Using Computer Models to Apply Concepts in Math

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The MIT System Dynamics in Education Project
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Title: Applying Math using STELLA Models

Purpose: This paper is to encourage teachers to think of creative ways for their students to apply mathematics by using computer models.

Overview: I begin by expressing the importance and value for science and math teachers to demand that their students apply the concepts they learn by manipulating computer models. I offer two examples of applying math using computer models. The first example is an activity called, "Compounded Interest" and the second example, called "Rats," is a piece of a much larger project that I taught last year in two high school ecology classes. I defend my opinion that math and science should be taught together since they are very much the same endeavor and, therefore, the two models described can be used in a high school math or science classroom, grades 10-12.

Length of time for activities described: The first example STELLA model is a ready-to-use activity with teacher directives, sample questions, and sample data tables. It is a two-four hour activity. The second example is a ready-to-use activity, but is only a piece of a much larger project in which a food web is modeled\(^1\). It does not have teacher directives or supplemental material. Materials needed other than those provided in this paper are STELLA\(^2\) software (STELLA 1.02, 2.00, 2.02) and enough Macintosh computers so that your students can work in pairs at each computer.

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\(^2\) STELLA softwares are made available from High Performance Systems Inc. 45 Lyme Rd. Hanover, New Hampshire, 03755: Phone (800) 332-1202.
2. ABSTRACT

Most high school learning is lost shortly after students graduate because it has never been applied. This paper applies knowledge in a high school science classroom with the premise that science and math should be taught together and that computer modeling is an extremely effective means of applying math in a science classroom. It begins by first explaining why application of knowledge is especially important today in our high schools. It also defines applied mathematics and its importance in a math and science classroom and discusses how STELLA models encourage students to apply math in their science class thereby creating an atmosphere of excitement, success, and purpose.

3. FORWARD

I am a high school science teacher in a large urban comprehensive public high school of two thousand students. Shortly after the MIT System Dynamics in Education Project\(^3\) was formed, I was introduced to computer modeling with STELLA in the winter of 1991. In the spring of 1991, people from the System Dynamics group helped me use the Glucose Regulation\(^4\) model with my biology class. It was a great success for me because I had discovered an effective and different teaching and learning tool that my students responded to with enthusiasm. I then saw that STELLA models could be of great benefit in my other class, Ecology and Environmental Studies.

In the summer of 1991, members of the System Dynamics group at MIT helped me create a model of a food chain. A comprehensive curriculum was developed around it which included a step by step approach to modeling beginning with graphing skills and simple generic models and ending with a rather large and complex model. The final model in the series investigates the effects of certain human-influenced and natural environmental changes on the interrelationships of four populations in a food chain. The entire curriculum lasted for two months.

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\(^3\) For inquiries about the Gordon Brown Fund of the System Dynamics Society, mail to Professor Jay Forrester, System Dynamics Group, E40-294 MIT, Cambridge, MA. 02139

In the spring of 1992, I applied and was accepted for a writing grant supported by the Gordon Brown Fund of the System Dynamics Society so that I could share my students' and my own thoughts and impressions about the unique and refreshing type of teaching and learning that occurs when computer models are used.

I need to preface this paper with my opinion on how math and science teaching relate to each other. I think that math and science teaching are one and the same or that science is math realized. Science For All Americans\(^5\) says,

Science and mathematics are both trying to discover general patterns and relationships, and in this sense they are part of the same endeavor...Mathematics is the chief language of science...(it) provides the grammar of science. Mathematics and science have many features in common. (p.17)

I defend my opinion that math and science should be taught together since they are very much the same endeavor, and therefore, I encourage the use of any computer model in any high school math or science classroom.

