System Dynamics for Kids

By Jim Hight

In one corner of an immaculate, chilled computer room, two high school teachers are trying to help their simulated population of East African nomads stay alive. With a few keystrokes and mouse clicks on a Macintosh computer, they start a vaccination program to prevent infectious diseases, then watch as the machine plots the effects of their work over the succeeding years. Death rates go down and people start living longer; with more people to feed, however, the nomads' cattle herds begin to decline. Within 10 years, more people than ever are dying of starvation.

The pair then goes back to year one. This time, to increase the live-stock population, their plan includes preventing cattle disease and providing equipment for digging watering holes. Under this scheme, both the human and live-stock populations stabilize, then increase. Ten years later, the nomads and their cattle are thriving. But now the land is being grazed more intensively, eventually becoming arid. Within 20 years the country is plunged into a catastrophic famine.

As a relief effort, this simulation was a spectacular failure; but as a learning exercise, it holds a lot of promise. In a reform movement led by two emeritus professors from MIT, "system dynamics" exercises like this one are helping to turn K-12 classrooms around the United States into high-performance learning centers.

System dynamics is an approach to observing and analyzing any complex organization in a comprehensive manner: seeking to understand its structure, the interconnections between all its components, and how changes in any area will affect the whole system and its constituent parts over time. The discipline has its roots in engineering science, particularly in the development of feedback amplifiers for long-distance telephone lines at Bell Laboratories in the 1930s and the work of the MIT Servomechanisms Laboratory in the 1940s.

The basic building blocks of any system are simple "feedback loops" or causal loops," a good example of which is the household thermostat: a device in which temperature is the trigger that turns a furnace on and off, in turn regulating temperature. But larger, more complex systems—like a society of East African nomads—are constructed of many interacting feedback loops, and a change in any one will affect all the others in dynamic ways.

Since the early 1960s, the principles of system dynamics have been extended to social systems, such as corporations, cities, ecosystems, and regional economies. The efforts of

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innovative educators to introduce these analytical tools into the classroom, as early as kindergarten, began only in the late 1980s, but already they are bearing fruit.

"Education has taught static snapshots of the real world. But the world's problems are dynamic," writes Jay Forrester, SM '45, the founder of system dynamics. Six years into his official retirement from the faculty of the Sloan School, he is the founder/director of the System Dynamics in Education project (operating with private funding under the aegis of Sloan) and mentor for many K-12 educators.

"Missing from most education is direct treatment of the time dimension," Forrester explains. "What causes change from the past to the present and the present into the future? How do present decisions determine the future toward which we are moving?" Conventional teaching, he believes, ignores such questions, the answers to which "lie in the dynamic behavior of social, personal, and physical systems." Forrester is convinced this behavior can be taught and can be understood, even by very young children.

Nearly 300 teachers, administrators, and students gathered to hear Forrester's most recent ideas and to learn from other leading practitioners at a conference on "Systems Thinking and Dynamic Modeling in K-12 Education," held this past summer on the campus of Concord Academy in Concord, Mass.

In an open lab, they shared their latest computer software, including the African development model that is the work of teachers at Sunset High School in Beaverton, Oregon "I play the role of an ambassador from an East African country, and teams of students act as aid agencies like the Red Cross and World Vision," explains Matt Hiefield, a social studies teacher who developed the computer program with three of his colleagues.

Hiefield, who served in the Peace Corps in Mauritania, uses the simulation at the end of a unit on Africa. The nomadic group he presents to his students is self-sufficient but suffers from chronic hunger and persistent diseases. Almost invariably, he says, students are surprised to see their well-intentioned aid measures making things worse. "At first they think 'The death rate is high and certain diseases are rampant, so let's vaccinate.' But this program allows us to see that the most apparent 'solution' may create more problems," says Hiefield.

There is no "correct" answer for this exercise. It is possible, however, to propose meaningful aid that is unlikely to throw the nomads' complex and delicate system of survival out of balance, provided each student team coordinates its efforts with the others, and they test assumptions of what works and what doesn't.

Forrester has been researching and documenting just how complicated social systems can be since the mid-1950s, when he moved form MIT's engineering labs to the Sloan School. In this new arena, Forrester's focus was on the behavior of corporations, the subject of his first book, *Industrial Dynamics*, in 1961. He subsequently expanded his field of interest to larger systems and in 1969 published *Urban Dynamics*, analyzing, in part, how government policies aimed at alleviating urban poverty often made cities poorer. Low-income housing projects, for instance, were intended to help the poor in economically depressed cities, but actually succeeded only in concentrating low-skilled people in cities where manufacturing jobs were declining, Forrester showed.

Forrester's *World Dynamics* in 1971 included simulation models that showed how exponential increases in population and consumption of natural resources would lead to crises from pollution, crowding, and hunger-unless there were major changes in economic policies. His predictions are still hotly debated. His current research project is a huge model of the U.S. economy, which he is turning into a two-volume book.

