the Creative Learning EXCHANGE

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THE MAMMOTH EXTINCTION GAME

Prepared with the support of the Gordon Stanley Brown Fund

by Gene Stamell, Alan Ticotsky and Rob Quaden, with Debra Lyneis

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.

BACKGROUND

Third grade students in Carlisle, Massachusetts learn about the ice ages as part of a prehistory strand leading to a unit about the indigenous people of the Americas. Students are fascinated by the mysterious demise of the giant ice age mammals. Before playing the games in this lesson, students study the wooly mammoths and discuss theories of their extinction.

The idea for adding system dynamics modeling to the mammoth study arose when third grade teacher Gene Stamell introduced the dice game to the mammoth unit. Suspecting that it might be a good systems application, he approached Carlisle's systems mentors Alan Ticotsky and Rob Quaden who then developed the model for Gene's class and helped him teach it. All three teachers were so impressed with the students' depth of insight and enthusiasm that they helped the other third grade teachers in the school adopt the lesson too. (For a more on what the students could do, see "Let the Students Surprise You" by Debra Lyneis, also available from the Creative Learning Exchange.) Before this lesson, the classroom teachers had been briefly introduced to system dynamics modeling, but none of them had built models or used them with their students. The two systems mentors in Carlisle are supported by the Waters Grant Foundation.

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.

***Mammoth** continued on page 3*

LET THE STUDENTS SURPRISE YOU

First in a series of "What It's Like to Be a Pioneer"

Prepared with the support of the Gordon Stanley Brown Fund by Debra Lyneis

Jay Forrester has suggested that we could speed the spread of learner-centered-learning and system dynamics in K-12 education by sharing tales of "what it's like to be a pioneer." It might help others who are starting out, or just curious, to know about other teachers' experiences, positive student outcomes, pitfalls, political issues, responses of administrators and fellow teachers, student and parent feedback, triumphs and tribulations. This paper presents one such vignette. If you have other tales to share, please let Deb Lyneis know. (LyneisD@cle.tiac.net)

Teachers are often amazed at how much their students can do when they are engaged in a lesson using system dynamics. For the students the lesson is just fun. For the teachers, however, it is an enlightening experience to see students display a depth of understanding and enthusiasm that the teachers would not have thought possible. Teachers who use system dynamics in their teaching say that one such experience was enough to get them going.

One example is a third grade lesson in Carlisle, Massachusetts. Third

***Surprise** continued on page 9*

UPDATES…

GIST

The GIST project in Glynn County, Brunswick, Georgia, has been in existence for seven years. Last summer they brought about 30 people to the national conference. That effort, on top of six years of work, has resulted in an ongoing system-wide study group including administrators and teachers.

The two mentors, Jan Mons and Steve Kipp, have been working extensively in the middle schools for the last several years. Next year, Steve will concentrate on both the middle school and the high school levels, while Jan will work with the elementary and middle schools.

They are concentrating on helping teachers work independently with pre-existing curricula in their classes, and encouraging those who are capable of developing their own curricula. They are working hard keeping the burden from being shifted to the interveners (in their roles as mentors). Their focus on this aspect is instructive to us all, and is an issue that we all need to work on in order to get independent users of system dynamics, both teachers and students.

A statement Jan made while I was visiting them has stuck in my mind and I think it is pertinent. In her seven years of experience trying to learn systems modeling and then to teach it, she has found two factors to be important.

1. Try not to have people (teachers or students) start to learn to model with a system they are not familiar with. You are then trying to teach two things at once, never a good pedagogical approach.

2. Teach modeling using a system that the student (or teacher/student) has an emotional investment in. Money is the best one. Everyone knows about money and is personally interested.

EDITORIAL…

As the end of the year approaches, we all try to make sure that the year's accomplishment for both our students and ourselves is significant. Not until we get to the summer is the opportunity to reflect available, when we get a chance to look at what was good and what needs improvement for next year. As this final CLExchange for the school year reaches you, we extend our best wishes for a full summer with plenty of opportunity for refreshment, cogitation, and learning. We hope that at this time next year we will all be looking forward to seeing each other in the early weeks of summer at the conference 2000 in the Portland area.

There is a significant opportunity that has not been sufficiently utilized in the K-12 systems education community. That is the Gordon Stanley Brown Fund. It is the opportunity to get reimbursement for writing up curricula which you have developed for your students. If you are uncertain about the time, or about whether what you have should be written up, please call. Deb Lyneis is available to give help and support, as well as to do the writing, if you wish. Please consider it. Call or write me at the CLE.

Have a happy summer!!!

Lees Stuntz (stuntzln@tiac.net)

RESOURCES…

MACSUNITE SPECIAL ANNENBURG PBS WEATHER EXHIBIT

I am pleased to announce that the website that I designed for the Annenburg Public Broadcasting Foundation, Weather, has been published on the internet for educational projects, activities and teaching and learning. I am most proud of the activity I designed, the "Storm Chaser simulation" in the Storm section. The setting takes place in Kansas.

Below are the URL links to the main exhibit page, the weather website and the main links resource page. All pages from the website can be viewed and accessed via the main page.

I hope that you enjoy it. If you have questions, please contact me.