4. THE APPLICATION OF KNOWLEDGE

Why have our high schools failed to apply math and science concepts? Science for All Americans\(^6\) says:

Sound teaching usually begins with questions and phenomena that are interesting and familiar to the students, not with abstractions or phenomena outside their range of perception, understanding and knowledge...Science, mathematics, and technology do not create curiosity. They accept it, foster it, incorporate it, reward it, and discipline it- and so does good science teaching...Scientists, mathematicians and engineers prize the creative use of imagination. The science classroom ought to be a place where creativity and invention-as qualities distinct from academic excellence-are recognized and encouraged. (p.170)

It is my opinion that today’s high school classrooms do not foster curiosity and the concepts being taught are far from familiar to our students’ experiences. Teachers must be sensitive and creative enough to apply a student’s everyday experiences to learning.

\(^6\) Ibid.
In educational psychology application is the ability to take knowledge and see a use for it in a new experience. Learning does not have value for a student unless that knowledge can be applied to something in that student's everyday experiences. Most of high school knowledge is lost because it has never been applied. Students want and need more application to give value to education. When students see the value in education, they become intrinsically motivated to continue asking questions and teaching themselves after formal education has ended. Isn't this the goal of the American education system?

There is an ever-pressing need to connect students with concepts through experience, and not through abstractions. Few high school students are at a level of intellectual maturity to enjoy, understand, and apply geometric proofs to their everyday lives. Too often word problems become a hassle and nurture the growth of math phobias that many students have by grade six. Students, instead, need something they can hold, feel with their hands, see with their eyes, and manipulate. They need to experience and experiment with math.

5. THE IMPORTANCE OF MANIPULATIVES

Math is an applied science, so an education in math should involve experimentation to solve problems. The whole industry of packaging is dependent on calculus. An exciting way to discover this fact is to invite your students to design the dimensions of a soup can so that the quantity of cans at a given volume put into a packaging crate of a given volume is optimized. It is not easy to manipulate tin can size in a high school math classroom (unless you move the class to the metal shop). This perceived road block should not discourage a creative teacher who can have her students create "cans" made of manila folder paper. Students can represent canning companies bidding for a contract with Campbell's Soup Inc. They can make models and support their optimal packaging scenario using derived maximum and minimum values from parabolic graphs of second degree equations. One can imagine student teams all dressed up with supporting diagrams and models trying to convince Campbell Soup executives their packaging method is the best.

Students need to learn by application. They need to develop, practice, and express their creative, manipulative, and social skills. Once they have developed these skills, they can be appreciated as a whole person who is not simply evaluated on the basis of academic intellect. Science-math and language abilities are only two forms of intelligence which Howard Gardner, of Harvard University Education School's project Ground Zero, claims get disproportionate attention in America's classrooms (the other five forms of intelligence identified by Gardner are kinesthetic, spatial, interpersonal, intrapersonal, and musical ability). Math and science education should have application projects as its foundation. The barrier seems to be lack of modeling resources (recently being called manipulatives in math circles, and traditionally labeled laboratory equipment in the science circles) and more tragically, a lack
of funds to develop and acquire such materials and curricula to accompany them.

6. THE COMPUTER MODEL AS A MANIPULATIVE

Computer models many times provide the manipulatives that students need to apply their knowledge of math and science. Granted, computer modeling is not exactly building something out of miscellaneous parts with your own hands, and then testing it in various conditions. However, computer modeling software like STELLA does offer symbols to represent physical parts. When the symbols are put together to model a system, their interaction produces behavior that students can manipulate. The enjoyment young adolescents and children experience with video games is evidence that manipulating symbolic representations can be fun.

The key to success of symbolically represented manipulatives is that they must be interesting enough to invite the user to employ his imagination. Once the student can imagine himself having a role in the symbolic world, he enters it with enthusiasm. And students will let the creative juices flow if they know they can have observable effects on the system or if the system directly relates to their own personal experiences.

Video games differ from computer modeling because video games do not invite the student to apply math or science concepts. They do not invite the question "Why?" With computer models, students are always applying math skills and concepts to explain why the system is behaving the way it does. They also have the opportunity to change the system.

