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# Building System Dynamics Skills in K-3 (Ages 5-8) Students

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**Abstract**

Over the course of the last five years, teachers in K-12 education community have gradually developed a series of games and activities appropriate for generating system dynamics understanding in the youngest school-aged children. A number of these activities will be presented along with examples of how they can be used in classrooms and with individual students. The materials presented are available on the Creative Learning Exchange website (http://www.clexchange.org)

**Introduction**

In 1991 Jay Forrester, with the financial help of John Bemis, founded the Creative Learning Exchange for the purpose of nurturing the use of system dynamics and learner-centered learning in K-12 (ages 5 to 18) education. At that time there were some examples of the use of system dynamics with older high school students, ages 16-18, and a few uses of simulations created with system dynamics models for younger children (ages 11-13.) The use of the first user-friendly system dynamics modeling tool, STELLA, greatly facilitated these inroads into the education of younger students. In 1978 Nancy Roberts demonstrated that 10 and 11 year olds were capable of understanding the concepts of feedback structures with the use of causal loop diagrams. (Roberts, 1978) Until very recently, however, no one has attempted to teach very young children (ages 5-8) the concepts and tools of system dynamics.

A number of enterprising teachers have started to bring system dynamics to their younger students in various creative ways. Many of these lessons are based on the premise that younger children need activity to construct knowledge. A good way of achieving this is through the use of gaming. Many games, which are appropriate for adults, can be adapted to be used by children. The games in the Systems Thinking Playbook by Linda Booth-Sweeney and Dennis Meadows have found a home throughout the education of 5-18 year olds. (Booth-Sweeney, 1996) A number of school systems have adapted these simple games to help construct systems knowledge. Scott Suter adapted some of the exercises specifically for 10-11 year old children in the Catalina Foothills district.

There are a number of games that have been created and adapted for very young children. I would like to highlight a few of them for you. All of these curricula are available on the Creative Learning Exchange website ( http://www.clexchange.org).

**The Friendship Game** by Peg Clemans **(**much of this section is directly quoted from SS1996-11FriendshipGame found on the Creative Learning Exchange website- http://www.clexchange.org) (Clemans, 1996)

This game was developed for the youngest age school children (ages 5-6.) The purpose of the game is to graphically demonstrate that friendly behavior leads to more friends while blocking (unfriendly behavior) leads to fewer friends within a classroom setting. This game is an example, as are the ones which follow, of activities which are then reinforced by debriefing and the use of system dynamics to increase metacognitive learning.

**Game Objectives:**

1. Students will be able to discuss specific behaviors for making and keeping friends, "friendship skills", and specific behaviors that block friendships, "blockers".
   *Procedures to achieve Objective 1:*
   - Brainstorm friendship skills and friendship blockers with students. Skills might include talking nicely, respecting each other, sharing, joining in, allowing others to join in games, helping someone, being polite, etc. Blockers might include saying mean things, hitting-not keeping hands to yourself, not sharing, not allowing others to play etc.
   - Have students illustrate each idea on a piece of construction paper.
   - Use the butcher paper to make two wall murals-one with the skill illustrations and one with the blocker illustrations. These can be displayed and reviewed before starting the game.

