the Creative Learning EXCHANGE

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Computer-Based Simulations as Learning Tools: Changing Student Mental Models of Real-World Dynamical Systems

Will Costello, Champlain Valley Union High School and the Waters Center for System Dynamics

The evolution of the World Wide Web (www), recent developments in interactive software, and the emergence of systems thinking provide a unique opportunity to create interactive, web-based simulations that address student learning. This paper explores current theory of mental model formation and its role in student understanding. It describes the potential of computer simulation to enhance student learning, here defined as a change in a student's mental model(s). As web-based simulations are newly emerging, an example will be provided in hopes the reader will take the opportunity to explore. The author's work involves the use of STELLA modeling program. High Performance Systems, Inc., producer of this software, has yet to deliver on a promised "web-runnable" version (now proposed for a Summer 2001 release), therefore this aspect of the proposed study had to be abandoned.

The Mental Model

If you understand inflation, a mathematical proof, the way a computer works, DNA, divorce, then you have a mental representation that serves as a model of an entity in much the same way as, say, a clock functions as a model of the earth's rotation (Johnson-Laird, 1987). "A mental model is a network of facts and concepts…that contains our understanding of social and physical phenomena." (Morecroft and Sterman, 1994).

Mental models are naturally evolving models. Through an interaction with a target system (area of interest) people formulate mental models of that system. These models need not be technically accurate (and often are not), but they must be functional. A person, through interaction with the system, will continue to modify the model in order to get a workable result. Mental models will be constrained by such things as the user's technical background, previous experience with similar systems, and the structure of the human information processing system. The scientist's conceptualization of a mental model is, therefore, a model of a model (Gentner and Stevens, 1983)

Don Norman's (1983) observations on a variety of tasks, with a wide variety of people, led him to a few general observations about mental models:

1. mental models are incomplete
2. people's ability to "run" their models can be severely limited
3. mental models are unstable...people can forget details of the system especially when those details have not been utilized for a while

Mental Modals *continued on page 3*

A Systemic Exploration of Future World Petroleum Production

Steve Kipp, Waters Foundation Mentor, Glynn County Schools, Brunswick, Georgia

Some assumptions of a systems education model are:

1. Our students actually arrive in our classrooms with a wealth of knowledge and experience that can and must provide the foundation for learning.
2. Useful knowledge is constantly changing as people continue to explore, discover, describe, and debate our world.

These are contrary to the *deficit model* of instruction (Senge *et al.*, 2000) which assumes that our students arrive empty, and it is our job as educators to fill them up with our whole and complete versions of "what is known."

Systems Thinking and Dynamic Modeling (ST/DM) continue to provide elementary through graduate school educators with powerful tools that can help students to make vital connections within their own prior knowledge as well as between their prior knowledge and new learning. These tools can also help students to appreciate and understand that human "knowledge" is ever-changing and

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UPDATES…

GIST

By Lees Stuntz

The GIST project in Glynn County, Georgia, has been active for eight years. Currently, the project is a Waters Project site with two mentors, Jan Mons and Steve Kipp, both of whom have been involved with GIST from its inception. Margie Varnadoe joined them on the project, currently as administrator, in the past few years. I visited them at the end of March this year, and, as usual, enjoyed the variety of classes I was privileged to see, as well as the stimulating discussions with Jan, Steve and Margie about the future of systems education in K-12.

GIST started at the middle school level, and one of the classes I visited was a 6th grade class which Steve led through creating BOTG's of many of the variables in *The Lion, The Witch, and The Wardrobe* to a stock/flow diagram depicting Edmund's bewitching by the White Witch. As I watched the sixth grade students wrestle with the issues of finding variables which change over time and of separating them from events, I was once more struck with the power of system dynamics tools to facilitate communication. The students were able to get their thoughts across quickly and accurately. My visits to the middle schools were rounded out by talking with three language arts teachers, who were so thoroughly immersed in the use of BOTG's, causal loop diagrams, and stock/flow diagrams to enhance and elucidate their students' thinking, that one of them said if anyone took away the tools, she would stop teaching—quite a comment on their effectiveness with her students!

