Bumbles and Woofs

A Population Model

by
Rachel Henry

Imagine a beautiful meadow filled with delicious, nutritious grass. Fluffy bumbles cavort across the greensward, nibbling blades of grass and reproducing with surprising speed. But lo, at the edge of the meadow, a woof is stalking the oblivious bumbles. Woofs eat bumbles, bumbles eat grass, grass regrows, bumbles have baby bumbles, woofs have pups, and so on.

But how do the populations change over time and affect each other??
TEACHER INSTRUCTIONS

Editor’s Note

The author used Vensim software with her students. Other system dynamics software applications are available. Vensim uses the terms “levels and rates.” Many other applications use “stocks and flows.” Class periods in high school at IACS are 80 minutes.

This four-day in-class project was implemented with calculus students at Innovation Academy Charter School (IACS) in Tyngsboro, MA. This public school incorporates system dynamics thinking starting in 5th grade, so students are already familiar with thinking about stocks and flows, connections, and feedback loops.

The “bumbles and woofs” project introduces modeling using Vensim PLE, which is free to download for personal or educational use. The students found the concrete (if fictional) scenario engaging, and it helped them persist through the learning curve.

Students begin by simulating a simple population model by hand to develop understanding of the way parts of the model interact. Then, they build the same population model in Vensim, and compare the results to understand the beauty of software able to do repetitive calculations.

“Bumbles” are fluffy little vegetarian animals that eat grass in the meadow and reproduce rapidly. Next, students add complexity and nuance to their model in the form of “Woofs” (predators that eat Bumbles) and a Meadow that can be eaten down and cause starvation among the Bumbles. Students are introduced to sudden event modeling in the form of a meadow-burning fire. Last, they are asked to modify the model by adding something of their own choosing.

At each stage of the model, students change variables and observe the effect by graphing important levels and variables. Teachers wishing to shorten the project could elect to stop after adding Woofs to the model and still have an interesting and complete lesson.

Included in this article: the complete handout for students, supplemental material for teachers, an answer key for the simulate-by-hand exercise, pictures of each model built in the handout, and a grading rubric.

Although my class was initially frustrated by the idiosyncrasies of Vensim, they learned quickly how to build and simulate models. They surpassed my expectations for building simple and then more complex models, ambitiously making creative additions to the model. In the future, I will emphasize the importance of making small, incremental changes to models and testing frequently. Without this guidance, they tended to build huge, complex models with multiple feedback loops that were difficult to de-bug.
Welcome to the land of Bumbles and Woofs!

Imagine a beautiful meadow filled with delicious, nutritious grass. Fluffy bumbles cavort across the greensward, nibbling blades of grass and reproducing with surprising speed. But lo, at the edge of the meadow, a woof is stalking the oblivious bumbles. Woofs eat bumbles, bumbles eat grass, grass regrows, bumbles have baby bumbles, woofs have pups, and so on.

But how do the populations change over time and affect each other??

**Day One:**
-- Simulate simple Bumble population problem by hand  
-- Install Vensim on computers  
-- Begin building model of simple Bumble population

**Day Two:**  
-- Complete simple Bumble population model in Vensim  
-- Play with variables  
-- Add Woofs, predators that eat Bumbles

**Day Three:**  
-- Add complex Meadow to model  
-- Play with variables  
-- Add a fire that burns the Meadow

**Day Four:**  
-- Add something interesting to the model!  
-- Write paragraphs for all three tasks  
-- Write intro and reflection paragraphs for project  
-- Publish project to digital portfolio
Simulate Simple Bumble Population Change By Hand

One way to understand a model (and appreciate the power of simulation software) is to do a hand-simulation first.