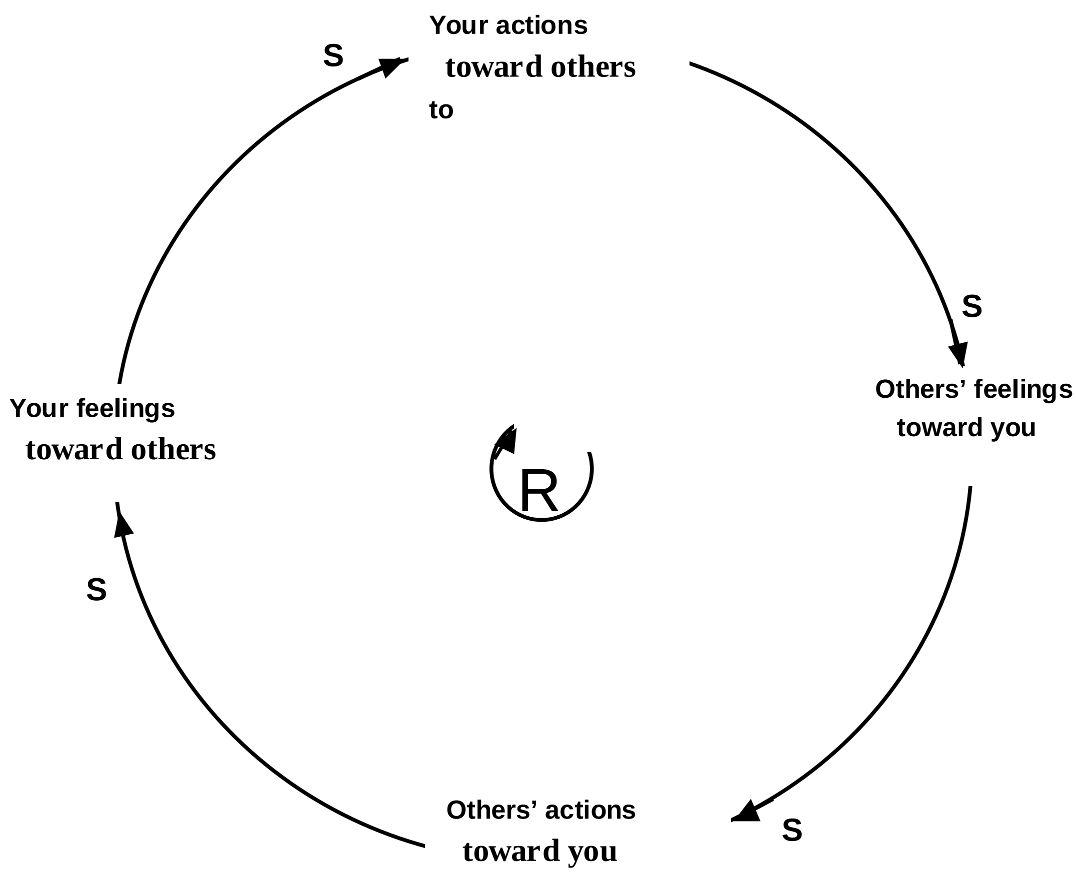
2. Students will state a relationship between: a) the number of friendship skills and the number of friends and b) the number of blockers and the number of blocked friendships.
   *Procedures to achieve Objective 2:*
   - Have a certain number of students acting as friendship skill people (yellow belts) and other students acting as friendship blockers (brown belts). The remaining students will act as classmates (3rd color belts). One side of the playing area is determined to be the friendship side and the other side will be the blocker side. Classmates sit in a row down the middle of the playing area. Choose 6 friendship people and 3 blocker people. This worked well with a class of 23 students.
   - Have the students predict the outcome of round 1. When the starter gives the go signal, the friendship people and the blocker people power walk to the center area where all of the classmates are sitting, tag a classmate and bring them back to their side. The round is over when there are no classmates left sitting on the center line.
   - Discuss results with class. You may want to use pictographs or behavior-over-time graphs (BOTGs) to record data.
   - Round two will be the reverse of round one (3 friendship people and 6 blocker people).
   - Have students predict the outcome based on the first round. Continue playing and changing the numbers of skills and blockers until everyone has had a chance to be a skill or blocker.
   - Discuss after each round having students state a relationship between the number of skills and blockers. Record on BOTGs.

3. Students will be introduced to the concept of reinforcing relationships. In this game, students will experience the concept that practicing their friendship skills could not only lead to a friendship, but could also make more friendships likely. The same relationship will be seen when blocking behaviors could block a friendship and could make future friendships less likely. (See Causal Loop Diagram)
   *Procedures to achieve Objective 3:*
   - Introduce the children to the concept of reinforcing relationships (having a friend could lead to more friendships, blocking a friendship could lead to more blocked friendships.) Extend the game by allowing each classmate tagged by a friendship person or a blocker

person to return to the center classmate line and bring back one more person to their side.

- Discuss and analyze with students.  We found that this version of the game worked better when played with another class (more children helped the results to be more dramatic).

**Causal Loop Diagram**
**Emphasizing the reinforcing nature of actions and feelings.**




**The In and Out Game** by Alan Ticotsky and Rob Quaden with Debra Lyneis (much of this section is directly quoted from SE1999-09In&OutGame found on the Creative Learning Exchange website- http://www.clexchange.org) (Ticotsky, 1999)

*The In and Out Game* is a preliminary system dynamics modeling lesson for kindergarten and primary grade students which is also adapted for use with upper elementary and middle school students. Young students learn about stocks and flows by physically moving into and out of the group of players in the game. They count and graph the stock of players over several rounds and discuss how the resulting graph describes the behavior they have observed. Older students play an abbreviated version of the game. They are then introduced to the mechanics of STELLA system dynamics modeling software and build their own simple computer models of the game.

