the Creative Learning EXCHANGE

Volume 6, Number 4 - Late Fall 1997

ASSESSING PROGRESS IN SYSTEMS THINKING AND DYNAMIC MODELING: SOME THOUGHTS FOR EDUCATORS

Jeff Potash & John Heinbokel, *Waters Center for System Dynamics, Trinity College of Vermont*

Educators' interest in systems thinking and dynamic modeling has grown over the last few years, with curiosity having been piqued through a wide variety of introductory experiences. Many who have become familiar with systems thinking in "learning organizations" have approached systems as an instrument for organizational reform; others have interacted with commercial applications such as "Fishbanks" and are curious both about its internal workings and other available simulations; still others have come into contact with a colleague, either within their school or system or at a meeting, who builds or works with models and waxes eloquent about the "power of systems" within the classroom.

TALKING PAST ONE ANOTHER

The diversity of entryways is, of course, testimonial to the wide-ranging strength of "systems" to address educational needs. However, experience also indicates that people's disparate knowledge of and interest in systems translates into a veritable plethora of discrete and asystematic conversations which encourage cliques to form: recall the "Tower of Babel" which reminds us of the great danger in people speaking a multiplicity of tongues. Particularly where people are seeking initial guidance to assist them to learn how and where systems may be useful in education, the absence of a common tongue oft-times proves thoroughly frustrating.

MOVING TOO FAST WITHOUT PAYING ATTENTION TO WHERE YOU'RE GOING

I'm reminded that the situation parallels to a large degree the story of the urban dwellers who, with their fancy cars and hefty summer vacation budgets, flock to Vermont to experience its proverbial bounty of pastoral pleasures. Yet, on more than one occasion, the road has led to a steadily narrowing, unpaved, and rocky lane. Though the specter of the archetypical Vermont farmer standing along the road offers an initial relief to the lost tourist, the actual conversation proves less than satisfying. One story has the city dweller, after having described the desired destination site, being told by the

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WHY USE BEHAVIOR-OVER-TIME GRAPHS?

Deb Lyneis

A Behavior-Over-Time Graph (BOTG) is a simple pencil and paper graph which shows how something changes over time. The behavior in question is plotted on the vertical axis, while time runs along the horizontal axis. This graph is often the first tool teachers meet when they are introduced to systems thinking and system dynamics in K-12 education. And it is a very good place to start because everyone has some familiarity with basic graphing. It is easy to learn, and easy to teach. There are many other good reasons for using BOTGs, however.

First, kids love them! The process of expressing their thoughts through a graph is very engaging for kids, whether they are explaining the growth of plants in a science experiment, or their predictions on crime in a hypothetical society without laws in social studies. The classroom discussion gets rolling quickly when students see the differences among their graphs.

BOTGs not only give students another way to express their thoughts, they also force students to formulate

***BOTGs** continued on page 10*

From the Editor . . .

We had the most delightful visit to the New England Center to look at the Center once more for room size and layout. Again we were impressed with the comfort and practicality of the Center, the excellence of the food, as well as the beauty of the site. We think it will be a wonderful place to have a conference. The program is still being formulated. If you have ideas for sessions which you would like to see given, don't hesitate to tell me. I am available through e-mail, phone or regular mail.

You will also notice the repeated announcement for the Gordon Brown Fund. I urge anyone who has a curriculum which they have used in their class to utilize this fund which supports the writing up of curriculum for dissemination by the CLE. We would love to see more good stuff which has made a difference to the learning of kids in our library for use by other teachers. I would like to also take this opportunity to thank those who have been generous with their time and energy to establish the base of curriculum which we now have. You are great— thank you.

I hope everyone has a wonder-filled and peaceful holiday season.

Lees Stuntz *(stuntzln@tiac.net)*

New Materials Now Available from the CLE or the Web Site

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

SYSTEMS EDUCATION

FLUENCAL ***Individual Progress toward Fluency in a Second Language.*** Anne LaVigne

From Catalina Foothills School District. A System Dynamics lesson plan guide where students will begin to see how various factors can influence their ability to use a second language. Based on a lesson and simulation created by Maritza Everist, Anne LaVigne, and Ron Michalak. [Systems Education, Administration, Dynamic Modeling, Behavior over Time Graphs, Causal Loops, K-Adult] (50¢ paper only; $5.50 paper + model on disk)

SD&K12JF ***System Dynamics and K-12 Teachers (D-4665-1).*** Jay Forrester

A lecture given by Jay Forrester at the University of Virginia School of Education, which discusses the use of system dynamics as a foundation underlying education in kindergarten through twelfth grade. [Systems Education, Overview, K-Adult] ($2.00)