Eric Flescher, Ed.D
(KCStarguy@aol.com)
Annenburg PBS Website Academic Specialist/Consultant Editor/ Webmaster, MacsU.N.I.T.E.-MacIntosh Users Network for Integrating Technology into Education- subscribe via macsunite-subscribe@egroups.com or at http://members.aol.com/kcstarguy/macsunite/unite.htm

Annenburg learning exhibits main page
http://www.learner.org/exhibits/

Annenburg Weather and Climate website designed by Dr. Eric Flescher
http://www.learner.org/exhibits/weather/

The Mammoth Extinction Game, continued from page 1

- In the dice game, students graph the mammoth population over time and use basic concepts of probability.
- With the computer simulation, students are introduced to system dynamics modeling 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.

PLANNING THE LESSON

Grade Level
The lesson is appropriate for elementary students in grade three and up.

Interdisciplinary Subjects
Social Studies, Science and Math

Time Requirements
Day 1: Allow one hour for the dice game.
Day 2: Allow 40 minutes to play one more time. (Older students would need less time.)
Day 3: Allow 30 to 45 minutes for the computer modeling lesson.

Materials Needed
For the dice game: 2 worksheets and 20 dice for each group of students, red and blue markers. (Scrounging enough dice is the game's biggest challenge for teachers!)

For the computer modeling: One computer with STELLA system dynamics modeling software. STELLA is produced by High Performance Systems, Inc., 45 Lyme Rd., Suite 300, Hanover, NH 03755. Although the accompanying model is in STELLA 5.0, this simple model can also be built on any earlier version of the software.
A computer projection device or a large monitor will help students see the model for the class discussion.

THE MAMMOTH EXTINCTION DICE GAME

The Context of the Game
From their study of the ice ages, the students know that huge herds of wooly mammoths roamed North America for more than a million years. Through that time, they survived several ice ages. However, at the end of the last ice age, about 11,000 years ago, the mammoths became extinct. Human hunters arrived on the scene at about the same time. As the climate changed, was the hunting by humans just enough to cause the extinction of the mammoths? The extinction dice game lets students test this theory.

Resources
The Mammoth Extinction Dice Game was adapted from a student activity on *Newton's Apple*, the PBS science program for children. The segment (Show Number 1509, copyright 1997, Twin Cities Public Television) visits a huge mammoth dig. The dice game is described in a two-page teacher's guide available online at http://www.ktca.org/newtons/15/mammoth.html. Although you do not need to download the guide in order to play this game, you may be interested in the other resources, activities, and background information which it provides. Another excellent resource for adults is the book, *The Call of Distant Mammoths*, by Peter D. Ward (Copernicus, 1997) which explores theories of mammoth extinction and relates them to modern species.

Playing the Dice Game: Day 1

1. Explain the concept of a "model." 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. Play the first game. 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" = eaten by a bear, 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 one is removed from the herd; each "3" 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.)

Mammoth *continued on page 4*

The Mammoth Extinction Game, continued from page 3

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 GAME

DIRECTIONS

1. Your group has 20 dice. Divide them as equally as possible among you.

Each die stands for 1 mammoth.
Each roll of the dice = 1 year.

2. The numbers on the dice will tell you what happens to the mammoths in your herd. Three things could happen to them:
   - A mammoth could continue to live well for another year.
   - A mammoth could die or be killed.
   - A mammoth could give birth to a calf.

This is what the numbers on the dice stand for:

1 = Death by starvation
2 = Killed by a giant bear
3 = A calf is born
4 = Mammoth keeps living another year
5 = Mammoth keeps living another year
6 = Mammoth keeps living another year

If a mammoth dies or is killed, remove that die from the herd.

If a mammoth gives birth, put an extra die into the herd.

If a mammoth keeps living, just leave that die in the game for the next round.

3.HOW TO PLAY

- Everyone rolls the dice at the same time.
- Do what the numbers tell you to do.
- On the chart, keep track of how many

mammoths are in the herd after each roll.

- Keep rolling the dice and adding or removing mammoths. Be sure to write down how many mammoths are left in the herd each time.
- Play the game for 20 years (20 rounds.)

Does your herd become extinct? If so, how many years does it take?

KEEPING TRACK OF YOUR HERD

Record the number of mammoths left in your herd after each round. *(Ed. note: Table and graph worksheets are provided.)*

THE MAMMOTH EXTINCTION MODEL

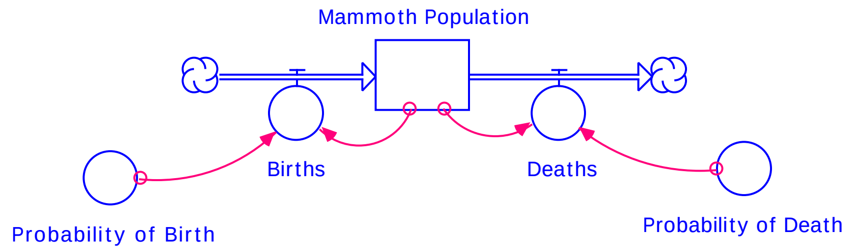
The dice game has given students a hands-on opportunity to learn about how the mammoth population changed. By adding and removing dice from their herds, they have learned that a population grows by births and decreases by deaths. When there are more deaths than births, the population declines. They have 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

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.

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.

These are the model equations.