The expansion of the use of systems education from the middle schools to the high school and the elementary schools has been more of the focus for the mentors in the last two years. Uses at the high schools at this point include a unit developed for an introductory technology class, utilizing a model of oil depletion (see the article elsewhere in this newsletter) as well as several health models, and uses in English classes and an occasional science class.

Work on systems education in the elementary schools is a joy to behold. It has been enhanced by the willingness of quite a number of teachers to experiment and try to utilize systems lessons in their classrooms. A group of three teachers has been especially active. Last year they had second grade students, and kept the same classes as they moved up to third grade this year. In consequence, the students and teachers have been able to build on last year's foundations and have expanded this year. Last year's lessons included such activities as the In and Out Game (SE1999-09In&OutGame on the web site (http://clexchange.org), BOTG graphs with numerous pieces of literature, and a population model from a Lynx and Hares model. This year all three classes built on those skills by continuing with BOTG's and causal loops in literature and class management issues, as well as playing the Mammoth Game (CC1999-04MammothExtinction) at the beginning of the year to review BOTG's, stock/flow diagrams and causal loop diagrams. One of the teachers has a daily "If…Then…" statement up on her board. Her students are expected to be able to tell her if it is simply a cause and effect statement or a causal loop. If they identify it as a causal loop, they are asked to categorize it as either reinforcing or balancing.

One of the effects on this particular elementary school, Golden Isles, is that the enthusiasm of these three teachers has been contagious. This year, with the assistance of Jan Mons, they have taught a series of Staff Development programs for their faculty. They are also developing a series of lessons to help other teachers introduce system dynamics tools and concepts to their students. Twelve other teachers at the school are using system dynamics in their classrooms. It is a great example of the generic infection model.

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EDITORIAL

As this issue comes to you, both Dynami**QUE*ST*** and SyM*Bowl will have happened, a heartening indication of the health of systems thinking and dynamics modeling in K-12 education across the country. Over the summer, many educators will get together at workshops on a variety of subjects, some planning for the future of ST/SD in K-12, some in beginning workshops, and some pursuing more learning in the field. We thank all of you, expert system dynamicists, expert teachers, concerned citizens and educators for all the effort you have put in throughout the school year, as well as for these activities coming up in the summer.

I hope each of you takes the time to smell the lilies, read a good book (or five) and learn something new. Have a wonderful summer.

Take care.

Lees Stuntz (stuntzln@clexchange.org)

Changing Student Mental Models *continued from page 1*

4. mental models do not have firm boundaries
5. mental models are unscientific, and often include "superstitious" behavior and/or distrust of technology as a factor...sometimes superstitious behavior persists even when people are aware of their faulty thinking...(they seek) to avoid a void and/or to maintain as easier model
6. mental models are parsimonious...people often do excess physical operations rather than the mental planning necessary ...they trade off physical action for reduced mental complexity, especially when reduction of complexity can be applied to multiple systems thus avoiding confusion.

Norman (1983) cites typical use of hand-held calculators as examples of the latter observations. As a classroom teacher I often see similar behavior. Students, especially those less comfortable with the technology, will persistently and repeatedly hit the clear key, often 3-4 times, before beginning a new calculation. It is a mistrust of the technology but it resides in a faulty mental model, one that cannot accommodate to the capacity and precision of the device. Students are reluctant to use more complex functions, for example the memory registers, despite my having shown them (more than once). Upon completing a problem in physics, their first assumption is that the error lies in the calculation (the "device") and not in their conceptual thinking. This drives them to re-calculate, sometimes repeatedly, assuming the "calculator system" did not behave. Similar reiterative behavior is observed in students in physics lab exercises where video analyses or graphical functions are repeated in hopes of correctness. Students who have internalized a sufficient mental image of the calculator or computer functioning do not seem to exhibit this behavior.