In the next section, I show an actual application using math in a STELLA model. I will discuss the idea of compounded interest as it relates to the solution interval (called the DT, for Delta Time, meaning the difference in time). At the same time, I will show how models can be used to teach students what kind of equations create linear and nonlinear growth. I will also share the excitement my students experienced when solving for an unknown within a modeled system.
7. THE COMPOUND INTEREST ACTIVITY

7.1 STELLA Basics in the Bath Tub

- Teacher Directions and Suggestions

Start the students off by modeling a bathtub using STELLA. Introduce stock and flow symbols. Assign an original stock value of five gallons to the stock and a flow of ten gallons per hour. Have the students set up a graph to eight hours with a maximum y value of one hundred and a minimum of zero. For the tabular display, just enter the stock of water in the tub. Run the model and have the students characterize the type of graph. If they are able, have them determine the linear equation for the line shown on the graph. It should be \( y = 10x + 5 \). If time permits, you could also create a situation in which there is a constant outflow from the tub (down the drain) when the tub starts with thirty gallons and loses three gallons per hour. You can have the students set the run for eight hours. This way, they can see a negative slope being generated on the graph with a linear relationship expressed by \( y = 30 - 3x \).

If still more time permits, have the students create a tub situation which has an inflow and an outflow occurring at the same time. Students will ultimately obtain a graph which shows the net flow, whether it be positive or negative. Students can also be asked to generate an equation for the situation they have created. After completing the bathtub scenario as a warm up exercise, the students are ready to begin creating models which will express non-linear relationships.

7.2 "In the Interest of Londell"

- "In the Interest of Londell" is the problem students will have to solve by experimenting with a computer model designed for the problem. It is presented on the next page intentionally so that it can be reproduced for the students without teacher notes on it.
IN THE INTEREST OF LONDELL

Your team has now become Investment Brokers! Give your company a name. You're probably wondering what an investment broker does. Basically, investment brokers help people make money from money they already have. You have a customer, a high school student, named Londell who works 20 hours a week and makes enough money so that he has 200 dollars he would like to tuck away. He wants you to advise him how to best invest this money. He wants to make a forty-year investment. Your company has 200 dollars in hand and you are deciding to put the money into one of two different banks. Liberty Bank will give you 8% interest on the money and compound the interest four times a year. Freedom Bank will also give you 8% interest on the money but they work extra hard and compound the interest 16 times a year. Because it takes more work to compound the interest so frequently, Freedom Bank charges a special fee of sixty cents for every year the money has been in the bank. In other words, Freedom Bank charges sixty cents a year per year for all the extra compounding they do. This compounding fee as Freedom Bank calls it is only assigned and collected the minute you take out any money from that savings account. Londell did say that if he took the money out he would probably only do it after each ten year mark.

You're probably very confused and do not know where to begin. Perhaps you do not even know how interest can accumulate on your savings in a bank account. You probably do not know what compounded interest means either. You're not alone! Most high school students never learn about compounded interest, yet there will come a day soon in their future that they wish they had. You can lose lots of money by not investing it properly. And you can make your money earn money all by itself if you know what you're doing!! Your teacher will help you understand the basics of interest and compounded interest using STELLA computer models. With computer models as your secret weapon, you can start your business with confidence!
7.3. How Does Interest Work?

- Teacher directions and suggestions

Begin a discussion about interest. Some questions may include:
1. What is it?
2. Who uses it?
3. Does it go up and down or stay the same?
4. Has it gone more up or more down lately?
5. Does interest depend on how much money there is?
6. What does compounded interest mean?

Show the students an example of 2000 dollars earning 10% interest, compounded once a year. Have the students calculate:

i. how much money there will be in the bank at the end of year one.

ii. how much money there will be in the bank at the end of year two.