Mammoth_Population(t) = Mammoth_Population(t - dt) + (Births - Deaths) * dt
INIT Mammoth_Population = 100
DOCUMENT: Units: Mammoths

Births = Probability_of_Birth*Mammoth_Population
DOCUMENT: Units: Mammoths/year

Deaths = Mammoth_Population*Probability_of_Death
DOCUMENT: Units: Mammoths/year

Probability_of_Birth = 1/6
DOCUMENT: The fraction of the numbers on the dice that represent births.
Units: Fraction/year

Probability_of_Death = 1/3
DOCUMENT: The fraction of the numbers on the dice that represent deaths.
Units: Fraction/year

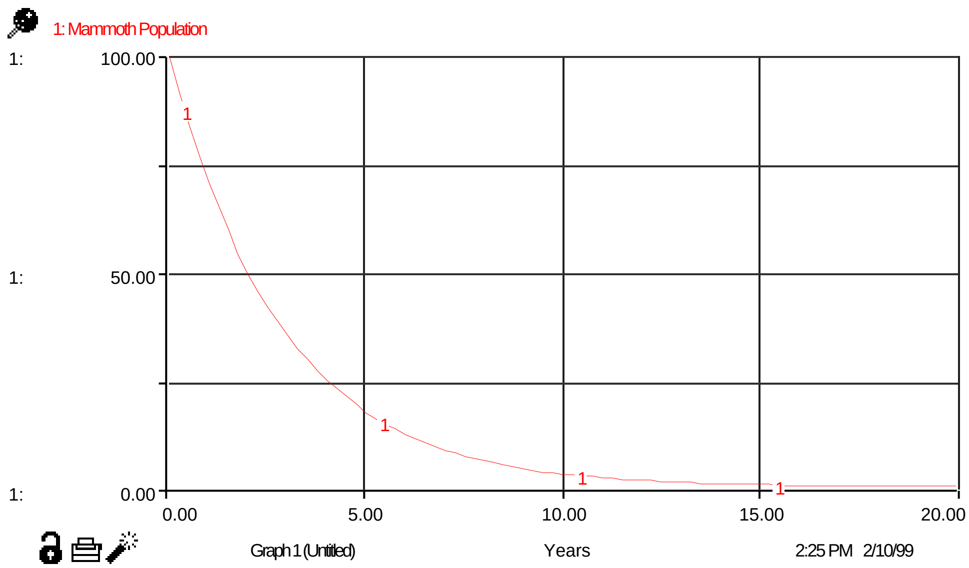
[Set the model to run and display 20 years.]

Mammoth *continued on page 6*

The Mammoth Extinction Game, continued from page 5

Run the Model

Run the model with the probability values from the first dice game: 1/6 for births and 1/3 for deaths. Display the graph to the students.



Examine the graph carefully with the class.

- What are the numbers on the horizontal axis? Time goes for 20 years.
- What is on the vertical axis? This counts the number of mammoths in the herd. The computer's herd starts out with 100 mammoths, which would be like combining all of the class team herds into one big herd.
- Why is the line smooth? Refer to the dice game graphs when putting all the graphs together averaged out to one line. The computer shows the averages for all of the mammoths rather than every little detail.
- What does the graph say? Ask students to point to the graph and tell approximately how many mammoths there are in 5, 10 or 15 years; then ask them to extrapolate for 4 years, or 7 years, etc. Ask them what year the mammoth population is down to half its original size. Do this until students can read points on the graph.
- What happened to the mammoth population? What is the "story" of this graph? The population declines very rapidly at first. Did the mammoths go extinct?

Experiment with the Model

Students are now ready to conduct experiments on the model. Briefly review the probability equations in the model and how they are similar to the dice game. Remind students how they played two dice games and that different values yielded different graphs. Then ask students to speculate what would happen to the mammoth graphs if they told the computer to try other numbers for the probabilities. Let students get carried away with this and they will want to try all sorts of different combinations of birth and death rates.

Follow these steps for each experiment:

1. Let students suggest a probability of birth and death. Keep it concrete by referring to the dice. If three numbers will stand for deaths, then the chance of death is *three out of six*, which is 3/6, or 1/2. Count on your fingers if it helps to explain it.

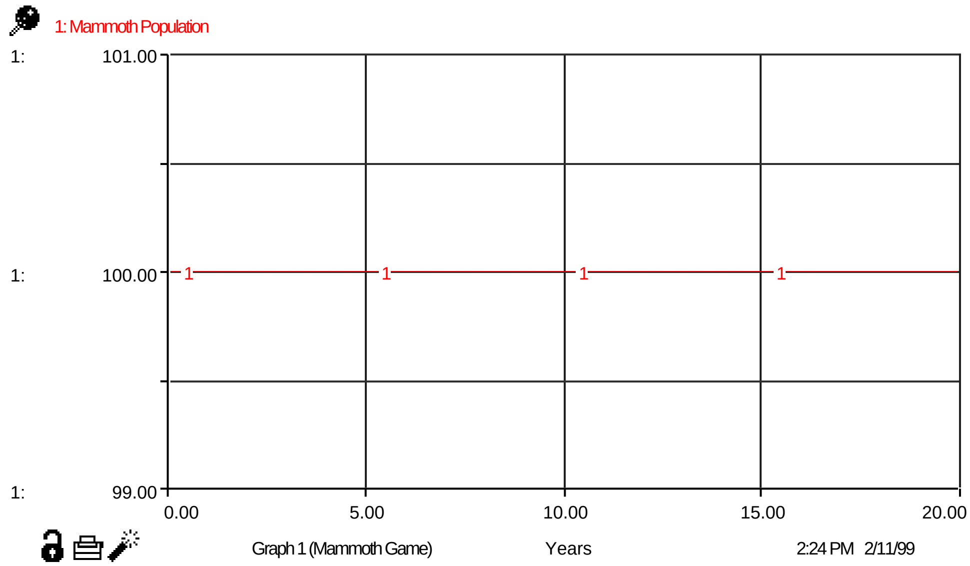
2. Ask students to *predict* what the graph will say with the new values. This is *very important*. Students should *think* about what will happen, *before* you run the model.

