Dynamic Modeling with Computers: A Tool for Learning

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" I felt that computers had limited usefulness in education until I came across STELLA. It uses the capabilities of the computer to enhance student thinking and understanding rather than just drilling them on facts or processing words and data."

Al Powers, an enthusiastic thirty-year veteran science teacher, was frustrated with traditional approaches to teaching when he found STELLA (Structural Thinking Experimental Learning Laboratory with Animation), a user-friendly system dynamics modeling program. It transformed his attitude about teaching as well as his pedagogical approach. The power of this tool has enabled his students to model, simulate, and explore the dynamic nature of the scientific systems they are studying.

During a recently observed day, Al was incorporating the use of modeling in all four of his high school science classes. His 'alternative class' (composed of students who are not functioning adequately in the school program) was playing a simulation game, *Fish Banks, Ltd.*, based on the scarcity of common resources. The students were enthusiastic and involved, trying to make the most money and to beat the game. Later in the week, he used a STELLA model to help the students understand the system and to evaluate the impact of policy decisions that might be instituted to protect the common resource.

"The difference with this approach is that I am seeing students engaged in learning in a way not commonly seen. They are generating insights and understanding that have been previously denied to most students. It is a thrill to have a student who has had a history of difficulty tuning in to school come up to me and say 'I was thinking about what we were doing in class, and I really understand it!' " The ability to engage these students in their learning through the use of STELLA becomes especially effective when extended beyond science. Al currently has plans to work with a colleague to model the personality dynamics within the book, Sybil.

The same day, Al's other classes showed different uses for dynamic modeling. His physics classes were engaged in trying to recreate a model of throwing a ball that had been simulated the previous day. Its purpose was to elucidate the often hard-to-understand relationships between velocity and gravitational acceleration. The structure of the model as well as the definition of terms forced by the modeling process often trigger learning in a way untapped by other methods.

Al's honors chemistry class was engaged in yet another exercise. In groups of three or four gathered around a computer, they were using a dynamic modeling exercise to figure out what really happens as a cup of hot liquid cools. The discussion in the small groups was engaged and animated.

Debates explored whether the graph of cooling would be linear or exponential. To help, they had a tool in front of them (STELLA) that allowed them to play out their scenarios to see which made the most sense. A follow-up to this lesson was a lab in which the actual temperatures of the liquid would be taken over time. This data would then be compared with the simulation and differences would be reconciled either by restructuring the model, if appropriate, or by conducting further investigations in the laboratory. Al is looking forward to many of these students developing and exploring additional STELLA models of chemical systems throughout the year.

He has already had reinforcing experiences with students building models. During his recent sabbatical, he created a number of STELLA models depicting chemical equilibria. For him, the process of creating the models generated an increased level of understanding that proves invaluable when working with students. He also introduced an interested student to the STELLA models. That student went on to develop his own model of a specific chemical equilibrium that now serves as the foundation for the student's own, original hypothesis concerning the system's early dynamics.

Interdisciplinary Thinking Tool

Modeling using STELLA, a powerful tool to explore systems as well as to create interdisciplinary curriculum, generates a deep understanding of interconnections. It gives students much-needed insight into the dynamics of systems over time. Mandinach and Cline of Educational Testing Service have had extensive experience with teachers using modeling through their STACI^N (Systems Thinking and Curriculum Innovation Network) Project . They define three stages of modeling within a curriculum: parameter manipulation, constrained modeling, and epitome modeling. All three are useful for different purposes and a combination of approaches in any one curricular unit may be the most effective.[1]

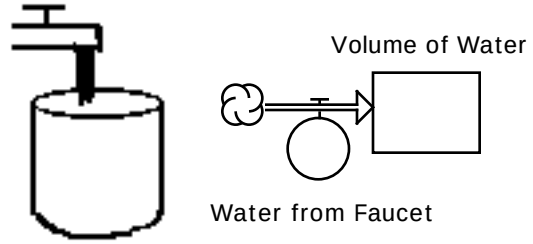
STELLA models have been used as the basis for developing simulation games or projects in middle schools. Frank Draper and Mark Swanson at Orange Grove Middle School in Tucson, Arizona, have used simulations of real-life situations in eighth-grade science classes. Through the use of Hypercard interfaces (computerized stacks of pre-made and arranged "cards" with pictures, words, or options for action), the students are able to manipulate parameters of a system dynamics (STELLA) model which they cannot see. Since they cannot access the model they are unable to change its structure. These units have proven to be valuable interdisciplinary learning tools. As with any good simulation, different areas of the curriculum can be stressed. A fractions study in math can be reinforced by using fractions in a simulation rather than decimals; the social skills acquired in a " Skills for Adolescence" program can be used and assessed in the small groups formed for working with the computer simulation. At the end of the simulation, having created a system with which everyone is familiar, modeling a small part of the system (constrained

modeling), or modeling the whole system as understood (epitome modeling) creates extended understanding.