*The In and Out Game* comes at the very beginning of the sequence. For kindergarten and primary students, the game provides a concrete way to learn about stocks and flows. It also introduces them to graphing behavior over time. The game is used in an abbreviated form for older students who do not need to actually act out the game but who still need some link to the concrete process. Once students have played the game at any level, referring back to it quickly refreshes their understanding of stocks and flows in subsequent lessons.

**Objectives**

- Students will learn that a stock is an accumulation governed by flows in and out over time by physically moving into and out of a stock of players at set intervals.
- Students will graph the behavior of the stock over time on a line graph.
- Students will observe how the graph changes if the flows are changed. They will make predictions and test them. They will learn that a steeper line means faster growth.
- Students will be introduced to a system dynamics stock and flow diagram of the game.
- Students will recognize that the concrete game, the graph, and the stock and flow diagram are all different ways to describe the same behavior.
- Older students will be introduced to STELLA modeling on the computer.

These objectives are achieved by extensive debriefing after the game is played.

**Playing the Game: Kindergarten and Primary Grades**

1. Explain to the students that they will be playing a game and keeping track of the number of players in the game. They will be making the rules of the game, counting the players, and recording their data on a table and on a graph. Designate a place in the room for the players to stand and delineate it with rope or masking tape on the floor. Also delineate the flow "pipes" into and out of the stock of players.

2. Set the rules for the first game as "2 In and 1 Out." This means that for every round of the game two students will go into the group of players and one student will go out. The designated place on the floor is empty to start.

3. Play several rounds of the game with the teacher selecting volunteers. Ask all of the students to count how many players are in the box *at the end of each round* and record that data on a table on the blackboard or easel pad. Record the initial number of players (0) on the first line.

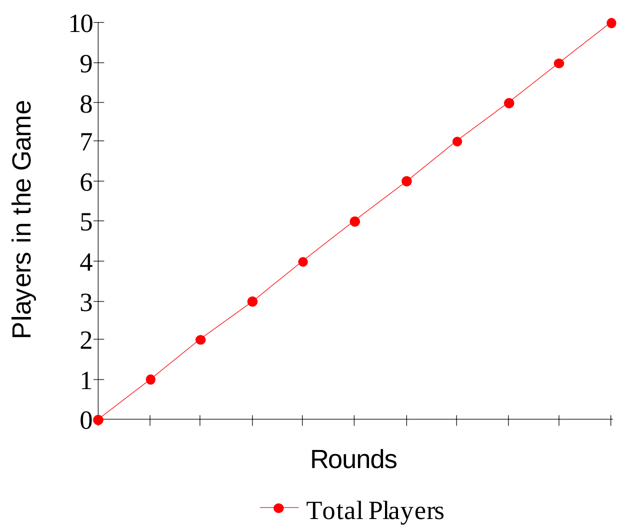
4. Analyze the data a bit by asking students to look for patterns. Discuss how the number of children going in or out each round remains constant while the total number of players increases. Why is this? Solicit predictions for the next rounds.

5. Graph the total number of players over time. On a large graph, explain that the vertical axis tells how many players are in the game and goes from 0 to the number of students in the class. Time, in this case the number of rounds, is on the horizontal axis.

    - Explain to students that this will be a *line graph, which* will show us patterns of behavior over time. Since most young students are familiar with only bar graphs, line graphs may need their own introduction either as part of this lesson or beforehand. Use Unifix cubes and large grid graph paper to explain the line graph in a concrete way. As you count the total number of players each round, stack that number of cubes and hold it against the graph just as students would build a bar graph. This time, however, instead of coloring in the column on the graph, just put a dot on the graph representing the *top* of the stack of cubes, "to save time." Do this for a few rounds until students are able to understand the dots and connect the line without the cumbersome blocks. In system dynamics, it is very important that students use line graphs because they show patterns of behavior over time.

- The vertical scale on the classroom graph goes from 0 to the number of students in the class just to give that scale a concrete meaning for students in this introduction. Later, this scale will change.

