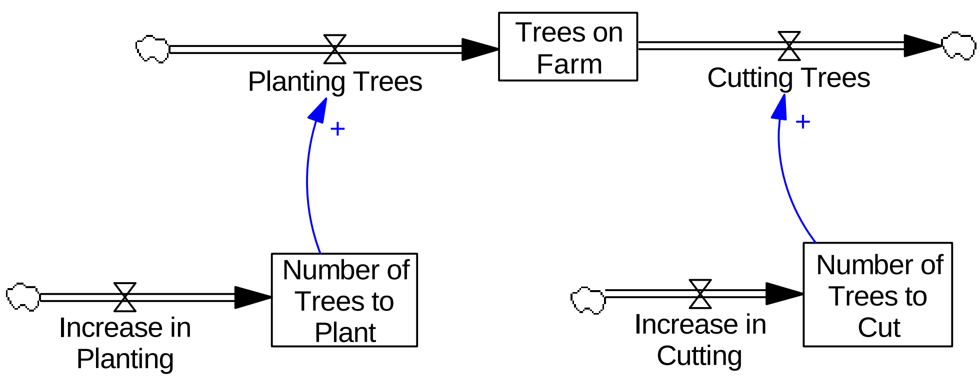
Seeing the structure

After students have made up their own rules, have matched graphs to rules, and have had a chance to talk about the different rules, ask them to draw stock/flow maps. Student-made rules often fall into the following categories or combinations of them:

Policy	Planting Rule	Cutting Rule
1	Linear increase	Linear increase
2	Constant	Proportion of trees
3	Proportion of Trees	Constant
4	Exponential increase	Exponential increase

Policy 1 This policy uses a linear increase in planting and a linear increase in cutting. For example, "Plant 4, 5, 6 … and Cut 3, 5, 7 …"

To show that the flows are increasing at a steady rate, a second set of stocks has to be introduced to represent the policies.

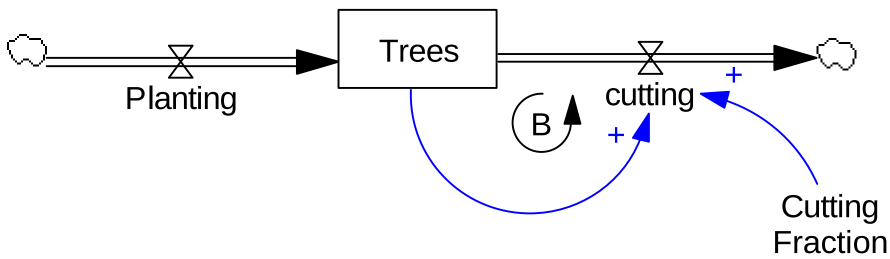


Tell the story of each link as you add it.

Does it make sense?

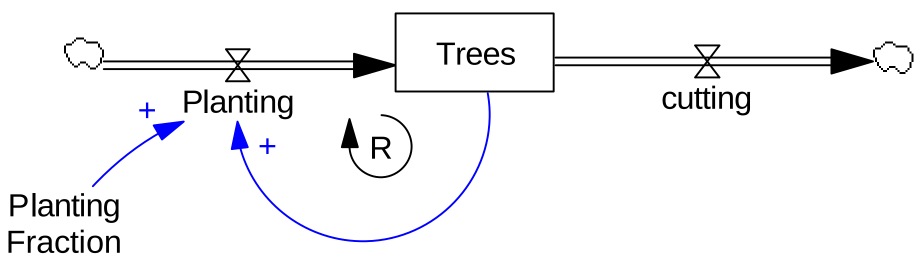
Policy 2 This policy keeps the number of trees planted constant. The number of trees cut is a fraction of the total number of trees.

For example, "Plant 8 trees per year. Cut one-tenth of the trees each year."



The cutting structure is like deaths in the Mammoth Game. The number of mammoths dying depended on the number of mammoths in the herd times a death fraction. The balancing loop caused the mammoth population to decline to extinction in a pattern of exponential decay, just as it would for the trees.

Policy 3 This is somewhat similar to Policy 2. For example, "Plant 25% more trees every year and cut 5 trees." Students may combine these elements in other ways too.



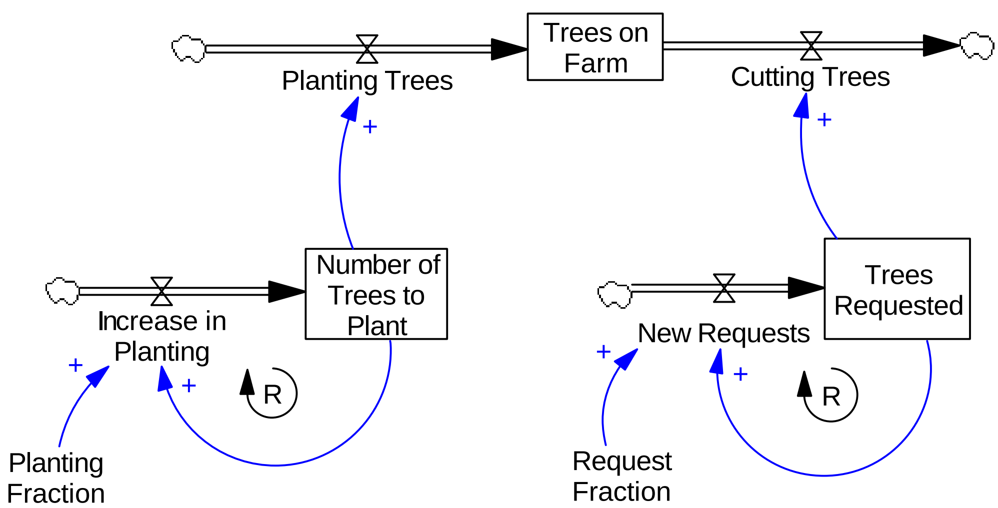
The planting structure is like births in the Mammoth Game. The number of mammoths born depended on the size of the herd and the birth rate. This reinforcing loop caused exponential growth.