ENGLISH

ROMEODJ ***The Tragedy of Romeo and Juliet: A STELLA Model.*** Dorothy Johnson in collaboration with Lees Stuntz

A model to help teach a deeper understanding of the characters in the play and the times in which they lived, as well as the influences at work within the play. [English, Dynamic Modeling, High School] ($1.00 paper only; $6.00 paper + models on disk)

Newly available on disk:

SYSTEMS EDUCATION

LMNTRYNR ***Teaching Dynamic Feedback Systems Thinking: An Elementary View.*** Nancy Roberts

This paper explains how system dynamics has been applied at an elementary school level. [Systems Education, Implementation, Elementary School] (50¢)

Seamless Integration of System Dynamics into High School Mathematics: Algebra, Calculus, Modeling Courses

Diana M. Fisher and Ron Zaraza

Introducing system dynamics concepts is very natural in mathematics. The reform Calculus movement that has been in progress for ten years in the United States sets a useful backdrop for introducing systems. The reform movement has as its fundamental precepts the use of a four pronged approach to a conceptual understanding of Calculus and functions. To understand functions one must view them symbolically, graphically, numerically, and verbally. This is referred to as "the Rule of Four." Adding a fifth rule would provide a natural link to other disciplines and real applications. The fifth rule would be to view functions from a system dynamics perspective. This perspective is natural in Calculus. Functions can be viewed from their characteristic behavior-over-time/rate-of-change patterns."The Rule of Five" can be implemented as early as Algebra I.

The introduction is most easily accomplished with the use of a motion detector, connected to an analog to digital converter interfaced to a computer. The computer is also connected to an overhead viewing system so the class can observe the activities. Students are asked to walk in front of the motion detector slowly and steadily or quickly and steadily. The graph produced is linear and a discussion centers around the characteristics of the motion that caused the graph to be linear. It is noted, via a questioning strategy (so the students make the determination), that the slope is dependent upon the speed. The connection between speed and slope is used as the foundation concepts for the study of all other functions from Algebra I through Calculus. Additional exercises are used to guide students to the obvious conclusion that, in order for a graph of motion to be non-linear there must be some acceleration/deceleration. Students know this, intuitively, but experiences crystallizing this concept are not usually provided in math classes. Students in Algebra I are then expected to interpret written explanations of movement into graphs, distance graphs into velocity graphs, and distance graphs into written explanations. In Algebra II students are also expected to continue this interpretation to include parabolic and oscillatory motion. Additionally they are expected to translate velocity graphs into corresponding distance graphs, velocity graphs into written explanations of motion, and velocity graphs into acceleration graphs. In pre-calculus classes the extensions include translation of acceleration graphs into corresponding velocity and/or distance graphs. As simple as these experiences may seem most students have not had concrete experiences in a math class, with the attendant vocabulary and reinforced connections that are so important to interpreting the equations and word problems that are found in the courses. The exercises truly crystallize for the average student, the connection between slope and speed that is fundamental to understanding Calculus. The exercises begin with motion producing straight line graphs and evolve to demonstrate first and second derivative concepts.

A vocabulary using a systems perspective can be developed using an intuitive set of exercises that most students find easy to understand. Some of the vocabulary is introduced in the motion detector activities. Using "characteristic behavior-over-time" in addition to "rate of change" to describe the standard linear, quadratic, exponential, and periodic functions is reinforced repeatedly. Using the motion detector as early experiences for students at each level allows repeated reference to the motions and their interpretations on the graph.

Lessons follow that use the method of finite differences, a numerical view, to reinforce the vocabulary introduced in the earlier motion exercises. Tables of values for linear, quadratic, and exponential functions are studied to show that linear functions have first differences that are always constant (first differences indicating velocity), quadratic functions have second differences that are always constant (second differences indicating acceleration), and exponential functions have first quotients that are always constant. Additional exercises are given where the function is not specified but the student must determine, via analysis on the tabular output of the function, it's characteristic behavior over time.

Finally, a modeling software, such as STELLA is introduced. With the vocabulary and rate-of-change concepts previously emphasized it is not difficult to expand problems to include a wider scope. The first set of lessons begin with problems that occur in most traditional math texts. Most standard Algebra, Pre-Calculus, and Calculus texts contain "word" problems that are supposed to provide students with applications of the functions they are studying. It is a simple task to choose those problems that involve time as the independent variable and create a handout where students design very simple STELLA models to solve those problems. Discussion with the class about the standard structure of the diagrams can refer to the earlier motion exercises. Once the standard diagrams are developed, students should be able to apply the correct diagram to the appropriate problem. This is not a very high level use of system dynamics, but it connects system dynamics to the traditional curriculum smoothly, providing a leverage point for expanding analysis of applications and functions via the system perspective in future exercises.