Now explain how it would be done if the interest were compounded twice a year. You need to make it clear that the interest rate is a rate per YEAR and that if you were to calculate interest at the half year mark you would have to use 5% * 2000 dollars and then at the end of the year the remaining 5% * 2100. Now ask the students to compare the amount of money in the bank after one year when it has been compounded once, and then twice.

Ask the following question:
1. Which situation is better for the customer who puts his money in the bank—the compounded once a year situation, or the compounded twice a year situation? What's the difference in money between the two?

You can now challenge your students to figure out how much money would be in the bank at the end of two years if it were compounded twice a year. This particular calculation is very laborious and starts to include portions of a cent. For less motivated students you can simply say "Isn't it a real hassle to compound interest? How do you suppose real banks do it for thousands of accounts?" Your students should reply that computers must do it. Now tell them that in order to solve the problem given to us, they will use computer models. They know how to model a bath tub system with STELLA, but are they totally prepared to model a bank account system?
7.4. Building the Interest Model

- Teacher directions and suggestions

Begin with a short review of the bathtub scenario, and discuss the following questions:
1. In the bath tub situation which just had an inflow, was the inflow at all dependent on the amount of water in the tub? In other words, did the amount of water in the tub ever change the inflow?

2. What would eventually happen if the inflow kept going and there was no outflow?

3. There is something in your bathroom at home that does not work at all like your bath tub and it's a good thing because the inflow and outflow to it are determined by the amount that is in it at every instant in time. Can you name this bathroom item? A discussion of how a toilet works would be of great benefit here especially when you consider how it applies to your students' everyday experiences!! An actual model of a toilet would be a great thing to have in the classroom.

Have the students begin to build a model. First, have them identify "Money in the bank" and "Interest" as either a stock or flow. Introduce the students to the use of a connector to show that connectors are a way of showing that a flow is influenced by a stock. The amount of interest flowing in at a certain time is not only dependent on the amount of money (stock) but also on the interest rate. Have the students place a converter into the model, labeled "interest rate."

Now have the students enter the initial values of your warm up scenario. Start them out with 20,000 dollars in the Bank and an interest rate of 10%. When they double click on the inflow icon, be careful to lead them through the generation of the equation "Money in Bank * Interest Rate." Lead the students to the graph window and set up a Y axis that goes from 0 to 24,000. Have the students go to the tabular display window and have them enter "Money in Bank." Go to time specs under the run window and have the students set an initial DT of 1, click in the box that says print every interval, and set the run time for 2 (years).
Explain to the students that the DT (solution interval) feature is really asking you how many times the interest is compounded per year. The solution interval describes how frequently the model equations will be computed within the given time unit. A value of one means that it happens only once a year; a value of one half means that it happens every half a year, or twice a year; a value of one quarter means that it happens every three months, or four times a year etc. Spend as much time as necessary to make sure that the students understand this important concept since this will be the parameter they change when they conduct their computer experiment.

7.5. Manipulating the Interest Model

- Teacher directions and suggestions

Pass out the data table (copy provided in appendix). Notice in the data sheet, that there are boxes for the amount of money at each quarter of a year. When interest is compounded only at the end of year one, the boxes labeled 1/4, 1/2, 3/4 of a year will all have the same value as the box just before the 1/4 box. Have the students use the table display to collect data to be entered onto their data sheets. Once they have finished the first run with DT set at 1, have them investigate how the initial bank balance will grow if interest were compounded twice a year. All they have to do is change DT to 1/2. When they finish collecting data from that run, have them experiment with interest compounded four times a year.

Ask the students to tell you how much more money you can make after two years of 20,000 dollars being compounded once a year versus the same amount being compounded four times a year for two years. The difference should be 168 dollars and 6 cents. Have the students regenerate a graph of the last run they did, and ask them if the graph appears to be a straight line or non-straight line graph. Because of the axes and short duration of run time, the graph will look linear.