Assumptions
- Bumble birth rate is based entirely on existing population
- Bumbles eat more than they need to if enough grass is available
- Bumbles die from starvation if there isn’t enough food
- Grass is plentiful and regrows completely every month

Starting condition
- Starting Pop = 20 bumbles

Fixed variables
- Meadow Available = 1000 grass/month
- Bumble Birth Rate = .5 bumble/bumble/month
- Bumble Grass Eating Rate = 3 grass/bumble/month
- Grass Needed by Bumbles Rate = 2 grass/bumble/month

Rules for simulation
- Starting Pop = last month’s Pop After Starve + last month’s Bumble Births
  - The starting population for each month
- Eating Capacity = Starting Pop * Bumble grass eating rate
  - The amount of grass bumbles would like to eat
- Grass Eaten = the smaller value of (Eating Capacity, Meadow Available)
  - Compare the eating capacity to what is actually available, and write down the smaller of the two numbers (the bumbles can’t eat more grass than exists)
- Grass Required = Starting Pop * Grass Needed by Bumbles Rate
  - The amount of grass bumbles need to avoid starvation
- Grass Deficit = the larger value of (0, Grass Required - Grass Eaten)
  - If there’s plenty of grass, there’s no deficit. If the bumbles require more grass than was available to be eaten, there is deficit.
- Bumbles Starved = Grass Deficit/Grass Needed by Bumbles Rate
  - Calculate how many bumbles die of starvation (round up!)
- Pop After Starve = Starting Pop - Bumbles Starved
  - Calculate the number of bumbles that survive any grass shortages.
- Bumble Births = Pop After Starve * Bumble Birth Rate
  - Surviving bumbles re-populate the world (round up!)
Fill in the following grid to simulate bumble population by hand.

(You can stop when the population hits equilibrium.)

<table>
<thead>
<tr>
<th>Month</th>
<th>Starting Pop</th>
<th>Eating Capacity</th>
<th>Grass Eaten</th>
<th>Grass Required</th>
<th>Grass Deficit</th>
<th>Bumble Starved</th>
<th>Pop After Starve</th>
<th>Bumble Births</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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</tr>
</tbody>
</table>
Install Vensim!

- Go to https://vensim.com/free-download/
- Enter your information
- Follow directions to download Vensim PLE
- Install Vensim PLE

Vensim has extensive online documentation: https://www.vensim.com/documentation/

Simple Bumble Population Model

Open Vensim and start building the model we simulated by hand using the software. Follow the instructions below to build the first part of the model, and then test it. When building models, it is essential to add just a few things at a time, and then test to make sure the model is behaving.

- Click on New Model
  - Time Bounds tab
    - Set time step to .125 (this makes smoother graphs)
  - Units tab
    - Enter “bumble, bumbles” (so we don’t have to be perfect about special units)
  - Hit Save (access these settings later via Model -> Settings)

- Add these items to your model:
  - Level
    - Bumbles
  - Rates
    - bumble births (going into Bumbles)
    - bumble deaths (going out of Bumbles)
  - Variable
    - bumble birth rate
  - Arrows
    - Bumbles -> bumble births
    - bumble birth rate -> bumble births

- Units/Equations/Values
  - Click on “equation” and enter the following for each item

<table>
<thead>
<tr>
<th>Item</th>
<th>Units</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bumbles</td>
<td>bumbles</td>
<td>Starting value = 20</td>
</tr>
<tr>
<td></td>
<td></td>
<td>bumble births - bumble deaths</td>
</tr>
<tr>
<td>bumble births</td>
<td>bumbles/month</td>
<td>bumble birth rate*Bumbles</td>
</tr>
<tr>
<td>bumble deaths</td>
<td>bumbles/month</td>
<td>0</td>
</tr>
<tr>
<td>bumble birth rate</td>
<td>bumbles/bumble/month</td>
<td>0.5</td>
</tr>
</tbody>
</table>
● SAVE YOUR MODEL

● Simulate!
  ○ What do you expect to see?
  ○ Click Simulate
  ○ Select “Bumbles” and click Graph
  ○ Describe the shape of this graph
  ○ Does the bumble population behave as you expected?

● Make it pretty!
  ○ Click on Move/Size
  ○ Move the items around and re-shape arrows to make the model visually pleasing
  ○ You can click and drag a box around many items, and then move them as a group

**Complete the bumble population model**
Open your existing bumble model and add the remainder of the bumble population model, as hand-simulated earlier.