3. Type in the new values, run the model, and display the graph for the class to interpret. What does the graph say? Were their predictions accurate? What is the "story" of this graph? For example, what could have happened to the mammoths to cause a very high death rate? Could it be due to food shortages from bad weather, or to hunters, or both?

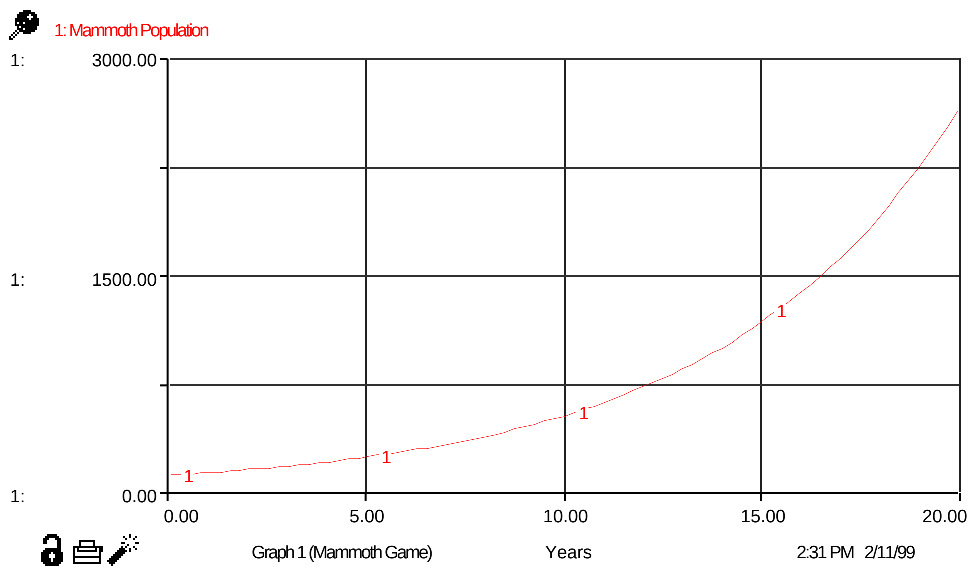
Let the students try many different sets of values for births and deaths. Be sure they try some with births equal to deaths. They should also try some with births greater than deaths, and deaths greater than births. Students enjoy this experimenting, and they quickly get very good at predicting the outcomes of their experiments.

Sample Graphs

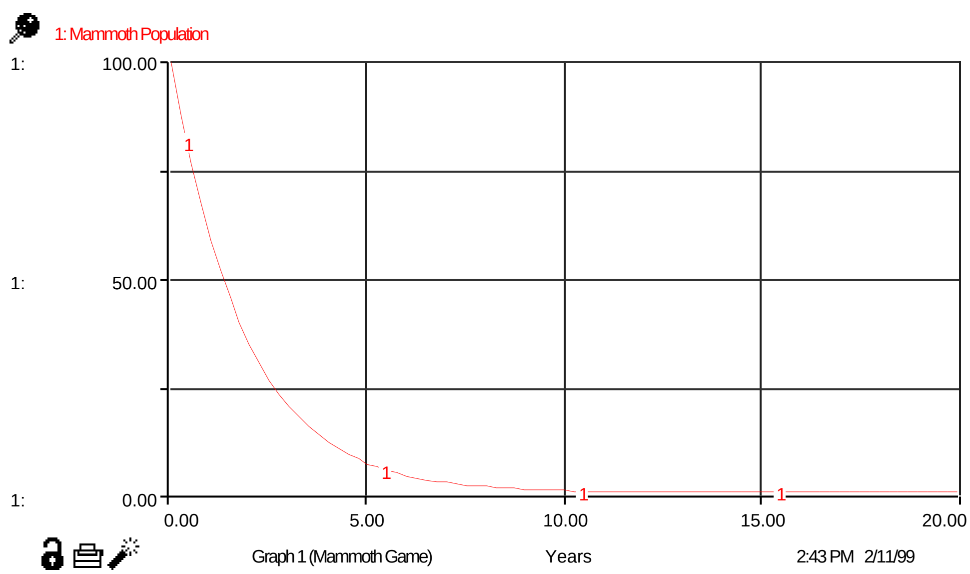
This first graph shows a 1/3 probability of birth and a 1/3 probability of death. The population is in equilibrium because the same number are born as are dying each year. Could this happen? (Notice that STELLA has changed the vertical scale.)



The second graph shows a growing population with the probability of birth at 1/3 and the probability of death at 1/6. Notice that the vertical scale has changed again to accommodate the large numbers of mammoths. Ask students how the population could get so large in just 20 years. Why does the line go up so fast at the end? Students will be able to say that there are so many births because there are so many more mammoths to have babies. (Note: When students choose very high birth rates, the vertical scale will show values in scientific notation. For example, “3e+007” means “3 followed by 7 zeroes”, or 30,000,000 mammoths! In telling the story of the graph, could the birth rate really get so high, say 5/6, since only females have babies and mammoths probably did not have multiple births?)



The thrid graph shows a rapidly declining population with probability of births at 1/6 and with probability of deaths at 2/3. What is the story of this graph? What could have caused so many deaths?



***Mammoth** continued on page 8*

The Mammoth Extinction Game, continued from page 7

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.

YOUR FEEDBACK

We welcome your feedback about this lesson. What was helpful, and what could be improved? Please send any comments or suggestions to us through the Creative Learning Exchange.