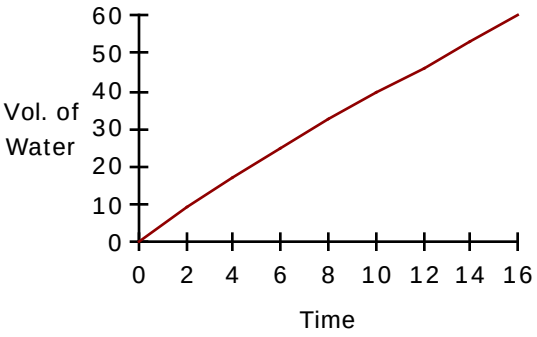
In Glynn County, Georgia, middle school teachers are creating interdisciplinary curricula with two different uses of parameter manipulation. One is using an implicit (or hidden) model, similar to some of the simulations at Orange Grove, where the model is imbedded in a curriculum interface using Hypercard stacks or other tools, and the students do not interact with the model itself. The implicit model lends itself to furthering the exploration of the subject by presenting the opportunity to then build a model from scratch (epitome modeling) or modeling small portions of the system (constrained modeling). In contrast, one environmental unit, Eatordie Island, presents the students with an explicit model of a predator-prey system for manipulating both the parameters and the structure. Both constrained and epitome modeling can be done by individuals, by small groups working together on computers, or even by a teacher leading a large class discussion with an LCD overhead display attached to a Macintosh. The explicit, or visible, model creates an understanding of what a model is and how it works. All the approaches are useful within a curriculum.

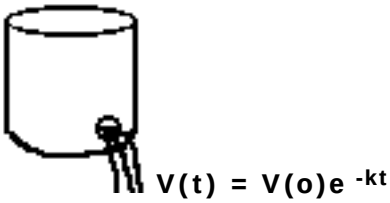
The game Fish *Banks, Ltd.*, a National Diffusion Network selection, can be used from fourth or fifth grade through adulthood as a foundation for discussing a dynamic system. The game was created by a system dynamicist, Dennis Meadows. It lends itself well to either constrained modeling or epitome modeling. "Building the Fish Banks Model" by Joseph Whelan of the Systems Dynamics in Education Project[2] at MIT is a tutorial to help participants who have played *Fish Banks* start the modeling process. Another useful resource is "Renewable Resource Depletion", a curriculum based on both the *Fish Banks* game and a STELLA model of the fishing system represented by the game. Participants manipulate parameters in the model to "execute" policy changes. The curriculum guides the participant through various policies and their effects to see if it is possible to stabilize the fish population and continue fishing.

STELLA modeling allows the student to compress time and thereby discover the long-term results of actions. Because students are interacting through the computer and generating results in graphical, tabular, and animated formats, their attention and, therefore, learning is maintained. Even the simplest modeling of a system can give insights certain to be missed without it. For example, the graphical representation of the rather complicated equations representing buckets emptying into each other provides an explicit and interactive way to illustrate such things as drug or alcohol levels in the blood.[3]