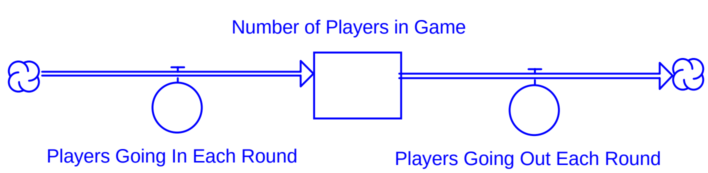
6. Draw the line graph. Start with 0 students at time 0, and graph the number of players as a class, one round at a time, continuing on as the students play out a few more rounds. Play long enough for students to see a pattern.




7. Discuss the graph with the students. What does it say? What predictions can they make?

8. Let the children change the rules (3 In and 2 Out, for example) and play the game again. Depending on the class, you may be able to omit the table or just briefly set it up and focus on drawing the graph. Graph the behavior on the same graph as the first game to compare them. What is different, and why? Let students observe that a steeper line means that the number of players is growing at a faster rate; a flatter line shows slower growth.

9. Introduce the students to a stock and flow diagram on the blackboard as another way to describe how the number of players in the game is changing. The "Number of Players in the Game" is the "Stock." The stock can increase by the flow of "Players Going In Each Round;" it decreases by the flow of "Players Going Out Each Round." Let the students help in defining these terms. The clouds mean that we have as many players as we need to use and that once they are out of the game we don't have to think about them.




Use the bathtub analogy as another example of a stock and flows. The level of water in the tub depends on the amount of water flowing in the faucet and out the drain over time.

**The Mammoth Extinction Game** by Gene Stamell, Alan Ticotsky, Rob Quaden with Debra Lyneis (much of this section is directly quoted from CC1999-04MammothExtinction found on the Creative Learning Exchange website- http://www.clexchange.org) (Stamell, 1999)

In this interdisciplinary science, math, and social studies lesson, third graders examine how the wooly mammoth became extinct about 11,000 years ago. First, they play a hands-on game with dice and graphing to understand how the mammoth population declined. Then, as a class, they use a system dynamics model to see what would happen to the population under varying conditions. With the game and the model, students gain a deeper understanding of the process of extinction. They learn about graphing, probability and exponential decay in math, and they are introduced to system dynamics modeling as a useful tool for looking at problems.

**Objectives for Students**

- Students learn that extinction is a process that plays out over time.
- Students explore the causes of the decline of the wooly mammoth population and examine the theory that the advent of human hunting dealt the population its final blow.
- Students use two simulations of the mammoth population: a hands-on dice game, and a computer simulation. They discuss how these are both "models" of the mammoth population because we cannot study and count the real animals.
- Students graph the mammoth population over time and use basic concepts of probability during the dice game.
- Students are introduced to system dynamics modeling with the computer simulation as a tool for studying a problem more deeply. They make predictions about the population's growth or decline under varying conditions, and they read and interpret the model's behavior-over- time graphs. Students are exposed to the idea of exponential decay (without using that term.)
- Students learn the importance of cooperation when working in groups.

**Playing the Dice Game: Day 1**

1. <u>Explain the concept of a "model</u>." Explain to the students that this game is a "model" of a mammoth herd. Each die stands for one mammoth. This is a useful way to look at the mammoth population because it would be impossible to do this with real mammoths. Remember, of course, that some children will still understand it from their own point of view. One third grader "cried" whenever a mammoth died; her team began rigging the game under the table to prevent any of their animals from dying! Older children would have a more mature understanding of "pretend."

2. <u>Play the first game.</u> Distribute the attached "Mammoth Extinction Game" instruction sheet to students and go over the rules as written on the sheet.
    - Divide the students into small teams. Each team begins with a herd of 20 mammoths; each die represents one mammoth. The numbers on the dice represent what happens to each mammoth. For example, "1" = death by starvation, "2" = birth of a calf, etc.
    - Each roll of the dice represents one year. Students share the dice and roll them simultaneously. After each roll, students adjust their population according to the numbers rolled. For example, each "1" rolled is a death and is removed from the herd; each "2" rolled is a birth and adds one mammoth to the herd; etc.

- Students roll the dice for 20 turns, representing 20 years. Each year, one student records the data on the first column of the "Keeping Track of Your Herd" worksheet, in red.