GORDON STANLEY BROWN FUND

To support preparation for distribution ofmaterials for using system dynamics in K-12 education

The Gordon Stanley Brown Fund has been established to promote system dynamics and an understanding of dynamic behavior in feedback systems in kindergarten through 12th grade schools. The Fund will focus on making teaching experiences available to others. Small and medium sized proposals are encouraged.

The Gordon Brown Fund can support teachers for:

- Released time or summer time used to put into transmittable and usable form materials and methods that have already been used in schools and that could be of help to others,
- Communicating experiences that did not meet expectations so that others can be forewarned.

Work supported by the Fund is to be available for distribution through the Creative Learning Exchange and any other channels that the author arranges.

The Fund honors Gordon Brown, who pioneered the theory and practice of feedback dynamics and engineering control systems at MIT in the 1940s. Brown went on to be head of the Electrical Engineering Department and Dean of Engineering at MIT. During retirement, he devoted energy and skillful leadership to bringing system dynamics into the Catalina Foothills school system in Tucson, Arizona.

Address applications, with an outline of the proposed project, to:
Lees N. Stuntz, Creative Learning Exchange, 1 Keefe Road, Acton, MA 01720

Let the Students Surprise You, continued from page 1

graders study the extinction of the wooly mammoths as part of a science/social studies unit on the ice ages. Math became part of the unit when teacher Gene Stamell added a dice and graphing game. With 20 dice representing a herd of mammoths and certain numbers on the dice representing births or deaths, teams of students roll the dice and graph their herd's population over time. Gene suspected a "systems" application, so he approached Waters Grant systems mentors Alan Ticotsky and Rob Quaden with the idea. Gene had been introduced to system dynamics, but he had never used a model. Alan and Rob had used models with older children, but never with third graders. Together, they built a simple STELLA model of the mammoth population based on the hands-on dice game and gave it a try in Gene's class. Then the kids surprised everyone.

These are some of the things the students could do after they played the dice game and used a system dynamics model to experiment with other birth and death probabilities:

- Students could read the behavior over time graphs produced by the computer model. They could extrapolate to determine the size of the herd for any time on the graph, even when the vertical scales changed or when the values were in scientific notation.
- Students readily interpreted the graphs, using the language of graphing. They could tell if the population was increasing or decreasing over time. Furthermore, they saw that a population with a "steep" rate of decline would become extinct sooner than one with a "flatter" rate of decline. They *wanted* to figure out what the graphs said.
- Students could make predictions and test their hypotheses on the model. They tried many different birth and death rates. It didn't take long for them to accurately predict that the population grows when births exceed deaths and declines when deaths exceed births. When someone suggested making births equal to deaths, they could see that the population would remain unchanged.
- After experimenting with varying death rates, students could discuss the effect of human hunters on the final demise of the mammoth population.
- Students grasped the concept of probability, at their own level. When they played the dice game, students learned that if one number on the dice represented a death, then there was a one out of six chance of death. When they used the model, students were able to change those probabilities. They understood that two out of six, for example, meant a higher probability of death. Following the concrete dice game, most students were able to make that abstract leap.
- As they played with probabilities, students also reinforced their understanding of fractions. Two out of six, or 2/6, is the same as one out of three, or 1/3, for example.
- Students worked cooperatively in groups to solve problems. There were fewer of the usual group dynamics issues because the students were busy working.

These were all impressive accomplishments for eight and nine-year olds in their first exposure to modeling, but the students' understanding of exponential decay really "blew the teachers away." The class was discussing how the mammoth population kept going extinct whenever deaths were greater than births, at any level. Someone pointed out that the computer model had only 100 mammoths in the initial herd. Would it be different if they started out with 1000 mammoths instead? Could they avoid or delay extinction that way? Everyone scratched their heads, including Gene who had never thought about the problem in that way. Students guessed that the mammoths would last ten times longer. Then, one child eloquently hypothesized in his own words that if one out of three mammoths died each year, it didn't matter how many there were to start because one out of every three would still die every year; half the population would be gone by the same time, and the whole population would go extinct by the same time! Then they ran the model, and, sure enough, he was right! Gene was sold! With a little bit of discussion and a few more runs, most of the class understood exponential decay and half-life at their own level, without using those terms specifically. Remarkable!

There were a few issues with the mammoth lesson, however. Some had to do with developmental readiness. For example, although the teachers explained at length that the games were "models" of the mammoth population because they could not grow and count real mammoths in class, a few students had trouble with this concept. One young child rigged her dice to prevent any of her animals from dying! Other children had problems with probability because they believed that 1/6 meant exactly one out of six every time, and they needed reassurances about averages. Teachers always need to pay attention to developmental levels in class, but it is also an important concern for system dynamicists preparing curriculum for elementary grades. Every new lesson teaches us more.

Another issue has to do with the difficulty of introducing a lesson like this in a school. Gene had been introduced to system dynamics and he had used behavior over time graphing with his class, but he probably could not have developed the modeling lesson without the help of Alan and Rob, the systems mentors. After the lesson yielded such positive outcomes for kids, Alan and Rob helped three other third grade teachers adopt it too. Each time they worked out a few more glitches, and each time the new teachers were able to conduct the lesson more on their own. Finally, Gene, Alan, and Rob wrote the lesson up under the Gordon Stanley Brown Fund for other teachers to try.

EXPERIENCES IN DEVELOPING SINGLE–DISCIPLINE AND CROSS–CURRICULAR MODELS FOR CLASSROOM USE

This paper was presented at the 1996 International System Dynamics Conference in Cambridge, MA.