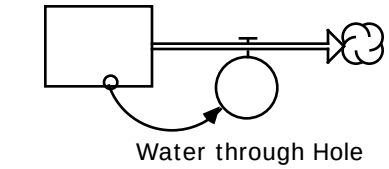


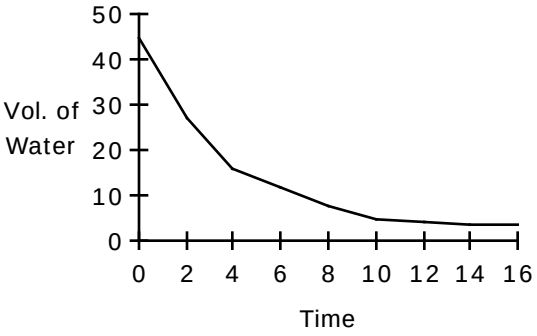
$V(t) = V(o) + 4t$



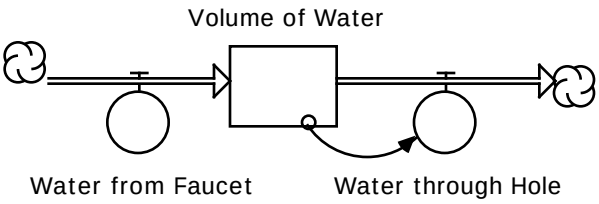


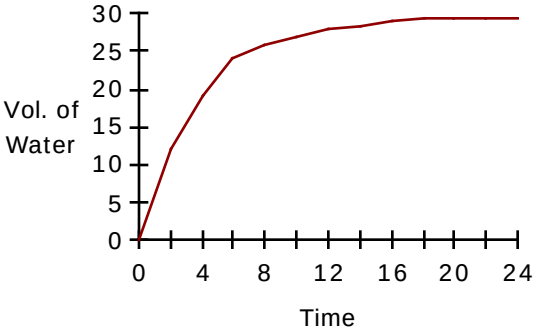
$V(t) = V(o)e^{-kt}$





$V(t) = V_A(1 - e^{-kt}) + V(o)e^{-kt}$





The rectangles in STELLA represent stocks or accumulations. The double arrows with circles attached going in or out of stocks indicate flows or rates. The single arrows are inputs to the rate.

Applications throughout the Curriculum

Because STELLA is a mathematical modeling system, straightforward uses in the math curriculum abound. STELLA can be easily applied to physics as well as to the other hard sciences. Al's use in the chemistry and physics classrooms are examples of dynamic modeling giving new breadth and depth to critical understanding. Since dynamics is a factor which is routinely studied in these sciences, STELLA is a logical and highly effective tool.

Its power to help gain new levels of understanding, although significant at the math and physical science level, is magnified when applied to social systems. Traditionally there has been little discussion or concentration on the ongoing dynamics of changing social systems. STELLA is a tool to give new insights and different perspectives.. Diana Fisher and Ron Zaraza, principal investigators for a three year NSF grant in Portland, Oregon, are building on their knowledge of the use of STELLA in math and science classes to create a foundation for interdisciplinary curricula. In their training seminars they are including teachers of social studies and English, in order to encourage the creation of broad-based curricula. Jeff Potash has demonstrated the use of STELLA at the college level in history, and social systems such as revolutions have been modeled and used as the basis for courses in high school.

One of the first examples of successful use of STELLA in the classroom occurred in the Brattleboro High School, Brattleboro, Vermont. One of the courses offered was on Wars and Revolutions. The students participating had gained experience with modeling through workshops and a physics course. They spent a semester modeling wars and revolutions from different historical contexts. Within a semester's time they were able to create working models which reflected historical reality. It was these demonstrations of success in the classrooms at Brattleboro that contributed to the founding of the ETS STACI^{N} Project, of which Brattleboro teachers are charter members.

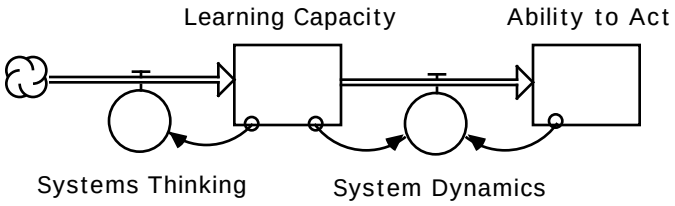
The use of STELLA to model literature successfully and capture students' attention has been demonstrated. Pamela Hopkins simulated Hamlet in her eleventh grade English classroom. It proved to be a powerful tool to hold her students attention, beyond any technique she had used before. She found her students, who came from a lower socio-economic population, uninterested in Shakespeare. By using a system dynamics model in STELLA, she was able to explore different responses to the same situation. as well as rearrange the time sequence within the play. The model encouraged students to change and manipulate its parameters and to become involved in the play. It is that involvement which created learning.

K- 12 continuum

Although much of the work with system dynamics has been done at the middle school and high school level, there is precedent for introducing it in elementary school as early as kindergarten. Lucas and Langheim indicate that use of terminology and preliminary work with cyclical systems has validity in kindergarten classes in the schools in Ridgewood, New Jersey. Even before the appearance of STELLA as a user-friendly program, Roberts found that ten and eleven year old students are capable of dynamic understanding. Lucas did constrained modeling with his fourth grade class based on a simulation "Lemonade Stand". After playing the simulation, the class did a group modeling project using STELLA icons, and eventually STELLA on the computer. They ended up basing a very successful fundraising project on the insight provided by the modeling exercise.[4]

The Link between Systems Thinking and System Dynamics

Our tools for learning can be enhanced by the coordinated use of systems thinking and its companion tool, system dynamics. In education there is currently a high level of interest in utilizing the techniques of systems thinking and in creating learning organizations. Systems thinking is Peter Senge's Fifth Discipline, in his book by that title. It is the discipline which ties his other four management disciplines together and gives those in a learning organization the tools to create a functional and dynamic organization. Al Powers created a simple diagram using STELLA's stocks and flows to illustrate the power of using systems thinking with system dynamics.