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1998 SYSTEMS THINKING AND DYNAMIC MODELING CONFERENCE

June 28 - June 30, 1998

New England Conference Center, UNH, Durham, New Hampshire

The summer conference for 1998 will be held at the New England Conference Center on the lovely wooded campus of UNH. Here at the Exchange anticipation and excitement are rising.

First, we are thrilled to announce our keynote speakers: Dr. Jay W. Forrester, Dr. George Richardson, and Dr. Peter M. Senge. Dr. Forrester, Germeshausen Professor Emeritus, at the Massachusetts Institute of Technology, directed the system dynamics program at the MIT Sloan School of Management until 1989. He is the founder of the field of system dynamics. He also holds the patent for magnetic core memory, which for many years was the standard memory device for digital computers. Since his retirement in 1989, Dr. Forrester has worked to bring system dynamics into classrooms through the Pre-College Education Project at MIT.

Professor Richardson founded the *System Dynamics Review* in 1985 and served as its executive editor from 1988 through 1995. His teaching and research center has applied simulation modeling and a feedback perspective to policy problems in mulitple sociological arenas. He has published work on model-based policy analyses, the theory and practice of system dynamics modeling, and an intellectual history of feedback and circular causality. His most recent book is entitled *Modeling for Management: Simulation in Support of Systems Thinking*

Dr. Senge is the author of *The Fifth Discipline: The Art and Practice of the Learning Organization*. He is a Senior Lecturer at MIT and Director of the Organizational Learning Center. Dr. Senge's current research involves developing and testing "learning laboratories" and related innovations in organizational infrastructure for learning, and in continuing to articulate fundamental ideas for healthy systemic management.

Second, we are happy to have found a site as perfect as the New England Center. We took the questionnaire responses from the past conference to heart and are delighted with the result. The center has excellent meeting facilities with flexible space and many little nooks with a few chairs and tables for informal meetings or small group conversation. The meeting rooms are pleasant with comfortable seating, and the restaurant serves delicious, award-winning food in a glass walled room. The in-house pub is open until late in the evening for snacks and light meals.

The adjacent hotel has delightful rooms—with gorgeous views of the surrounding woods—and all the amenities, including lovely furniture. Gourmet coffee is provided in the lobby early in the morning. There are 115 guest rooms and a total of 186 beds. The number of single rooms is limited.

Additional space is available in a nearby dormitory at minimal cost. These rooms are not air conditioned, and there are no private baths.

Conference attendees may also stay at the Days Inn, in Dover, NH, which is about a 5 mile/10 minutes drive away. We have obtained a low conference rate. Shuttle transportation is *not* provided.

Durham is about an hour north of Boston. Regal Limousine Service offers transportation from Boston's Logan airport, from Portland, ME, or from Manchester, NH. They have both sedan and van transportation available. C&J Trailways bus has regular service between Logan airport and downtown Durham, leaving a walk of 15 minutes to the conference center.

We hope that this preview has generated enthusiasm for the conference. Look for your registration brochure coming soon.

Call For Papers

1998 International System Dynamics Conference
Quebec Hilton, Quebec City, Canada
July 20-23, 1998

Plenary sessions will emphasize state-of-the-art applications and methodological advances in simulation modeling and systems thinking.

Contacts: R. Joel Rahn, conference Chair, 3460 De Nevers, Ste-Foy, Quebec, Canada G1X 2E1 (e-mail: rjrahn@microtec.net or joel.rahn@osd.ulaval.ca)
Alexander Pugh, Program Chair, 49 Bedford Road, Lincoln, MA 01773, USA (e-mail: JandJpugh@aol.com)

Abstracts are due February 1, 1998.

For further information, contact Roberta Spencer, Executive Director, System Dynamics Society, Milne 300 - Rockefeller College, University at Albany - State University of New York, Albany, New York 12222 USA (e-mail: System.Dynamics@albany.edu)

Assessing Progress in Systems Thinking and System Dynamics,

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taciturn farmer that "c'aint get there from here." A variation has the city dweller, asking if he could get to his desired destination by taking one or another roads, being told curtly by the farmer that he "don't quite know." When finally the tourist lashes out at the farmer in frustration, "Don't you know where you are?" the farmer responds, "Well, t'aint lost."

Getting lost is easy in systems and there are sufficient numbers of folks who've initially gotten excited, only to lose interest as the challenges of learning about systems loomed ever larger and more daunting.