In the three years of the CC–STADUS Project more than thirty cross–curricular and one hundred single discipline models have been developed by project staff and participants. These models and their accompanying curriculum are intended to expose students to the use of system dynamics as a problem-solving tool, as well as to address the problems presented in their specific content. Patterns have emerged that point out the dangers and advantages of both types of models. In part, these patterns are a result of the techniques used to teach the teachers basic modeling skills, as well as their needs in the classroom. The experiences of the CC–STADUS staff and participants lead to recommendations and suggestions for model development, model documentation, and training programs for teachers.

Increased use of system dynamics in the K-12 educational environment has been a goal of many in the system dynamics community for a number of years. The rationale has been that learning to think from a systems perspective and to problem solve through understanding the system being studied, when begun at an earlier age, would allow students to become better thinkers and learners, as well as system thinkers.

The CC–STADUS (Cross Curricular Systems Thinking and Dynamics Using STELLA) Project is one effort to introduce systems concepts to teachers and students in the pre-college environment. Its focus and methodology are good reflections of assumptions that seem rather widespread among educators working with system dynamics. These assumptions can be summarized rather simply:

- Teachers and students learn new concepts and tools best by actually using them to address problems.
- Models are most likely to be used by teachers if they are actually involved in building or modifying those models.
- The highest and most important use of systems concepts is in a multi-disciplinary environment, or as a second-best case, examining a multi-disciplinary problem in a single discipline course. This use emphasizes the complexity and inter-connectedness of real world problems. It also demonstrates the unique ability of systems dynamics to address such problems.

These assumptions directly affected the evolution of the CC–STADUS program. A major goal was to develop basic modeling skills in our teachers, allowing them to build and understand relatively simple models. In the three-week institute teachers spend most of their time "hands-on", being directed through the building of models or building models of their own design. Another goal was to develop a "library" of major cross-curricular models for use in the classroom. Teachers leave the summer institute with a major multi-disciplinary model that they constructed with a team of other participants, as well as other cross-curricular models developed by previous participants in the project.

Our expectation has been that participants in the summer institute will use modeling in their classrooms the next year. The success rate has been high (70%+) when compared to patterns of implementation experienced by many NSF institutes. What has been surprising, however, has been the type of model used by the teachers. We anticipated that the large models developed in the summer would be used by most of their creators. In fact, that has often not been the case. While teachers who have developed a specific cross-curricular model are more likely to use it than other participants, all teachers are more likely to use much simpler models that are specific to their content areas. Many of these models are similar to or based upon those models that teachers built in the earliest part of the summer institute, while working in their own content group.

Emphasis on simple models with one, or at most two stocks, and on basic concepts within a discipline, may appear to some as a step backward from learning about systems. The models may be so simple that they can be easily explained with linear or quadratic equations. The systems described have so few links as to scarcely seem to be true systems. However, it is important to remember that the focus should be on developing an understanding of both the tools and process of systems thinking. Most classrooms are still single–discipline environments. Working with models in that environment, teachers can build their expertise within their own "comfort zone", their field of specialization. The increase in the expertise with which they use modeling concepts and language makes possible communications with other disciplines through the language of modeling. The focus on both tools and process can be enhanced by looking at the simplest cases first, an approach reflected by the first few days of the CC–STADUS summer institute. When teaching an adolescent to drive, putting them in a complex Formula 1 car, part of a race at speed up to 300 km/hr, would not be the best first step. Instead, we start them out in simulators, parking lots, enclosed courses, or quiet residential streets. The same is true of systems dynamics. Our students can start by using larger models to explore complicated situations. However, in doing so they are frequently using the model as a "black box", a device that yields results without involving students in understanding the model itself. They may learn a little about the system portrayed by the model, but they do not necessarily learn about that system in depth, nor do they learn about systems in general. By starting with simpler systems, they learn how systems work. Then, when confronted with larger problems and models, their understanding is enhanced because they can see the systems within the systems. This seems to be a powerful argument for emphasizing use of simple systems with students and, at least initially, ignoring the very exciting larger models that have been developed.

While systems may allow us to address the large problems facing society in our classes, it is important not to lose sight of the process of problem solving. The tools that system dynamics gives us seem so powerful that we have a natural temptation to immediately try to use them on problems "worthy" of their power. This tendency has been observed by every group that teaches modeling. Students, whether eighth graders, high school students, college students, or teachers, begin trying to model far too complicated systems as soon as they learn how to connect a flows to stocks. Rather than concentrating on models of simple systems, novice modelers attempt to model complex systems, "interesting systems", with far too much detail. The result is a sense of frustration and can lead to dissatisfaction with the idea of modeling. The focus of the CC–STADUS project on the cross-curricular models has lead to an emphasis on these more complicated models. While excellent representations of fairly complex systems, they are comparatively hard to understand in detail, and hard to explain to students. Additionally, they are not very adaptable within the current curricular environment. It appears that teachers who have gone through the institute intuitively move away from the models when confronted with the need to use them with students. Instead they focus on simpler models and simple systems.

This tendency does not weaken the development of modeling and systems in their classes. By working with simple systems, students begin to look at even simple problems from the analytical perspective of system dynamics. They will begin to look at more complicated problems as combinations of systems. The key is to use the language of systems in approaching the simple problems. This will effect a shift in the way we think about problems. This shift is consistent with the reform recommendations currently being proposed in most disciplines. If models are simply used as a substitute for traditional mathematics or presentations without developing the understanding of the system (as might be the case when models are a "black box"), then there is no development of systems thinking. However, even simple linear models, when used in conjunction with systems language and concepts, can lead to a growing mastery of systems thinking.