● Variables
  ○ meadow
  ○ bumble grass eating rate
  ○ bumble eating capacity
  ○ grass needed by bumbles rate
  ○ bumble eating requirements
  ○ grass actually eaten
  ○ grass deficit
  ○ bumble deaths from starvation

● Arrows
  ○ bumble grass eating rate and Bumbles -> bumble eating capacity
  ○ bumble eating capacity and meadow -> grass actually eaten
  ○ grass needed by bumbles rate and Bumbles -> bumble eating requirements
  ○ bumble eating requirements and grass actually eaten -> grass deficit
  ○ grass needed by bumbles rate and grass deficit -> bumble deaths from starvation
  ○ bumble deaths from starvation -> bumble deaths

● Units/Equations/Values
  ○ Click on “equation” and enter the following for each item

<table>
<thead>
<tr>
<th>Item</th>
<th>Units</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>meadow</td>
<td>grass/month</td>
<td>1000</td>
</tr>
<tr>
<td>bumble grass eating rate</td>
<td>grass/bumble/month</td>
<td>3</td>
</tr>
<tr>
<td>bumble eating capacity</td>
<td>grass/month</td>
<td>bumble grass eating rate*Bumbles</td>
</tr>
<tr>
<td>grass needed by bumbles rate</td>
<td>grass/bumble/month</td>
<td>2</td>
</tr>
<tr>
<td>bumble eating requirements</td>
<td>grass/month</td>
<td>grass needed by bumbles rate*Bumbles</td>
</tr>
<tr>
<td>grass actually eaten</td>
<td>grass/month</td>
<td>min(bumble eating capacity, meadow)</td>
</tr>
<tr>
<td>----------------------</td>
<td>------------</td>
<td>------------------------------------</td>
</tr>
<tr>
<td>grass deficit</td>
<td>grass/month</td>
<td>max(0, bumble eating requirements - grass actually eaten)</td>
</tr>
<tr>
<td>bumble deaths from starvation</td>
<td>bumbles/month</td>
<td>grass deficit/grass needed by bumbles rate</td>
</tr>
<tr>
<td>bumble deaths</td>
<td>bumbles/month</td>
<td>bumble deaths from starvation</td>
</tr>
</tbody>
</table>

- **SAVE YOUR MODEL!!**

- **Simulate!**
  - What do you expect to see?
  - Simulate
  - Graph “Bumbles” and hit Graph
  - Graph “bumble births” and “bumble deaths”
  - Describe the shapes of these graphs
  - Explain any interesting or surprising results

- Choose a variable and change it ..... then, simulate!
  - What do you expect to see?
  - Simulate and graph
  - Explain any interesting or surprising results

**Enter the Woofs**

Now, let's add a simplified predator. We’ll assume that a local pack of woofs move into the meadow. Woofs are ravenous beasts, and kill as many bumbles as they can catch. Add the following to your model:

- **Variables:**
  - woof predation rate
  - bumble deaths from woofs

- **Arrows:**
  - Bumbles and woof predation rate -> bumble deaths from woofs
  - bumble deaths from woofs -> bumble deaths

- **Units/Equations/Values**
  - Click on “equation” and enter the following for each item

<table>
<thead>
<tr>
<th>Item</th>
<th>Units</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>woof predation rate</td>
<td>fraction/month</td>
<td>.25</td>
</tr>
<tr>
<td>bumble deaths from woofs</td>
<td>bumbles/month</td>
<td>Bumbles * woof predation rate</td>
</tr>
<tr>
<td>bumble deaths</td>
<td>bumbles/month</td>
<td>bumble deaths from starvation + bumble deaths from woofs</td>
</tr>
</tbody>
</table>
● SAVE YOUR MODEL!!

● Simulate!
  ○ What do you expect to see?
  ○ Simulate
  ○ Graph "Bumbles" and hit Graph
  ○ Graph "bumble deaths from woofs" and "bumble deaths from starvation"
  ○ Describe the shapes of these graphs
  ○ Explain any interesting or surprising results
  ○ How does the addition of woofs change the onset of starvation deaths?