MAXIMIZING SUCCESS

There are a couple of basic concepts which, albeit almost self-evident, nonetheless need to be made explicit:

> Regardless of where one starts and where one hopes to travel, there remains a *learning curve.* Teachers need first and foremost, when interacting with systems, to picture themselves as STUDENTS trying to learn a new language and a new way to see things. Putting pressure on oneself to apply one's knowledge in a classroom and/or institutional setting without spending the requisite time LEARNING how to think and (if desired) model using system dynamics will invariably prove counterproductive. In sum, respect the learning curve and be patient!
>
> *There is a hierarchy* of sorts which exists when trying to become a systems thinker and/or a dynamical modeler. This hierarchy dictates that one start simple, then gradually add complexity. "Simple" oft-times is uncomfortable because many view "simplification" as a dirty word. Those who equate expertise or mastery with complexity need to understand that the power of systems rests in starting simple and building gradually. What one will discover is that complexity is often linked with PARTICULARITY; that is, one adds lots of detail to address specific cases, not the general scenario. Recognize, having the power to build complexity will not necessarily facilitate communication between educators.

BUILDING BLOCKS TO SUCCESS

Having presented some basic overviews, it's time to address the generic HIERARCHY, through which one enters and, ideally, through which one passes while building a desired level of success.

I. UNDERSTANDING SYSTEMS THINKING

People who seek to build models or people who seek to effect organizational/institutional change have one common need: to develop a basic understanding of systems thinking; that is, what defines systems and makes them function. The key components (and the logical sequence for learning about them), which form the basis for what must be understood as a common language that will promote effective conversation, are:

A. Dynamic systems operate through FEEDBACK(S).

B. Feedback defines itself through behavior over time.

Once having mastered these concepts (no small feat, to be sure: recall, mastery means that one's understanding transcends the specific illustrations used to "learn" the concepts; in effect, one must demonstrate "transferability" in seeing systems behaviors beyond those with which one is initially familiar), one may choose to progress as follows:

C. Modelers need next to understand that dynamic systems incorporate two distinct components:

1. The movement of "stuff": Using the terminology of STELLA, STOCKS and FLOWS are at the heart of systems; these two operate in tandem to identify dynamic "stuff" which increases and/or decreases as it moves about, within, into, or out of the system in question.
2. Information controls the movement of "stuff": Again, in the parlance of STELLA, CONNECTORS move various types of information from STOCKS, FLOWS, AND CONVERTERS to define the rates at which stuff will flow in the system.

D. Once having conceptualized how and where the system functions, one then reviews and/or collects information with which to better appreciate the dynamic features of the system; its properties, leverage points, etc.

II. MODELING: RATIONALES AND OCCASIONS

Those interested in organizational behaviors and systems thinking may, at this juncture, choose to employ their knowledge of systems as a launching point for developing conversations around large and complex organizational systems without building models. This seems entirely appropriate, given desired costs and benefits; if relatively simple models aren't useful for convincing others how actual systems are functioning, non-modeling activities can yield an acceptable cost-benefit ratio.

For those interested in developing models, care must be taken as well to nurture those skills. Armed with

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the knowledge that building models to simulate (not duplicate!) systems involves a learning curve, one needs to progress in a logical order to minimize frustration:

1) The objective for building the model needs to be understood from the outset. It is essential that one articulate, in 25 words or less, what objectives the model will be designed to address, before commencing model construction. Otherwise, one frequently finds him or herself sliding, either adding more and more complexity, or building a model which doesn't serve its original design.

2) One must ALWAYS simplify at first — to the point that one greatly OVERSIMPLIFIES how the system works. One stock, one flow, and one or two converters often initially suffice. The model, too, must work in this simple state.

- One must be able to acquire and incorporate information needed to define each factor to run a mathematical model of the feedback loop.

- One uses the model to simulate a systems behavior; graphical and/or tabular data generated must be understood.

- Model data are compared with one's anticipated result; the output is used to ask new questions, make new predictions, and test these predictions by running more simulations or changing the model.

3) Complexity must be added carefully and gradually. Rapid enlargements of models translate into compounding problems and difficulty in problem-solving. Beware: grow the model slowly!

III. MODELING: INTERPRETATION

1) Models can be used to explain how a complex system works.

2) Models can be used to draw conclusions or make policy decisions

3) Models of one system can be used to understand how other systems work.

4) Models can identify shortcomings in our factual understanding of relationships.

IV. STRATEGIES FOR MAXIMIZING SUCCESS: CURRICULAR DEVELOPMENT

All educators share a common desire to communicate what they've learned with others. To avoid having ideas either dismissed as incomprehensible or, worse yet, as unrealistic, requires that one consider the following:

COLLABORATION: Models shouldn't be constructed as individual exercises. There are many dangers associated with working alone:

1) There is an often unwitting and unintentional propensity to interject personal assumptions and/or biases which jeopardize the value of one's work.