Forrester's attention was originally brought to bear on K-12 education through his relationship with another well-known MIT professor: former Dean of Engineering Gordon S. Brown, '31, ScD '38. Brown was the head of the Servomechanisms Laboratory, where Forrester worked in the 1940s, and Brown encouraged the junior researcher to make his move to the Sloan School. The two have continued to share ideas and cite each other's work ever since.

In 1973, Brown retired to Tucson, Arizona, where he wound up having long discussions about the problems in local schools with his neighbor, a retired teacher. Brown decided that systems thinking and modeling methods could "help kids improve their interest in learning and not become dropouts," and he set out to champion a systems approach to education.

A pivot point in his lobbying activities came in the spring of 1988, when he took a Macintosh computer loaded with STELLA dynamic modeling software to a meeting with the superintendent of the local Catalina Foothills school district. The superintendent was intrigued by this quick demonstration and suggested that Brown meet Frank Draper, a biology teacher at Orange Grove Middle School. At that encounter, Brown suggested that Draper borrow the STELLA software for the weekend. It was an inspired gesture. "This is what I have always been looking for," Draper reported to Brown.

Brown and Draper were able to line up enough computers and software for Draper's classes when school began. As more teachers became interested, Brown helped the school secure a $150,000 contribution of hardware from Apple, then helped to link the program to support from MIT alumni. James Waters, '46, had been a supporter of the System Dynamics Group at MIT. Now Jim and his wife, Faith, provide the financial backbone of what's known as the Waters Grant Project, which supports innovative teaching and administration in seven schools in the Catalina Foothills district. Another supporter was

Barry Richmond, who received a PhD in system dynamics from MIT in 1989. His company, High Performance Systems, which created the STELLA modeling program, provides software at discount rates to educators and sponsors workshops to train teachers.

The schools in the Waters Grant project provide valuable models of how systems learning can work. "Instead of hearing from a teacher or reading in a textbook that antibiotics kill bacteria, students simulated the role of a doctor discovering which minimum dose of penicillin is most effective in curing a case of strep throat," says Frank Draper. "Instead of laboring through the immune response, with its long list of names and actions," he continued, "students worked toward an operational understanding of the relation between their bodies and pathogens by changing antibiotic levels in an infected person's body." In a separate simulation, students played the roles of public health officials to determine "when a community should be immunized—before or after the flu hits town."

While many dynamic modeling exercises in schools make use of computers, machines are not always essential. Joan Yates, manager of the system dynamics track within the Waters Grant Project, estimates that about half of the middle school and high school projects monitored by her office are computer based.

However, even if they don't require a big investment in hardware, teachers cannot implement a systems approach on sheer inspiration alone, without resources and administrative and community support. In the mountain community of Conway, N.H., teachers had high school students create their own model based on a local forest to learn math, science, and English skills. The students explored the forest's potential yield in timber products and interviewed paper companies and the U.S. Forest Service to elicit different policy perspectives. The students then worked in teams to design management plans, which they presented to the Forest Service.

"It taught the kids to write reflectively and to make connections between economics, ecology, and government," teacher Helen Steele reported at the Concord conference. But the project required a Herculean effort by the teachers, all of whom were carrying full loads, to coordinate the work across disciplines. And by the end, only a handful of students had the motivation and concentration required to derive the full benefit from the experience, Steele admits.

Intensive, hands-on training for teachers and a program of full-time mentor teachers have been key ingredients in making systems thinking a success in Tucson. Gordon Brown says that much of the funding he helped generate has been used "to provide the release time for the teachers sot hey could change away from their regular paradigm." Learning system dynamics well enough to use it in the classroom is *not* something teachers can accomplish by "just reading about it," he observed.

"It's a very new set of ideas that are not easy to internalize," echoed Forrester. "There's no organized body of material to pick up and use. Everybody here is pioneering their own way." And aside from the efforts of Professor Nancy Roberts at Lesley College in Cambridge, Mass., Forrester knows of no other teacher-training programs in the United States employing system dynamics. In contrast, he notes that Norway, Finland, Sweden, and Denmark have formed a consortium to develop system dynamics applications for high school use.

Right now, there is anecdotal evidence but no hard data on the quality of student work based on dynamic models or on the effect of a systems approach in a classroom or school. Staff members and teachers in the Waters Grant Project are consulting educators who can help them measure the impact of this teaching and learning strategy. Solid results could persuade other U.S. school districts of its value. For Jay Forrester, teaching more students to "appreciate the nature of complexity and to look beyond their immediate setting in search of the fundamental causes of problems" is a mission of monumental importance.

In addressing the Concord conference, Forrester maintained that students "should develop optimism about understanding those problems of society that earlier generations have found so baffling. Inflation, wars, unfavorable balance of trade, and destruction of the environment have persisted for hundreds of years without public understanding of the causes. Such problems are too serious to be left to the self-appointed experts; the public must acquire the insights that permit participation in debates of such importance."

So what it comes down to is that Forrester and Brown really want to save the earth. Quite a retirement project.

Note: Jay Forrester's books on system dynamics are available from Productivity Press, PO Box 13390, Portland, OR 97232. Phone: (800) 394-6868.