While most policies reflect similar structures seen in earlier lessons, others may require students to stretch their thinking to new situations.

Policy 4 Another common rule combines an exponential increase in planting with an exponential increase in cutting (similar to the original tree game).
For example, “Plant 2, 4, 8, 16 … and Cut 1, 3, 9, 27 …”

The variables “Planting Fraction” and “Request Fraction” show that the planting/cutting policies do not have to be the same: in the example, the number of plantings doubles every year while the number of cuttings triples.

Notice that although reinforcing feedback loops drive the increased planting and demand for trees, there is no feedback tying these to the number of trees on the farm.



? **What stories do your stock/flow maps tell?**

After students have matched the graphs with their rules, ask student teams to relate the stories of their stock/flow maps for the class. This is a good way for students to discuss different ways to view a problem, refine their stock/flow maps, learn from one another and examine their own thinking processes. This is the most important part of the lesson.

? **What about sustainability?**

The focus of this lesson has been to help students understand how various inflow and outflow rates cause the stock to change over time. Students have learned how to express different policies in their stock/flow maps. Since students were not asked to think about sustainability when they defined the planting and harvesting policies for their puzzles, their graphs and stock flow maps will show a range of behaviors and structures. (Usually, students are more driven by the challenge to create puzzles that will stump their classmates!)

Ask students to look again at their policies for feasibility and sustainability. Remember from the previous Tree Game lesson that sustainability requires a balancing of inflows and outflows: If you cut more trees than you plant, the forest will eventually disappear.

Which policies would maintain the forest for future generations? Which are realistic? How do they compare to current resource management policies and practices?

Connection to Characteristics of Complex Systems Project

Lesson Title:
Shape of Change, Lesson 6: The Tree Game, including Stocks and Flows
Shape of Change, Lesson 7: The Tree Game Puzzle, including Stocks and Flows

Overview:
In these kinesthetic games, students experience the decline of a natural resource. They can try different "policies" to see what creates a variety of trends as connected to math and science systems.

Related Characteristic(s) of Complex Systems:
- Conflicts arise between short-term and long-term goals.
- The cause of the problem is within the system.

Ideas and Examples for Connecting to the Characteristic:
Individuals or groups may use resources to meet short-term goals at the expense of sustaining those resources over the long-term. Students can read an article or watch/listen to a real-world story about how this can occur (see link to an example story). Students can then graph the trends, e.g., amount of a resource, demand for goods.

An archetype, such as the Fixes-That-Fail, can illustrate how short-term fixes can lead to long-term unintended consequences. It can also make inherent interdependencies explicit and illustrate how a system's structure can contribute to a problem worsening over time.

Other systems tools, including stock/flow diagrams and computer models, are also useful when considering both short- and long-term goals as well as system structure.

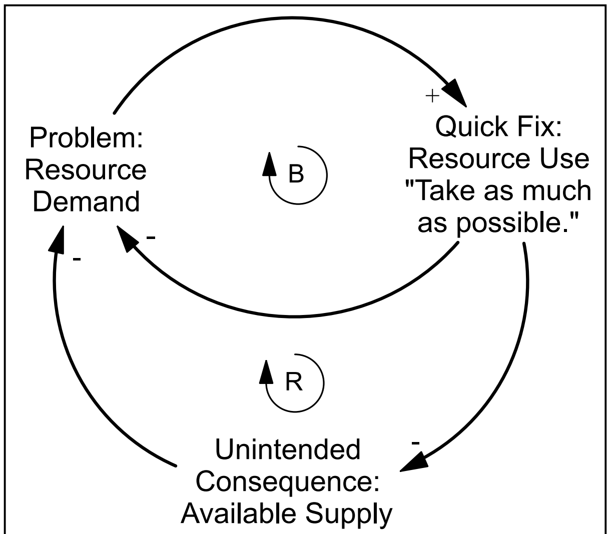


Figure: Fixes-That-Fail Archetype example

Resource(s)
NPR Report: "As China Builds, Cambodia's Forests Fall"
http://www.npr.org/2013/01/29/170580214/as-china-builds-cambodias-forests-fall

Tree Game Simulation
http://forio.com/simulate/cle/treegame/simulation/