2) Two heads (or more) are better than one. Enough said.

3) Everything from framing a question on up to successfully building a model improves with explicit questions being raised and assumptions and presumed relationships being challenged.

In our experience there are four basic curricular roles that need to be filled in any successful model-building exercise; several of these roles can be played by the same individual, but a fully productive team of four can distribute these roles to individual team members.

1) Knowledge of the system in question: What are the Stocks, Flows, and Controlling relationships that characterize the system?

2) Technical modeling skill: How can the mental model best be translated to a computer simulation?

3) Pedagogic insight: How will the model be incorporated into the curriculum?

4) Constructive critic: This is the role that requires at least a second individual in each project.

INTERDISCIPLINARY EFFORTS: On a higher scale, collaboration focused on interdisciplinary topics requires all parties to *communicate* how their systems work and to work toward developing projects which have the broadest potential to educate (i.e., to raise questions, develop unfamiliar connections between systems, etc).

V. CONCLUSION

All this is simply a guide for thinking about what one hopes to accomplish, within what time frame, and with what desired results. Knowing where one wants eventually to go and appreciating what it takes to get there will facilitate success, and accord one the means to avoid ending up on a one-lane dirt road with an uncooperative Vermont farmer as one's guide.

VI. GOOD LUCK!

F

Systems Thinking and System Dynamics in K-12 Education

A study supported by The Waters Foundation—School Year 95-96—by Mary Scheetz

The Spring 1997 issue of the Creative Learning Exchange newsleter featured Mary Scheetz's study of twelve school districts around the country which are integrating systems thinking and system dynamics into their programs. In that issue (Volume 6, Number 2) we excerpted the summary from the Carlisle, MA, Public Schools. Following is the summary from the Harvard, MA, Public Schools.

HARVARD PUBLIC SCHOOLS
THE BROMFIELD SCHOOL
Harvard, MA

Setting

The Harvard Public Schools are located in the suburban community of Harvard, outside of Boston, Massachusetts. It is a K-12 system consisting of a high school (9-12) and a middle school (7-8) located on the same campus and called The Bromfield School with a student population of 450. The elementary school is located nearby and serves a student population of approximately 600. The working adults in the community of some 5000 residents are employed in a wide range of occupations which include, for the most part, managerial or professional positions. A correspondingly high level of educational attainment and above-average family income have resulted in a community that values education and has high academic aspirations for its children.

District Philosophy/Goals

The Harvard Public Schools are dedicated to giving every student the opportunity and means to acquire essential and applicable knowledge in the content areas, and command of the critical reasoning and higher order thinking skills requisite for problem-solving, research, and continuous learning. Complementary to its focus on students as learners, the schools are commited to helping students develop the interpersonal skills necessary for working effectively and cooperatively with others and to become responsible school, community, and world citizens. In support of the realization of this mission, the schools will embody the community's standards and expectations.

Project Goals/Philosophy

Our beginning philosophy was simple: to explore ways in which to involve our classrooms in "systems approach" activities and evaluate the benefits and drawbacks of doing this.

It is important to illustrate to students the connections between apparently unrelated aspects of a complex system. It enlivens the potential for interdisciplinary teaching and the development of more critical thinking in the learning process.

1996-97 goals include the expansion of the use of systems thinking and system dynamics in the classrooms and in the organization of the Harvard School District and the exploration of ways in which system dynamics can be used to integrate various disciplines.

History of Project

Initially, the classroom teachers involved looked for existing models, talked with people using them, and went to conferences and workshops to learn more about the techniques. As teachers became more proficient, they knew how to better judge the relative benefits and appropriateness of various techniques. They were interested in exposing students to models and systems analysis which paralleled real life experiences, including at least several which dovetailed with experiments they would be likely to complete in the labs of their classes.

June 1996 marks the end of the first eighteen months of the project, "The Introduction of System Dynamics into the Classroom" supported in part by the Center for Excellence in Science and Math Education (CESAME). This project involved two high school science teachers, one middle school science teacher and, peripherally, one high school math teacher. Each has introduced several activities into classrooms during the year. In science classes seventh graders observed bacterial colonies on agar plates and built a STELLA model of exponential growth. They also worked with a model of the spread of an epidemic as they studied a unit on AIDS. The ninth grade earth science classes played the Fishbanks game as well as worked on a Fishbanks STELLA model. The environmental biology class worked with a predator prey model. Physics classes worked with models for air drag and modeled a lab experiment on falling coffee filters. They worked with a bungee jumping model, and they related the exponential temperature drop of a coffee cup to a STELLA model of a cooling coffee cup. In Math classes, some students chose to do independent projects using STELLA Models. Their topics were: predicting proper drug doses, the mathematics of exponential growth, modeling infinitely converging series, and predicting optimal bets in monopoly games.