3. Draw the graphs. After students have recorded the population data from the first game, ask them to graph that information on the graph worksheet provided. Third graders may need help with this to get started. Show students how to use a red marker to place a dot at each data point and then connect the dots to draw a line graph. (Older students are able to draw the graph as they collect the data, but third graders need two steps here. Younger students may also need larger graph paper than the graph provided, depending on their graphing experience.)

4. Display and discuss the graphs. Questions such as, "Is anyone surprised by any of the results?" or, "Are the graphs all the same?" lead to discussions on *slope* and *rate of change.* Students may notice that although all of the graphs show the same downward trend in the populations, none of the team graphs are exactly alike. Explore the idea with them that even in real life no two herds would have exactly the same experience. Some may have better food; some may encounter worse weather; some may be closer to hunters; etc. However, all the graphs show a similar downward slope, and if you could put all the herds together, they would *average out* to one declining line on the graph.

   (This would conclude Day 1 activities for third graders, although older students could continue on with the next activity.)

**Playing the Dice Game: Day 2**

1. Play the game once more. Now it is time to introduce human hunters.
   - Use the second column on the data sheet and a blue marker to distinguish the second game from the first.
   - Ask students to change the odds in the dice game. Explain to them that in the second game all of the numbers on the dice will stand for the same things, *except* that "6" will now represent "a mammoth killed by a hunter" instead of "a mammoth keeps living." The probability of dying is now 3/6 (or 1/2) instead of 2/6 (or 1/3). Discuss the fractions.
   - Again, students play for twenty rounds, record their data on the worksheet, and graph their results. If students graph the second line in blue on the same graph worksheet with the first red line, they can compare the results of the two games.

2. Discuss the graphs. After all the teams have finished, display all the graphs and discuss what happened to the populations. Did the number of mammoths go up, down, or stay the same? Did any teams go extinct? What happened after the hunters were added in the second game?
   - Discuss how a population changes slowly over time because of births and deaths.
   - Compare the graph of the first game (red line) with the graph of the hunter game (blue line). The first game has a *flatter* line; the hunter game produces a *steeper* line. Reinforce this vocabulary as students explore the different *rates of change.* A flatter line indicates a slower rate of decline. The hunter game produces a steeper line because the mammoth population declines at a faster rate with the additional deaths by hunters.

- Discuss again why all graphs are not exactly alike. Even in real life, no two herds would have exactly the same experience, but if you put all the herds together, the line would *average out* to one smooth line with a declining slope; the hunter (blue) line is steeper than the first (red) line.

- Talk a little bit about probability and randomness. Many third graders believe that a probability of 1/6 means *exactly* 1/6 of the population *every time*. This is a developmental issue that needs discussion. A roll of the dice is random and a little variation is to be expected. Taken together, all of the dice rolled by all of the teams would *average out* to approximately 1/6. Older children will have a freer understanding of this idea.

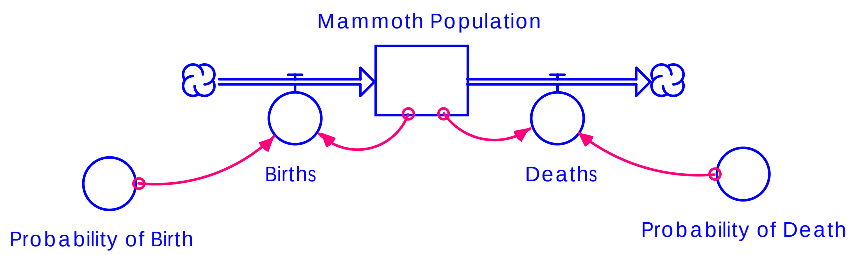
3. Discuss final debriefing issues.
    - Stress the importance of collecting *accurate data*. If the dice are accidentally (or deliberately) tipped, or if dice are incorrectly removed or replaced, the data changes. You cannot draw good conclusions from bad data. This is a significant issue for students.
    - Conclude the lesson by discussing group dynamics in the classroom. “How did someone in your group help make playing the game easier?” “Were there any problems?” Students need to cooperate to work in groups. This is another significant issue, at any age.

**The Mammoth Extinction Model**

The dice game has given students a hands-on opportunity to learn about how the mammoth population changed. By adding and removing dice from their herds, they have learned that a population grows by births and decreases by deaths. When there are more deaths than births, the population declines. They have also learned that the changes in their populations can be recorded and analyzed on a graph. Students are now ready to expand their learning by using a computer simulation of the mammoth population.