Functional factors apply to mental models as well. If we seek to engage students to both think systematically and employ the learning potential inherent in simulations, we must instruct students as to their purposes. Norman (1983) cites these factors:

1. belief system: the mental model is a reflection of the person's belief about the system
2. observability: correspondence between parameters/states of the mental model and the physical system (observed or able to be observed)
3. predictive power: purpose of mental model is to understand and anticipate the behavior of the system.

Mental models, therefore, serve a number of purposes related to what one believes, what one sees, and what one thinks (or hopes) might transpire. Thus the persistence of mental models, even when challenged, must be accounted for in any educational effort to foster learning.

So the mental models which students bring to class are resistant, boundless, incomplete, and unscientific. The educational process must first become aware of the existence of resident mental models, their components and functions, and then provide suitable and powerful educational experiences to allow students to engage in the process of changing their mental models (learning).

Systems Thinking

Despite the traditional educational predominance of reductionism, current brain research indicates that a more holistic approach to learning is preferable. Many students are unable to sequentially build concepts and skills from parts to whole, the basic "pathway" of reductionism. Thesã students often stop trying to see the wholes before all the parts are presented to them. We need to see the "whole before we are able to make sense of the parts." (Brooks and Brooks, 1993) "Systems thinking" is an emergent field that sees knowledge systematically, as a "whole", and provides a set of tools and a methodology for understanding both simple and complex systems. Russell Ackoff (Johnson, 1997) describes the present dawn of "Systems Age" thinking following the decline of "Machine Age" thinking. The basic tenets of the Machine Age Ackoff cites are:

1. the universe is completely understandable
2. analysis is inquiry
3. cause-effect relationships as key mechanism

These tenets, especially the third, carry some consequences: God must be the eventual cause of all things, that environment is irrelevant, and that all is predetermined, leaving nothing to probability. Merely deconstruct the system of interest and all will be understood. Isaac Newton embodies this approach to knowledge. This way of thinking began to decline with the development of new ideas in the physical sciences: uncertainty, quantum mechanics and chaos theory. A new view of the universe was needed. A vision was provided by Norbert Weiner in *Cybernetics* (1947) and by Ludwig von Bertalanffy in *General Systems Theory* (1954). These two works introduced the concept of "systems" and began a revolution in thinking.

A system is a whole that consists of sets of two or more parts. Each part effects the behavior of the whole, depending on the part's interaction with other parts of the system (Johnson, 1997). The properties of the system reside in the whole and not in the parts; remove a part and it does not behave as the whole. Remove the heart from the circulatory system and the heart behavior changes and the system behavior changes. The heart cannot adopt the function of the system nor the system respond to compensate for the lack of a heart. The circulatory system is not the sum of its parts, but the sum of its interactions. "Analysis" of a system is futile. To understand systems requires the use of synthesis (Johnson, 1997). Synthesis looks at the holistic "why" of system function as opposed to the "how." Context is as important (if not more so) than content.

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Cain and Cain (1991) state, "..most real systems are non-linear, complex, and highly interactive. Their functioning is normally counter-intuitive." They site the characteristics of "experts":

1. experts see larger chunks, bigger patterns, the system at hand
2. experts grasp context; where the important patterns exist in the world
3. experts remember via a specific framework (similar to "local" system)

Systems thinkers operate to see the larger "chunks," the context, and have a systematic framework to "store" their understanding (deeper knowledge). Even physiological research on rat brains supports the notion that a natural, complex environment results in the greatest brain functioning. The brain also exhibits the capacity to process parts and wholes together (Cain and Cain, 1991). Systems thinkers simultaneously see the "forest" and the "trees," looking through complexity to see and understand the underlying system structure generating change (Senge, 1994).