Plans are in place to involve more middle school teachers and to create more interdisciplinary involvement among the teachers. A leap forward is anticipated in terms of more time and resources, deeper involvement and increased numbers of teachers involved due to the acquisition of a grant to fund training and a mentoring position.

Teachers from the middle school are currently participating in a collaborative grant project as a part of

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Integration of System Dynamics into High School, continued from page 3

Students can, as a class exercise with the teacher, expand a simple problem. Again vocabulary is important. Assuming students have created simple STELLA models of the problems in the text, a problem of particular interest can be expanded/analyzed as an exercise with the entire class. Students have the opportunity to apply both growth and decay components to the same problem (something that is noticeably absent in most textbook problems before Calculus level). They can also combine functions within the same problem, applying for example, exponential growth and linear decay. Additionally students can be given exercises to expand the simple textbook problems into models on their own and explain their enhancements, thus providing a natural vehicle for including more written explanation in mathematics, as the US national math standards propose. It seems to be easier for students to explain STELLA models they have created, since the structure of the model is more closely connected to the application components than traditional symbolic representations of problems.

Once students have become accustomed to representing problems generally presented in their texts, they become comfortable using lessons that introduce problems that would have been beyond the scope of the course, via traditional symbolic, numeric, or graphical expressions. For example, periodic functions are presented in most second year Algebra courses. The application problems usually accompanying this study often rely on study of Ferris Wheels, oscillating springs, and swings. While these are useful problems, there are other applications which may appeal to students who do not have a particular interest in these physics concepts. One such example is predator/prey interaction scenarios. Using a structured diagram approach, such as provided by the STELLA software, students are able to design a model and study it , answering the traditional questions about period and amplitude, including determining an appropriate symbolic representation for the model. Beyond this, however, students may extend their study to include potential problems that may arise in an ecosystem and test scenarios for controlling problems that may require legislation. Students could support certain legislation using experiments conducted on their model to provide rationale for their approach. Hence, now there is a connection between mathematics and the social sciences and/or law classes in the school, another objective of the US national standards for mathematics instruction.

". . .they become comfortable using lessons that introduce problems that would have been beyond the scope of the course, via traditional symbolic, numeric, or graphical expressions. . ."

STELLA models demonstrating the connection between exponential, convergent (Newton's Law of Cooling, as an example of convergent), and logistic structures illustrates beautifully the similarities and differences between these three growth patterns. System dynamics and structured diagrams using STELLA illustrate elegantly the simplicity and connection between related function types. This view is not afforded by other methods.

The use of differential equations can be expanded formally in the development of models in a Calculus class. Generally differential equations is given very little time in most introductory Calculus classes. Unfortunately, this delays or (for many) eliminates the study of some of the most interesting applications in high school mathematics. Obviously, the study of models from the perspective of differential equation analysis was meant for system dynamics study using STELLA. As previously stated, providing experiences for students to study what may have been beyond their grasp via the traditional views is very powerful. Students can experiment with SIR infection models and Lotka-Volterra predator/prey models, among others. Designing and playing with models using STELLA provide useful insights into problem structures that provide deeper understanding when these topics are studied using more traditional methods later in a student's educational career.

In earlier classes (Algebra and Pre-Calculus) the vocabulary when studying functions can focus on the flow equations as a description of the behavior of the system over time. The system dynamics perspective, beginning as early as introductory Algebra classes, sets the foundation for those concepts that are at the core of Calculus. Starting with the motion detector and gradually studying and building STELLA models support what is currently being taught in mathematics. A course in modeling using a system dynamics approach is where the difference between what is currently being taught in high school mathematics and what can be taught is dramatically different. Students in system dynamics modeling classes have produced models and technical papers that are a quantum leap above the traditional work of high school students in math in the United States.

The ultimate development of a system dynamics view of problems is in a systems modeling course. Here students proceed through exercises, during the first half of the school year, that develop their ability to look at problems differently, to look at problems from varied disciplines, to de-

Integration *continued on next page*

Summaries of ST/SD Projects in K-12, continued from page 7

the Center for Excellence in Science and Mathematics Education at Northeastern University. The purpose of this grant project is to develop a series of lessons and activities that enable middle school students to think more rigorously about how things change. The team of teachers from Harvard and from four other middle schools in the area will develop hands-on, inquiry-based activities, lessons, and assessments, in conjunction with STELLA simulation software, that would introduce middle school students to mathematical modeling and a systems approach to complex problem solving.