Tell the students to double click on the graph and change the y scale maximum to 1,000,000. Then go to time specs and change the length of the run to 40 years. Now tell them to re-run their model to see how 20,000 dollars matures after 40 years when it has been compounded four times a year at 10% interest, and ask the following questions:

1. How much money is there in the bank after 40 years?
2. How much money did you start out with in the bank?
3. How much money did you make off of your initial deposit by just letting it sit in the bank for forty years?
4. Explain the term some rich people often say, "Money makes money."
5. (Mastery level question) During what month of what year would you become a millionaire if you put 20,000 dollars in the bank at the first day of the year 2000 at 10% interest compounded four times a year?
6. If the 20,000 dollars had interest compounded once a year, would you be a millionaire by the end of forty years?
7. If the 20,000 dollars had interest compounded twice a year, would you be a millionaire by the end of forty years?
8. What situation yields the most profit in the end?
9. Would the previous question be easy to answer if a bank which compounded interest frequently put a price on that service?

Of course, the answer to question number nine depends on what the price for the compounding service is. You have a working knowledge of compounded interest and a computer model to do all the dirty work for you. You are now a certified Investment broker. Get to work on the problem at hand!

7.6. Teacher Suggestions and Hints

The students are absolutely on their own. If they were taken through the previous material carefully and have understood it well then you really won't have to be teaching at this point. It's your job to walk around creating an atmosphere which invites the students to use their imaginations and feel like they are really investment brokers.

You may even set it up as a competition for the customer Londell. You may ask for a data sheet presentation that would convince Londell that you knew what you were doing and you could be trusted.

Students should work in pairs and create a data sheet with a report which recommends to Londell which account would be better suited for him and in which instance. Remember, Londell did say he might pull his money out after a 10 year increment. Do not tell the students how to create the data sheet. Just tell them to read the problem very carefully and use the warm up scenario data sheet as a model.

• Some things to watch out for

1. Liberty Bank, which compounds interest at 8% four times a year with no compounding fee, is the better bet up to and including year 20. If the money is kept in there any longer than 20 years, then the investment should be made with Freedom Bank (which compounds interest 16 times a year at 8%) since at the point greater than year 20 the compound fee from Freedom Bank is less than the accumulated balance difference between the two banks.

2. If students are assessing how much the balance may be at year 24 for Freedom Bank they need to access the accumulated balance from the tabular display for that run and then subtract 60 cents for each year ran (since the compounding fee is six dollars for each 10 years), or 24 * .60 or $14.40 subtracted from the bank balance at year 24.
8. SOLVING FOR THE UNKNOWN VARIABLE

8.1. The Model

I would like to share an example of applied math skills in my science classroom. We were studying food chain and food web dynamics and were modeling a food web with STELLA on the Macs. In one of the preliminary models we were studying the behavior of a rat population. Rat population was the only stock (100 initially). It had an inflow called "Birth Rate" which was dependent on three converters; one labeled "Rat Offspring per Litter (value of 2)," another being "Rat Litters per Year (value of 1.0)," and a third being "Female Rats (Rats/2)." The outflow called "Death Rate" was dependent on the converter called "Rat Average Lifetime (value of 1)," and on the Stock of Rats (100 initially) by the equation Death rate = Rats/ Rat Average Lifetime.

8.2. Excerpts From the Daily Planner

Students were asked to explore the model to understand the values and equations behind the icons and then run the system. What they first saw was a case of dynamic equilibrium because the inflow was set to equal the outflow. They were invited to change any of the values to see how the population growth would be effected. They were asked to document the changes they made and hypothesize what the growth curve would look like. They were asked to share their manipulations the next day with the whole class in the classroom with a Mac overhead set-up. I had asked them to tell me what the inflow and outflow equations were and how they had to be equal in order to obtain dynamic equilibrium. In other words, at dynamic equilibrium:

Rat offspring/litter*Litters/year*Rats/2 = Rats/Ave. Lifetime
When students input the values which generate dynamic equilibrium, they obtain $100=100$. From here, I'll just quote my diary to tell the rest:

Day 12, Friday, November 22, 1991  5th period

I had made another in-class worksheet on what we experienced yesterday. First we reviewed the STELLA diagram of the Rats situation...First we ran an inflow>outflow situation and then an outflow>inflow situation and then an equilibrium situation that a student arrived at in the Mac Lab...The new guided sheet created asked the students to define the equations for the inflow and the outflow. So we plugged in the numbers and obtained equilibrium, which Nikki showed us with her great Mouse Mac skills. Larry offered a situation of 2 rat babies per litter and 3 litters per year and we arrived at an average lifetimenumber in order to maintain equilibrium. It worked(!) as Nikki displayed with the overhead display run. Then I bet the class if they gave me any numbers for rat babies per litter and litter per year, then I could arrive at the average lifetime number. A bet was made and I came out victorious! It was one of the most fun classes I have had yet! It was so neat to see all the kids focused on what was happening and enjoying the novelty of the Mac overhead display. I give this class a thumbs up!!

Day 13, Monday November 25, 1991  Period 5

We reviewed Larry's simulation with rat babies per litter at two and litters per year at three to get an average lifetime of $1/3$ years to obtain equilibrium. The class was asked to calculate the average lifetime to maintain equilibrium when the rat babies per litter was four and litters per year was three. The answer was $1/6$ with an initial rat population of ten. The Mac overhead display was used to verify the students' hunches. The Mac overhead is becoming my favorite instructional toy these days. The students kept asking when we were going to go back to the Mac Lab.
8.3. Analyzing the Success

There was a lot of excitement in my classroom those days. When a teacher has such a successful class, it encourages a special effort to document everything that happened and then analyze why it was so successful.

Doing algebraic manipulations to solve for the unknown has never really been an exciting activity, but it was for me and my students. Why? First of all, the students were able to tinker with the model at their own pace and get acquainted with it. The next day, they brought their scenarios to class where the Mac overhead allowed them to share their scenario with the rest of the class. They were all eager to share their scenario because it was pre-tested and success was guaranteed.

The students could have validated their equilibrium values by plugging them into the equation to make sure the inflow value had equaled the outflow value, but very few had done it this way. Most of the students had arrived at equilibrium values by trial and error and had validated dynamic equilibrium by seeing the straight non-sloping line work its way across the graph display. There's nothing wrong with this approach; after all, scientists who are not aware of the math behind a phenomenon discover it only after seeing repeated patterns and relationships resulting from trial and error experiments.

It's the job of the teacher to help students see that there is a mathematical way to determine equilibrium values and that ultimately the workings of the model are based on math. Students are motivated to experiment with math and try to solve for unknown values, because they can prove that they did the right thing in a way that is exciting for them. They receive visual, animated, dynamic feedback.

It makes sense that students who do not feel strong in math latch onto this form of validation. After all, if you're not usually successful in math, how confident will you feel with your answer if it can only be checked by the type of math you employed to get that answer? This is a source of frustration for math phobic students who often hear from the teacher, "It's easy! You can't go wrong because you can plug in your answer to see if it works!" Isn't it better to offer a form of validation in a non-threatening atmosphere in which students experiment and apply math to solve what they see as a non mathematical problem?
8.4. Computer Model Validations, the Catalyst for "Mathematical Proofing"

I am not down playing the value of mathematical proofs. On the contrary, I am simply using a different means of validation which helps me lead the students to prove by mathematics in a less threatening way. Notice in the diary entry for the first day back from the Mac Lab, students were allowed to share their values that they had obtained through experimentation. This was immediately followed by my bet that if they gave me any values for rat babies per litter and litters per year, I could determine the average lifetime value, and without the use of the model. I cupped my hands around the quick scribbles I was doing at the blackboard and "mysteriously" arrived at an answer within seconds to the students' amazement. Nikki was asked to plug the value in the appropriate converter and run the model to see if I had chosen the correct value to reach equilibrium.