Additional things to try in Vensim!
● Graph other items
● Print a graph
● Check out Causes Strip
● Check out Table and Table Time Down

Add a More Complex Meadow
Previously, we assumed that our meadow was a fixed size and that it completely re-grows every cycle. Now, we are going to build a meadow model that grows based at least partly on the existing grass, and that can be eaten down to low levels. As long as we’re changing things, we’ll start this new fancy meadow at half the maximum size.

Complex Meadow Assumptions
● A fixed amount of grass grows back every cycle.
● Grass is limited by the size of the meadow.
● The amount of grass that grows back each month is based on the amount of space available.

Open your existing model and "save as" to make a new copy. We will build the new Meadow model separately at first, and then link it to the existing bumble population model.

FIRST: rename your existing variable "meadow" to “simple meadow”

New items:
● Level
  ○ Meadow
● Rates
  ○ meadow growth (going into Meadow)
  ○ meadow loss (going out of Meadow)
● Variables
  ○ grass reproduction rate
  ○ meadow carrying cap (cap is short for capacity)
● Arrows
  ○ grass reproduction rate and meadow carrying cap and Meadow -> meadow growth
- **Units/Equations/Values**
  - Click on “equation” and enter the following for each item

<table>
<thead>
<tr>
<th>Item</th>
<th>Units</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meadow</td>
<td>grass</td>
<td>Starting value = 500 meadow growth - meadow loss</td>
</tr>
<tr>
<td>meadow growth</td>
<td>grass/month</td>
<td>grass reproduction rate*(meadow carrying cap-Meadow)</td>
</tr>
<tr>
<td>meadow loss</td>
<td>grass/month</td>
<td>0</td>
</tr>
<tr>
<td>grass reproduction rate</td>
<td>grass/grass/month</td>
<td>0.25</td>
</tr>
<tr>
<td>meadow carrying cap</td>
<td>grass</td>
<td>1000</td>
</tr>
</tbody>
</table>

- **SAVE YOUR MODEL!!**

- **Simulate!**
  - What do you expect to see?
  - Simulate
  - Graph “Meadow”
  - Did the meadow grow the way you expected?

**Link new Meadow model to Bumble model**
Time to let the bumbles loose in the meadow! What will happen when bumbles start to eat grass?
- **New assumptions**
  - Grass loss occurs when bumbles eat the grass
  - Grass actually eaten now depends on grass available in the complex meadow

- **First: Delete the “old meadow” variable**

- **Arrows**
  - Meadow -> grass actually eaten
  - grass actually eaten -> meadow loss

- **Units/Equations/Values**
  - Click on “equation” and enter the following for each item

<table>
<thead>
<tr>
<th>Item</th>
<th>Units</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>grass actually eaten</td>
<td>grass/month</td>
<td>min(bumble eating capacity, Meadow)</td>
</tr>
<tr>
<td>meadow loss</td>
<td>grass/month</td>
<td>grass actually eaten</td>
</tr>
</tbody>
</table>
● **SAVE YOUR MODEL**

● **Simulate!**
  ○ What do you expect to see?
  ○ Simulate
  ○ Graph Meadow and Bumbles

● Choose a variable and change it ..... then, simulate!
  ○ What do you expect to see?
  ○ Hit Simulate
  ○ Graph Meadow and Bumbles

---

**Then Came The Fire**

Imagine a fire that sweeps through the meadow, burning a significant amount of grass. We'll choose a time when we know the model has already reached equilibrium, in order to see the effect better. Our fire will happen at month 75, last 1 month, and kill off 90% of the meadow.

We'll make use of the PULSE function, which returns either 1 or 0 depending on the variables you enter. PULSE takes two arguments: the first is the time the pulse begins, the second is the duration of the pulse. Look up PULSE in Vensim's online documentation. What are some other functions related to PULSE?