This was beautifully illustrated in a Conceptual Physics class taught by one of our Principal Investigators. Students were looking at the differences between classical and relativistic mechanics at near light speed. They looked at a simple linear model of relativistic momentum, then one of relativistic momentum. The core of both models was the same, a **force** flow that increased momentum over time. However, the relativistic model included converters that adjusted the velocity for relativistic changes in mass. Students looked at the output graphs of momentum, which were identical, and the velocity graphs, which were different. They immediately began to talk about what had to be different *in the relativistic* ***system!*** They concluded that something had to be happening to the mass, namely, that the mass must be increasing. Their reasons focused on the fact that the system as a whole (the momentum) appeared to be reacting the same in both cases, so something that was not obvious within the system had to be changing. They arrived at a very sophisticated conclusion by looking at the system result.

Increasing emphasis on introducing students to system dynamics through simple models does not mean that the more complex cross-curricular models of the type developed in the CC–STADUS institute should be ignored. Their power and interest are what may actually attract teachers to look at system dynamics. However, they should only be used after some basic understanding of systems has been attained. Otherwise, while interesting and useful in themselves, they may contribute little or nothing to students' understanding of systems. It takes some time and experience for teachers to transfer what they know about their discipline to systems.

Interest in the development of these more complicated models has been driven by the work of Frank Draper, commercial products like Fishbanks, and the set of Plagues and People models developed by Heinbokel and Potash. These models deal with complex and important issues, and encourage use of system dynamics to address other vital and interesting issues. However, the use of other complex models often focuses students on the problem, rather than the system. They are often content rich and very specific, limiting their utility. Most documentation in these models has focused on the specifics of the problem being addressed, rather than on the structure of the system.

Documentation of models remains the weakest link in the process of learning systems. The documentation for most models, whether simple or complex, tends to focus on the content of the model. Thus, it consists of information like "the growth fraction of .035 is based on data from…" Actual explanation of the model structure, as well as numerical model details, is necessary for others to use models. In single content area models, the implicit assumption seems to be that anyone competent in this field understands the structure. Too often that assumption is made by a person who is probably more advanced in systems than the prospective user, and quite possibly more skilled in the content as well. It is essential, on all models, that documentation be improved so that both content and systems information are provided to the user. Additionally, more emphasis must be put on validation of models. It is vital that models accurately represent the system being modeled. It is equally important that be-

Experiences *continued on page 12*

Experiences in Developing Models for Classroom Use, continued from page 11

haviors are the result of the model design rather than artifacts of the integration engine.

The three years of work done by the staff and participants in the CC–STADUS project allow us to draw some general conclusions about appropriate model development. Our plan and instincts divided our emphasis. It was clear that teachers first had to master basic modeling before they could take on more ambitious projects. However, once a very basic level of mastery was attained, our focus shifted strongly to more complicated models. The experiences of our teachers show that more emphasis must be put on continually developing simple, content specific models. These are used far more often than the cross-curricular models, and in fact are the building blocks that will develop an understanding of system dynamics, allowing students to maximize the benefits of the cross-curricular models when they finally see them. It is also necessary to increase support of teachers during implementation of systems in their classroom.

As a reflection of this realization, in the summer 1995, participants were encouraged to start a simple model before leaving the institute. Our work with individual teachers during the year has focused on developing such simple models for use in their classroom. Additionally, in this interim year for the project, experienced modelers will be developing sets of simple, content specific models for physics, chemistry, earth science, literature, and history. This should yield a base of usable, easily modified models that will facilitate teachers getting started in systems in their classroom. These models will include suggested answers which will provide a basis for comparison with class results.

The summer 1996 institute will feature slightly altered training. The session will be reduced from fifteen to twelve days. During the school year participants will attend three Saturday sessions. These sessions, held in the fall, winter, and spring, will deal primarily with the problems of implementing systems in the classroom, There will be particular emphasis on building, modifying, and using simple models. These meetings will provide an opportunity for participants to discuss their successes and problems.

This does not suggest that a continued emphasis on larger, cross-curricular models should be abandoned. Those models are valuable once a teacher or group of teachers has used system dynamics with students long enough for systems thinking to begin to develop. However, these models are difficult for a single individual to develop. Most have neither the varied expertise, nor the time to construct a larger model. Institutes and workshops like the CC–STADUS project and the work done at Trinity College in Vermont present ideal environments for developing such models. Work on those models should continue, providing a wide range of models available for use as teacher and student sophistication grows.

For pre-college use of systems to grow more rapidly, there must be a significant emphasis on developing and releasing simple, content specific models and curriculum. At the same time, those projects that can actually assemble groups of modelers must continue to develop cross-curricular models so they will be available as the need and demand grow with the spread of systems thinking.

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A LETTER TO PROFESSOR FORRESTER

Below is a letter to Jay Forrester from Leslie Martin, a former MIT SDEP student. We thought you would enjoy a practical example of what can happen when students are taught system dynamics.

Dear Prof. Forrester,

How's it going? Guess where I am right now? Arequipa, the second largest city in Peru, up at 2000m in the Andes. My father is working on a project here and I came down for three weeks to help him out.