A majority of the class had these "How doja do that" looks on their faces as the bell rang to dismiss class. The next day, I explained how one could mathematically arrive at the answer using the equilibrium equation:

\[
\text{Rat offspring/litter} \times \text{Litters/year} \times \text{Rats}/2 = \text{Rats/Ave. Lifetime}
\]

I showed them how to plug in all the knowns and solve for rat average lifetime. I told them that I was so sure of my bet because I could verify my answer by plugging in my value and showing that the inflow and outflow values were equal. The students were reminded that equilibrium occurs when net inflow to a stock is equal to net outflow from that stock, and that was exactly what the mathematical equation was expressing. The value was plugged into the model and run to prove again that dynamic equilibrium was established.

Students were then asked to determine rat average lifetime with rat babies per litter at four, with three litters per year and an initial rat population of 10. Nearly all the students had come up with 1/6 of a year as the rat average lifetime and were able to verify it by plugging it back in. However, they still insisted on seeing it plugged into the model and ran. Why deprive them of the fun?
8.5. Words of Caution

The rats model was a precursor to a much more complex model of a food web with four interrelating populations and how these populations are effected by various changes in the environment. The model and lessons created for it continually invite students to apply math in order to learn exactly how natural and human initiated changes in the environment effect the delicate interrelationships of the populations in an ecosystem\textsuperscript{7}.

Chris Prince, a member of the System Dynamics in Education Project at MIT and developer of the food chain curriculum with me, agrees that there were some aspects of the model's curriculum that the students did not respond well to. Chris Prince and I created some computer lab guiding worksheets which were not one hundred percent successful and dampened the students' enthusiasm.

The complex nature of developing the ideal computer lab guided worksheet stemmed from the nature of the model the students were manipulating. The students would manipulate environmental factors and generate a graphical output with the four populations going up and down in response to each other and the environmental change. The worksheets would ask the students to hypothesize, in writing, what the graphical output would look like before they ran the model.

Students did not respond well to this request because it was often laborious and difficult to write down the intricacies of four populations' simultaneous effects on each other over time. Industrious students toiled with long paragraphs of run-on sentences that were hard for me to decipher, while most the students simply ignored the requests for written hypotheses and conclusions. These behaviors pointed out to me that I was not understanding an important point about teaching and learning with computer models.

Learner-centered learning occurs when computer models are used because students direct the pace and sequence of their learning as they manipulate and change the model. With learner-centered learning it is absolutely essential that students work in pairs or in groups of three because ideal experimentation involves dialogue and criticism between scientists. The guided worksheets with requests for time consuming written hypotheses was diminishing the value of dialogue. Students greatly preferred and enjoyed telling me their hypotheses for a run and interpretations of a run while pointing to the graph display. One of the most important aspects of learner-centered learning is student dialogue.

The journal I kept when doing the food model curriculum does point out that some of the most lively classes occurred a day after the Mac Lab visits when we were in the classroom with one Mac overhead. Students would present what they did the previous day with their model on the overhead. This type of sharing spawned a lot of good discussions that everyone participated in. It was at this point that I realized the value and importance of oral presentation.

I would advocate that any teacher using computer models in the classroom give up traditional modes of teaching and evaluation, carefully look at and listen to the students as they experiment together and develop creative means of maintaining the student dialogue. Evaluation of student progress with computer models must include oral communication between students and the teacher. My next paper, "Interdisciplinary Evaluation Techniques when using Computer Models in the Math or Science Classroom," describes my initial struggles trying to effectively evaluate the students' progress with the food chain model and my discovery of new evaluation techniques that were more appropriate and enjoyable for me and the students.

9. CONCLUSION

I have shared two STELLA models with the intent to define and underline the importance and need for applied mathematics in high school classrooms. Math and science teaching needs to change. Computer modeling serves as a useful agent of change in the classroom. It provides the student scientist with something to manipulate and experiment with in his learning process.