● **Variables**
  ○ fire
  ○ burn dieoff

● **Arrows**
  ○ fire and Meadow -> burn dieoff
  ○ burn dieoff -> meadow loss

● **Units/Equations/Values**
  ○ Click on “equation” and enter the following for each item

<table>
<thead>
<tr>
<th>Item</th>
<th>Units</th>
<th>Equation</th>
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</thead>
<tbody>
<tr>
<td>fire</td>
<td>fraction</td>
<td>pulse(75, 1)</td>
</tr>
<tr>
<td>burn dieoff</td>
<td>grass/month</td>
<td>fire*(0.9)*Meadow</td>
</tr>
<tr>
<td>meadow loss</td>
<td>grass/month</td>
<td>grass actually eaten + burn dieoff</td>
</tr>
</tbody>
</table>

● **SAVE YOUR MODEL**

● **Simulate!**
  ○ What do you expect to see?
  ○ Simulate
  ○ Graph “Meadow”
  ○ Does the fire affect the meadow the way you expected?
  ○ Graph "Bumbles"
  ○ How does the fire affect the bumble population?

● Choose a variable and change it ..... then, simulate!
What Comes Next?

Now that you have some familiarity with the Vensim software, it’s time to get creative!

What question would you like to ask? What would be interesting?

Some ideas to get you started …

-- Plague: bumble flu hits the population hard
-- Hunters: humans with a license to kill woofs
-- Environment loss: meadow capacity decreases over time
-- ???

The choice is YOURS.

Task:

- Add something to the model
- Document what you have added
- Play with variables, make graphs, etc.
- Have fun!
SUPPLEMENTARY MATERIAL

Hand-simulated bumble population numbers:

<table>
<thead>
<tr>
<th>Month</th>
<th>Starting Pop</th>
<th>Eating Capacity</th>
<th>Grass Eaten</th>
<th>Grass Required</th>
<th>Grass Deficit</th>
<th>Bumble Starved</th>
<th>Pop After Starve</th>
<th>Bumble Births</th>
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<td>1</td>
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<td>60</td>
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<td>1000</td>
<td>1500</td>
<td>500</td>
<td>250</td>
<td>500</td>
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</tr>
</tbody>
</table>
Simple Bumble Population Model (first part)

Vensim Model:

Graph of Bumbles:

Things to notice:
- The “level” automatically integrates the rates in and out
- This graph shows exponential growth of the bumble population
Simple Bumble Population Model (Complete)

Vensim Model:

![Diagram of bumble population model]

Graphs of Bumbles and bumble births/deaths:

Things to notice:
- Bumble population grows exponentially until starvation deaths begin to occur
- Bumble births curve matches the population curve
- Bumble deaths curve begins abruptly but then curves smoothly
- Steady state happens in the population when births equal deaths
Simple Bumble Population Model (Complete, with Woofs)

Vensim Model:

Graph of Bumbles:

Things to notice:
- Bumble population grows more slowly, and reaches equilibrium later
- Equilibrium population is smaller
Complex Meadow:

Vensim Model (just the new meadow)

Vensim Model (with the meadow linked in)

Graph of Meadow and Bumbles:
Things to notice:

- The meadow and bumbles both reach equilibrium, but the values are different than before.
- The bumble population overshoots equilibrium a bit, growing faster than can be supported by the meadow.

**Complex Meadow (with Fire)**

Vensim model:

Graph of Bumbles and Meadow:
<table>
<thead>
<tr>
<th>150 Points</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>/50</td>
<td>Task #1</td>
</tr>
<tr>
<td></td>
<td>✑ Build simple-meadow Bumble model in Vensim</td>
</tr>
<tr>
<td></td>
<td>✑ Choose a variable and run simulations for different values of that variable</td>
</tr>
<tr>
<td></td>
<td>✑ Compare graphs of the simulations</td>
</tr>
<tr>
<td></td>
<td>✑ Write a paragraph discussing how the variable affects the simulation</td>
</tr>
<tr>
<td>/50</td>
<td>Task #2</td>
</tr>
<tr>
<td></td>
<td>✑ Add more complex Meadow to the model in Vensim</td>
</tr>
<tr>
<td></td>
<td>✑ Choose a variable and run simulations for different values of that variable</td>
</tr>
<tr>
<td></td>
<td>✑ Compare graphs of the simulations</td>
</tr>
<tr>
<td></td>
<td>✑ Write a paragraph discussing how the variable affects the simulation</td>
</tr>
<tr>
<td>/50</td>
<td>Task #3</td>
</tr>
<tr>
<td></td>
<td>✑ Add something new to the model</td>
</tr>
<tr>
<td></td>
<td>✑ Provide a list of any new Levels and Variables, including the relationships (Arrows), equations, and starting values.</td>
</tr>
<tr>
<td></td>
<td>✑ Choose a variable and run simulations for different values of that variable</td>
</tr>
<tr>
<td></td>
<td>✑ Compare graphs of the simulations</td>
</tr>
<tr>
<td></td>
<td>✑ Write a paragraph discussing how the variable affects the simulation</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>50 Points</th>
<th>Work Habits</th>
</tr>
</thead>
<tbody>
<tr>
<td>/25</td>
<td>Class time is used effectively to complete components of project</td>
</tr>
<tr>
<td>/25</td>
<td>Work for all components is accurate, completed, turned in on time and final product quality</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>30 Points</th>
<th>Digital Portfolio (Work Habits)</th>
</tr>
</thead>
<tbody>
<tr>
<td>/10</td>
<td>Appropriate selection of work is posted to Digital Portfolio</td>
</tr>
<tr>
<td></td>
<td>✑ with appropriate viewing permissions</td>
</tr>
<tr>
<td></td>
<td>✑ are easily viewed and able to be read</td>
</tr>
<tr>
<td>/10</td>
<td>Introductory paragraph about this project is posted and includes:</td>
</tr>
<tr>
<td></td>
<td>✑ overview of class</td>
</tr>
<tr>
<td></td>
<td>✑ description of project</td>
</tr>
<tr>
<td></td>
<td>✑ discussion of skills/concepts/topics addressed</td>
</tr>
<tr>
<td>/10</td>
<td>Reflection about your work is posted and includes</td>
</tr>
<tr>
<td></td>
<td>✑ reflection on progress with skills/topics/concepts</td>
</tr>
</tbody>
</table>
thinking during the course of this project, patterns you observed through the work or connections you made to course topics

Portfolio Grading for Statewide Assessment

Summary

<table>
<thead>
<tr>
<th>KDE</th>
<th>Evaluation*</th>
<th>Based On</th>
</tr>
</thead>
<tbody>
<tr>
<td>Systems Thinking</td>
<td>D P A N</td>
<td>Application</td>
</tr>
<tr>
<td>Practical Application</td>
<td>D P A N</td>
<td>Application</td>
</tr>
<tr>
<td>Independent Skills</td>
<td>D P A N</td>
<td>Work Habits</td>
</tr>
</tbody>
</table>

*Distinguished, Proficient, Apprentice, Novice

KDE Topics

Systems Thinking
- Using Feedback Loops & Connection Circles
- Using Stock & Flow Maps/Models

Practical Application
- Making connections: Recognize similarities between new tasks or situations and previous experience
- Using previous knowledge and skills: Understand how and when to use skills and experiences learned in new situations, within the context of future assignments and practical situations, both intradisciplinary and interdisciplinary.
- Applying understanding: Apply learning to real-world, authentic problems beyond the classroom walls.

Independent Skills
- Taking initiative: Independently initiate the first and subsequent steps of the task or challenge.
- Persevering: Work through challenges, demonstrating resourcefulness and perseverance. Consult teacher when additional information or guidance is needed. Keep with a task even when it is challenging or uninteresting. Work without need of redirection from teacher or peers.
- Following through: Meet deadlines and submit all elements of a task on time.
- Reflecting: Take stock of work and learning, reflecting on success, challenges, and strategies learned to continue building independent work skills in the future.