The problem here is that there is a cold current running along the coast so the whole-warm-water-leads-to-warm-humid-air-which-rises-and-cools-and-drops-the-water-as-rain thing just doesn't happen on this side of the Andes. If you drive from Arequipa down to the coast, which we did this weekend, all you see is rocky mountain followed by desert plains and more rocky mountain which suddenly drops into the Pacific. My dad's job is to build a dam way up in the mountains (around 4200m) to dispense the water collected in the rainy season down in the plains slowly over the course of the year in order to irrigate the land. The project finances itself more or less by the power generated when the water drops on its way down. My job is two-fold. First, I built a system dynamics model to figure out the optimal height of the dam and optimal water discharge rates, given historical data for precipitation, tunnel and canal size, intervening flows, water demand, etc. With help from my father's hydrolics engineer (to understand how the whole process works), I built a hydrolics model for the region that duplicated all of the results produced by this mammoth black-box of a model developed by the US Army Corps of Engineers. Running the model we found that we could decrease the height of the dam by 20m (saving quite a bit of money) without significantly reducing the supply

Letter *continued on page 14*

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The following new documents are now available from us or the Web site <http://sysdyn.mit.edu/cle/>

SYSTEMS EDUCATION

EXPERIEN ***Experiences in Developing Single-Discipline and Cross-Curricular Models for Classroom Use.*** Ron Zaraza & Diana Fisher

From CC-STADUS. The experiences of the CC-STADUS staff and participants in the CC-STADUS Project lead to recommendations and suggestions for model development and documentation, and training programs for teachers. Presented at the 1996 International System Dynamics Conference in Cambridge, MA. [Systems Education, Elementary School, Middle School, High School, K-Adult] (50¢)

HOWHIGHS ***Systems Thinking and System Dynamics in the CC-STADUS High School Project (How High School Students Become System Thinkers).*** Scott Guthrie & Diana Fisher

From CC-STADUS. Science teacher Scott Guthrie and math teacher Diana Fisher discuss their individual approaches teaching a year long course in system dynamics modeling. Presented at the 1996 International System Dynamics Conference in Cambridge, MA. [Systems Education, Cross Curricular , Middle School, High School, K-Adult] (50¢)

PIONEER1 ***What It's Like to Be a Pioneer: Let The Students Surprise You.*** Deb Lyneis

Prepared with the support of the Gordon Stanley Brown Fund. Jay Forrester has suggested that we could speed the spread of learner-centered learning and system dynamics in K-12 education by sharing tales of "what it's like to be a pioneer." It might help others who are starting out, or just curious, to know about other teachers' experiences, positive student outcomes, pitfalls, political issues, responses of administrators and fellow teachers, student and parent feedback, triumphs and tribulations. This paper presents one such vignette. [Systems Education, Elementary School, Middle School, High School, K-Adult] (50¢)

PIONEER2 ***What It's Like to Be a Pioneer: Politics and the "Lazy Teacher".*** Debra Lyneis

Prepared with the support of the Gordon Stanley Brown Fund. Jay Forrester has suggested that we could speed the spread of learner-centered learning and system dynamics in K-12 education by sharing tales of "what it's like to be a pioneer." It might help others who are starting out, or just curious, to know about other teachers' experiences, positive student outcomes, pitfalls, political issues, responses of administrators and fellow teachers, student and parent feedback, triumphs and tribulations. This paper presents one such vignette. [Systems Education, Elementary School, Middle School, High School, K-Adult] (50¢)

CROSS CURRICULAR

MAMMOTGS ***The Mammoth Extinction Game.*** Gene Stamell, A Ticotsky, R Quaden

Prepared with the support of the Gordon Stanley Brown Fund. In this interdisciplinary science, math, and social studies lesson, third graders examine how the wooly mammoth became extinct about 11,000 years ago. With a game and a hands-on model they learn about graphing, probability anda exponential decay in math, and they are intorduced to system dynamics modeling as a useful tool for looking at problems. [Cross Curricular, Math, Science, Social Studies, Dynamic Modeling, Elementary School, Middle School] ($1.00 paper only; $6.00 paper + model on disk)

NOMADSDL ***Nomads, Land Use, and Humanitarian Aid in the Sahel Region of Africa: A STELLA II Model for Use in the Classroom.*** Debbie Lindow, et al.

From CC-STADUS, newly available on disk. Demonstrates historical analysis; explores humanitarian aid and the destruction of a culture; includes extensive curriculum and background materials, extensions. [Cross-Curricular, Social Studies, Dynamic Modeling, High School] ($3.00 paper only; $8.00 paper + model on disk)

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2000 ST&DM CONFERENCE

The next Systems Thinking and Dynamic Modeling Conference will be held June 25-27, 2000, at Skamania Lodge in Stevenson, WA, just 45 minutes east of the Portland, OR International Airport.

Skamania Lodge opened in February of 1993 as a destination resort with first rate conference and meeting space which is connected to the guest room lodge. It is located in the beautiful Columbia River Gorge National Scenic Area. The rooms are lovely with lots of extra amenities, including telephones with a data port. The lodge is surrounded by an 18-hole golf course designed as an Audubon sanctuary, with hiking trails.

We're thrilled to offer this opportunity. Make plans now to attend.

Letter, continued from page 12

of water for irrigation. Here the main constraining factor is the flow capacity of some of the tunnels bringing the water down into the valley (whose size we can't increase). Right now I'm working to see how expensive it would be to bring additional water to the reservoir from different watersheds.

The next part of the job is to start incorporating into the model the effects the new reservoir will have on all of the economy of the region, specifically, what returns can be obtained from the irrigation and the power generation.

I hope that everything's is going well with the SDEP and the GSP. Say "Hi" to Nan (Lux) for me.

Take care!

Leslie

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Enclosed is ________________ to *The Creative Learning Exchange* to help invest in the future of K-12 systems education.

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Thank you!

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