Jay Forrester states "Because most of life deals with change through time, systems thinking must be supported by system dynamics...the study of real structure, nature and policies. Indeed, without system dynamics, systems thinking can be misleading and dangerous."[5] By using system dynamics, a basic tool in a systems thinking approach, to help generate understanding of the systems in which we live we will give our future leaders the tools necessary to become life long learners in learning organizations.

Footnotes:

[1]Mandinach, E. B.,and H. F. Cline. (1993). "Systems, Science, And Schools." *System Dynamics Review* 9, 2: 195-206.
[2]System Dynamics in Education Project utilizes MIT students to work on system dynamics projects applicable to K-12 education. It is supervised by Nan Lux and Jay Forrester, Germeshousen .Professor Emeritus. Professor Forrester is recognized internationally as the first to articulate the field of system dynamics.
[3]Fisher, D. M. (1993). "STELLA Vs. Equation Interface." Unpublished paper.
[4]Langheim, R., and T. Lucas. (1992). "The First Year: Integrating Systems Thinking and STELLA into the K-12 Curriculum." Unpublished paper.
[5]Forrester, J.W., "Systems Education as a Foundation for Learning." Systems Thinking in Education Conference, March 11-13, 1992. Tucson, AZ.

References:

Betts, F. (1992). "How Systems Thinking Applies To Education." *Educational Leadership* 50, 3: 38-41.
Brown, G. S. (1992). "Improving Education In Public Schools: Innovative Teachers To The Rescue." *System Dynamics Review* 8, 1: 83-89.
Draper, F. (1993). "A Proposed Sequence For Developing Systems Thinking In A 4-12 Curriculum." *System Dynamics Review* 9, 2: 207-214.
Draper, F. (1991). "Integrating Systems Thinking And Simulation IntoTheEighth Grade Science Curriculum." Unpublished paper.
Draper, F., and M. Swanson . (1990). "Learner-Directed Systems Education: A Successful Example." *System Dynamics Review* 6, 2: 209-213.
Fisher, D. M. (1993). "STELLA Vs. Equation Interface." Unpublished paper.
Forrester, J. W. (1971). "Counterintuitive Behavior Of Social Systems."*Technology Review* 73, 3: 1-16.
Forrester, J. W. (1993). "System Dynamics As An Organizing Framework For Pre-College Education." *System Dynamics Review* 9, 2: 183-194.
Gould-Kreutzer, J. M. (1993). "Foreword: System Dynamics In Education." *System Dynamics Review* 9, 2: 101-112.
Halbower, M. C. (1992). "Renewable Resource Depletion: A Systems Approach To The Tragedy Of The Commons." Massachusetts Institute of Technology.
Hopkins, P. L. (1992). "Simulating Hamlet In The Classroom." *System Dynamics Review* 8, 1: 91-98.
Isaacson, N. and J. Bamburg. (1992). "Can Schools Become Learning Organizations?." *Educational Leadership* 50, 3: 42-44.
Langheim, R., and T. Lucas. (1992). "The First Year: Integrating Systems Thinking and STELLA into the K-12 Curriculum." Unpublished paper.
Mandinach, E. B., and H. F. Cline. (1993). "Systems, Science, And Schools." *System Dynamics Review* 9, 2: 195-206.
Meadows, D. L.(1989). "Fish Banks, Ltd.." Durham, NH, University of New Hampshire.
Potash, J. (00/00/00). "A New Tool For Teaching History In The Classroom: Nonlinear Dynamical Modelling Using STELLA." Burlington, VT, Trinity College of Vermont.
Powers, A. L., (1993). *Sabbatical Report, September, 1992 to June, 1993.* Concord, MA, Concord-Carlisle Regional School District.
Richmond, B. (1993). "Systems Thinking: Critical Thinking Skills For The 1990s And Beyond." *System Dynamics Review* 9, 2: 113-133.
Roberts, N. (1978). "Teaching Dynamic Feedback Systems Thinking: An Elementary View." *Management Science* 24, 8: 836-843.
Senge, P. M. (1990). *The Fifth Discipline: The Art and Practice of the Learning Organization.* New York, Doubleday.

Stuntz, L. (1993). "Glynn Integration of Systems Thinking (GIST)." *The Creative Learning Exchange* 2, 3: 1-8.
Stuntz, L. (1992). "Brattleboro Union High School - A Start Down the Road." *The Creative Learning Exchange* 1, 2: 1-6.
Whelan, J. (1993). "Building The Fish Banks Model." Massachusetts Institute of Technology.

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