Mental Models and Conceptual Models

Shawn Glynn and Reinders Duit (1995) extend the mental model concept further to include the mental models teachers evolve over years of study, called "conceptual models." The notion is that teachers address their students within a framework of their own conceptual model(s). Conceptual models are devised as tools for teaching/understanding physical and natural systems while mental models are what people really have in their heads. Ideally, there should be a direct and simple relationship between the two. When the two are in dissonance is when learning opportunities arrive. As the teacher possesses the correct conceptual model, his task is to elicit the mental models of his students and decrease the dissonance via "teaching." So teaching becomes the task of eliciting student mental models and providing sufficient experience to allow students to adapt, modify, reject, and enhance their own mental models (again, here defined as "learning").

"For …instruction to be effective it is important for teachers … to be aware that significant differences often exist between their conceptual models and the mental models of students and that students' mental models often contain a variety of misconceptions that can be resistant to change." (Glynn and Duit, 1995)

Eliciting Mental Models

The initial task, then, is to develop strategies for allowing and encouraging children to "expose" their mental models. A variety of strategies exist for use in the business community (see Richardson (1996), Morecroft and Sterman (1994)). If systems education and the use of simulations are to succeed in education, we must first develop and employ techniques by which students can describe their current mental model of the situation or system under study. Requesting students to provide a written and/or artistic representation of what they believe is effective. Even more useful are visual tools that provide scaffolding for students to elicit their mental models. Hyerle (1996) groups visual tools into three broad categories based upon their purpose:

1. brainstorming for fostering individual and group creativity
2. task-specific organizers for fostering basic skills and deep content learning
3. thinking-process maps for fostering cognitive development and critical thinking

It is these second and third categories that have the most impact upon eliciting student models. These include mind mapping tools, flowcharts, annotated concept maps, Venn diagrams, causal loop diagrams, stock/flow maps, and numerous visual organizers. Beyond identifying the components or variables in the system, task-specific organizers and thinking-process maps include relational or behavioral connections among and between the variables. Maps and webs can point out "cloudy" thinking. (This is where opportunities for learning exist.) Visual maps and webs provide a bird's-eye view of patterns, interrelationships, and interdependencies—all aspects of mental models (Hyerle, 1996).

When visual tools are coupled with in-class discussion and map presentations, the learning is further enhanced. Thinking and discussion begets more thinking, and thinking and problem solving capacities are enhanced when students think aloud, discuss, and communicate their thought processes to others—when students make their implicit thought processes explicit. Simulations can then be employed to permit students to "explore" the systems that their mental models propose to explain.

Simulations and Learning

In this context, "simulation" refers to the use of computer-based, dynamic modeling simulations. Other simulations, from "role-playing" to "virtual reality" have valid application but are not included in this discussion.

A classroom simulation is a method of teaching/learning or evaluating learning of curricular content that is based on an actual situation. The simulation, designed to replicate a real-life situation as closely as desired, has students assume roles as they analyze data, make decisions, and solve the problems inherent in the situation. As the simulation proceeds, students respond to the changes within the situation by studying the consequences of their decisions and subsequent actions and predicting future problems/solutions. During the simulation, students perform tasks that enable them to learn or have their learning evaluated. A well-designed simulation simplifies a real world system while heightening awareness of the complexity of that system. Students can participate in the simplified system and learn how the real system operates without spending the days, weeks, or years it would take to undergo this experience in the real world (Chilcott, 1996).

Classroom simulations motivate students by keeping them actively engaged in the learning process through requiring that problem-solving and decision-making skills be used to make the simulation run. As the simulation runs, it is modeling a dynamic system in which the learner is involved (plays a role). Thus, participation in simulations enables students to engage in systems thinking and enhances their understanding of systems as well as of social science and/or science concepts (Chilcott, 1996).