**Introducing the Lesson**

1. Review the Concept of a “Model.”
    - Briefly review the rules and outcomes of the mammoth dice game. Remind students that the dice game was a “model” of the mammoth population, which made it easier to study the mammoths in their classroom.
    - Explain that a computer model is another kind of “model.” This time, they will be using the computer to play the same game as they did with the dice. The computer will count up and keep track of the size of the mammoth herd. The big advantage is that the computer can do this much faster than they could do it on paper, so they can try many different experiments with the numbers. There are no mammoths inside the computer! The computer is modeling a “pretend” herd and making a graph just as they did in the




dice game.

2. Introduce the Model Diagram.
    - Display the model diagram on the screen for the students and very briefly explain its parts. The "Mammoth Population" box is a "*stock*;" it tells how many mammoths are in the herd at any time. The pipes going in and out are "*flows*." "Births" flow into the population to make it grow; "Deaths" flow out of the population to make it decrease. Both happen at the same time.
    - The "Probability of Deaths" and "Probability of Births" converters take a bit more explanation. Relate the abstract concept of probability to the hands-on dice game to help students understand it at their level. Review the earlier discussions on probability. Remind students that in the dice game some numbers on the dice stood for births and some stood for deaths. There are six possible numbers on the dice. If one of them stands for a birth, then there is a *one out of six* chance for a birth, or 1/6. This is the number in the "Probability of Birth" equation. Similarly, if two numbers on the dice stand for deaths, then there is a *two out of six* chance of death, or 2/6. (This equals 1/3 for students who have learned to reduce fractions, but the model will accept 2/6 if they have not.) This is the number in the "Probability of Death" equation.
    - In the model diagram, there are arrows connecting the "Mammoth Population" stock to the "Births" and "Deaths" flows. Explain to students that after the computer counts the number of mammoths in the herd at each step, it will use the probability numbers to compute how many mammoths to add or subtract from the herd. For example, if there is a 1/3 probability of death, the computer will take 1/3 of the total number of mammoths in the herd, or *one out of every three* mammoths.
    - The number of mammoths added or subtracted each time depends on the number of mammoths in the herd times the probability fraction. Take the time to explain this general concept to students so that they will understand what the computer is doing when they begin changing the probability values later.

**Good Questions**

Many good questions arise as students are conducting their experiments on the model. Take the opportunity to discuss these ideas as they develop.

- What makes a population grow? Over time, births must exceed deaths. A higher birth rate compared to the death rate causes faster growth.
- What makes a population decline? Over time, deaths must exceed births with a faster decline for a higher relative death rate.
- What keeps a population the same? Births must equal deaths, at any level.
- Why does the line on the graph curve? Why is the growth so steep at the end; why is the decay so steep at the beginning? For growth, the birth rate applies to a larger and larger herd; more and more mammoths are having babies. For decay, many die off at first, but the death rate applies to a smaller and smaller herd, so fewer actual animals are dying as the herd gets smaller.
- Does the size of the herd matter? The computer model starts with 100 mammoths. What happens if you start with 1000 mammoths instead? Would a larger population take longer to go extinct? Ask student for predictions. This is a very sophisticated question for third graders, but some will get it and describe exponential decay very eloquently in their own words. Increasing the size of the herd makes little difference

to the time of extinction if the birth and death rates stay the same. The curve is exactly the same. Try this to prove it. Half of the herd is still gone at the same time.

- How could hunters fit into this story? A population that is at equilibrium (or growing) is safe. Births are keeping up with deaths. However, anything that tips deaths greater than births is a threat. Worsening climate might cause a slightly higher death rate causing the population to decline. This happened in previous ice ages and the population got smaller, but the reduced mammoth population must have been able to survive and grow again when the weather improved. If you add the high death rates caused by hunters at the same time as the climate worsens, however, the herd declines too quickly with no chance to grow again. The mammoths become extinct.

These are all excellent questions, which lead to a deep understanding of the process of extinction. However, students have learned a great deal more from this little modeling lesson. They have learned the fundamentals of population dynamics, how to make scientific predictions and interpret their results on a graph, and the basics of probability and exponential growth. Most important, students have learned to let their own good questions lead them to these discoveries

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