Quotations from Project Participants

Notable Results

• "As students cycle back and forth between hands on data from real events and STELLA models which attempt to simulate those events, they grow in their confidence to build and refine models to better approximate reality. This is an empowering experience for them as they begin to understand concepts to a greater depth."

• "The dialog which results as small, thoughtful groups discuss and refine models, promotes and reinforces critical thinking skills."

• "Students learn that the validity of a model is based on assumptions and that the predictive value of a model is directly linked to the quality of those assumptions."

Individual Learnings

• "Systems thinking is necessary for successful change."

• "The learning curve for systems thinking/system dynamics is very steep."

• "We need time for teachers to meet while at the same time dealing with the controversy over teacher release time."

• "We'll know that systems thinking and system dynamics are integrated into schools when the educators who now stand out as innovators in this area melt into the background."

• "Initial student built models were not sophisticated enough to challenge thinking. We needed to carefully plan instructional activities, including the use of models to stimulate and develop high level thinking."

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Seamless Integration of System Dynamics

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velop simple models from scratch, and explain them to others. During the second half of the year students choose a partner with whom to work. They choose a problem they want to study. With the help of the instructor they find a reference/expert who understands the problem they want to model. Using the library, the Internet, various books, and various databases, they try to collect data about the problem. They design a model, often finding they do not understand the problem well enough, or their expert cannot communicate effectively with them, or the data they found is inadequate or insufficient. Almost half of the students find they need to change their model topic in the first two weeks of data collection and early model construction. Once the groups have topics that appear to be appropriate, the students work to design a model that represents the structure of the problem sufficiently and try to validate the results produced by the model. To validate their models, students may use theoretical information, or their expert, or the data they have collected, or, if all else fails, a comparison of results that match reasonable expected behavior. Students then write a ten to twenty page technical paper explaining their model, how it works, what the graphs indicate, how they validated their results, and what they conclude. These papers never fail to impress all adults who have seen them, as they are far beyond the traditional expectations of students at high school level. For the past two years there has been a systems modeling competition, called SYM*BOWL, for high school students in Portland, Oregon. Students must explain their models to a panel of judges who are expert modelers.

At Franklin High School in Portland, Oregon the number of students taking the systems modeling class has increased from 11 to 60 in the last 5 years. At Wilson High School, also in Portland, the number has increased from a few students doing independent study to over 50 in the same amount of time. Three additional high schools will be adding a SD modeling course next year.

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More e-mail access at the CLE

It is now possible to reach the Creative Learning Exchange by means of another e-mail address.

Andrea Miller, administrator, can be addressed at milleras@cle.tiac.net.

Director Lees Stuntz still has the same address: stuntzln@tiac.net

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those thoughts more carefully, and broadly. The line can't go just anywhere; every point means something so you have to be explicit. In a broader sense, as you draw the line, you also begin to ask why something goes up or down. Rather than focusing on static events, you begin to look at the change itself, and what is causing it. For example, you could study the events leading up to the American revolution as a series of dates and isolated conflicts (as we all did). However, if you could graph it as the escalation in tit-for-tat hostility over time, wouldn't it be exciting to watch events unfold? Your understanding would be deeper, and it might even extend to other similar escalations.

BOTGs begin to bridge the gap to interdisciplinary learning. When students use graphs, math becomes a part of every other subject. Students sharpen their conceptual math skills as they apply them across disciplines and through the grades. As in the real world, school subjects become relevant to one another. This connection becomes meaningful not only for students, but also for the teachers who work together developing interdisciplinary units.

BOTGs can reveal deeper lessons. Once students get adept at reading and writing BOTGs they can see patterns and relationships. For example, they might recognize the exponential growth in a cultured yeast population or in a bank balance left to accumulate interest—slow growth at first which suddenly takes off. At this point students are ready to learn about the underlying system structure which is causing the change.

BOTGs are the basis of system dynamics computer modeling. A system dynamics model defines the structure which causes a behavior to change and then simulates it over time to see what happens. Before you even begin to build a model, however, you draw yourself a BOTG of the behavior you are trying to understand. For example, you might want to understand why the deer population in an area grew so quickly and then suddenly collapsed. You would draw that graph and try to build a model to replicate it. The computer output from that system dynamics model is a BOTG. In simulation, you might want to see what happens if you change the food supply or the number of predators. The model would produce another BOTG for each scenario, which you would read and analyze until you understood how the system works and what policies would be best to manage the deer population. Students, by the way, think this is fun. For those students who get into modeling, all the earlier benefits of BOTGs are reinforced even more: the engaged learning, the precise thinking, the broader interdisciplinary lessons. It all comes around. (If this reminds you of a causal loop diagram, you're right! We'll save those for another time.)

PLEASE SEND US YOUR IDEAS

There are lots of teachers across the country using BOTGs to take what they are already teaching and make it better. So that other teachers can also learn how to use this systems tool, ***we would like to publish examples of BOTGs used in the curriculum across all K-12 grades and disciplines.*** The BOTGs can be used alone in short simple lessons or they can be part of larger system dynamics units. If you have tried BOTGs, we would like to hear about any pleasant surprises with students as well as pitfalls to avoid, and we would love to publish any classroom materials that you have developed so that other teachers can use them.

We are asking for your curriculum ideas and materials. The good news is that they do not have to be polished or written up. Working with you, I'll do the writing and prepare your lesson for distribution through the Creative Learning Exchange. You'll get credit for publishing a great idea, and best of all, other teachers and their kids will benefit too. Your ideas will help other teachers get started as well as germinate lots of new ideas. We're all beginners at this; we can learn from one another.

If you don't have curriculum ideas to contribute but you do have questions or problems using BOTGs, please send those along too so that they can be addressed through these publications. The goal is to present the curriculum in a way that is most useful to teachers.

All your ideas and advice are welcome. Please send them to Deb Lyneis, Creative Learning Exchange, 1 Keefe Rd., Acton, MA 01720, or e-mail them to me, Deb Lyneis, at *lyneisd@cle.tiac.net* Remember that your curriculum can be in any draft form. Just include your address, e-mail address, or phone number so that I can reach you for more information as I write it up. And thank you for helping us get your ideas out to other teachers and students.

K-12 DISCUSSION GROUP

A lot of information comes to us from the K-12 Discussion Group Listserve. You, too, can become a part of the K-12 Discussion Group.

k-12sd@sysdyn.mit.edu

To join contact Nan Lux: ***nlux@mit.edu***

GORDON STANLEY BROWN FUND

**To support preparation for distribution of materials
for using system dynamics in K through 12 education**

May 1, 1998: Application deadline for funding for the summer of 1998

Be sure to submit your proposals prior to the deadline.

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 Gordon Brown Fund can support teachers for:

- Released time or summer time to put into 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.

The Fund will focus on making experiences available to others. The financial assistance can be used for released time and summer time for putting into transmittable and usable form materials and experiences that have already had classroom exposure. Small and medium proposals are encouraged.

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 the Massachusetts Institute of Technology in the 1940's. 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.

There is no standard application form. Address requests, with an outline of the proposed project, to:

Jay W. Forester, Committee Chairman
Massachusetts Institute of Technology
Building E60-389
Cambridge, MA 02139
e-mail: jforestr@mit.edu

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Summaries of ST/SD Projects in K-12. . . continued from page 9

• "Although models are accessible through the Creative Learning Exchange, we still need guidance in relationship to 'best use'."

• "We need a mentor to make connections between what's available and what teachers are doing."

• "Our latest thinking is that we need to minimize the need for teachers to build their own models."

• "We need enough models in use in classrooms for the students to see the threads, the progression between the models."

Challenges

• "We have made some progress in becoming more familiar with systems thinking terminology, techniques, and modeling, but the learning curve is very steep."

• "Several staff members have identified appropriate ways of introducing 'systems' activities."

• "Although there have been many challenges, we have been successful in struggling through initial model building/model refinement"

• "We are still working to find the time and resources to involve other colleagues in the systems approach to education thereby attaining a greater critical mass and better potential for interdisciplinary activities."

• "We could benefit greatly from locating a bank of models applicable to various curricular topics which could be refined to meet the needs of teachers just starting in systems thinking and the related pedagogical techniques."

• "We need help in defining local issues which could be modeled using STELLA and incorporated into classes as relevant topics of interest to students and the local community."

Please note: The entire text of the article from which this piece was excerpted is available from the CLE and the web site (*http://sysdyn.mit.edu/*). The 8-character title is SUMMARMS.

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The Creative Learning Exchange Newsletter is available in three different formats:

- On the web page at **http://www.sysdyn.mit.edu/**
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- In paper via US mail ($15.00 outside USA)

Since we vastly prefer electronic distribution to paper because it is so much less expensive, at any time feel free to e-mail us when you would like to have an electronic subscription.

milleras@cle.tiac.net

INTERESTED IN INVESTING?

If you would like to invest in our effort here at the Creative Learning Exchange, your contribution would be appreciated. You may donate any amount you wish; perhaps $50 is a reasonable amount for a year. All contributions are tax-deductible.

I am sending ________ to *The Creative Learning Exchange* to help invest in the future of systems education.

Name____

Address____

Thank you!!

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The Creative Learning Exchange is a trust devoted to encouraging exchanges to help people to learn through discovery. It is a non-profit educational institution and all contributions to it are tax-deductible.