Since student mental models are built upon assumptions that evolve over time as a result of experiences and prior learning, the simulation environment gives students a chance for "playing" with their assumptions, testing various beliefs, and seeing the response of the system to their inputs. In the "Soda Game Simulation" (Glass-Hussein, 1995), a supply and demand simulation, students test their understanding of basic business concepts: the impact of advertising, and the notion of supply/demand equilibria. In this interactive environment, students act as retailers and make decisions regarding advertising expenditures, purchases from wholesalers, and pricing policy. Work with a group of 100 students indicated that their initial mental model had a firm grounding in supply and demand schedules (from in-class learning), but a weak understanding of supply/demand equilibria. Their text (as do most classical economics texts) portrays a static picture of the interplay of price, supply, and demand. By working with the simulator, students can use a set price to eventually establish an equilibria, and then perturbate the system by introducing a price "slash" or price "hike," and observe the behavior of supply/demand dynamics as a new equilibrium point is sought by the system over 26 weeks. Moreover, in the space of 2 class periods, students can manipulate the system over 15 times, establishing new equilibria under different constraints. Post-testing indicates a significant increase in understanding of supply/demand dynamics. "Students have, for the first time, a real understanding of the equilibrium point and how changing price or advertising causes pressures to shift the equilibrium." (Lord, 1999) Students also developed an appreciation for the structure and behavior of the real-world system: that equilibria are dynamic, time dependent, impacted by information and material delays, and prone to oscillations (in part driven by the students' inputs). The students' increased depth of understanding was quite apparent and striking (Lord, 1999).

Glynn and Duit (1995) indicate five conditions for learning meaningfully:

1. existing knowledge is activated (source of motivation)
2. existing knowledge is related to educational experiences
3. intrinsic motivation is developed
4. new knowledge is constructed
5. new knowledge is applied, evaluated, and revised

The use of a simulation addresses each of these conditions. Engaging in the simulation activates existing knowledge. This speaks to the need to develop significant background information and prior learning before running the simulation.

Chilcott (1996) indicates that the authentic nature of many simulations can be highly motivating. The teacher's enthusiasm can be contagious, especially if the role-playing is presented to students as a wonderful opportunity to change their identities. Students are actively engaged in the learning process as they solve problems and make decisions as it is done in the adult world. Simulations provide a forum in which creative, divergent thinking is legitimized and valued. Because simulations are much more like the "real world" than many classroom methods, students do not stop learning when the class period is over. Their interest carries over into informal out-of-class discussions with other students and adults in which experiences and ideas are shared and evaluated. Enthusiasm bubbles and school attendance is high.

"Simulations provide a forum in which creative, divergent thinking is legitimized and valued. Because simulations are much more like the "real world" than many classroom methods, students do not stop learning when the class period is over."

Students become educational ambassadors as they continue their discussions at home. Students describe this kind of learning as authentic and not boring.

Conditions 4 and 5 (above) are evident in the learning that occurs as students play with, test, and revise the simulation while simultaneously doing the same with their mental models. This requires, however, that there be supportive materials that focus the students on what they are doing, how their thinking is being changed, and what is their final mental model of the system. Supportive materials might be process guides, reflective pieces, or directed worksheets. Without sufficient supportive materials, students often lapse strictly into "play" mode without any mechanism for assessing the impacts upon their mental models. Glynn and Duit, (1995), state that guided discovery is vital for students "in post-preschool environs…a situation, question, or experiment is exposed for students and leading questions provided to 'guide' student thinking." Feedback is provided to

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students immediately where it can support appropriate change in students' understanding.

In simulation environments, students explore by doing, often begin by failing, and then move incrementally to success, and come away with rich stories (war stories). The power of learning by doing is well supported in the literature. The importance of failing in a non-threatening environment (a non-judgmental machine) cannot be stressed too much. Research supports the concept that learning opportunities arise at points when failure occurs. The simulation provides immediate feedback regarding the failure, as well as an immediate opportunity to try again. If the student moves toward success, then we would assume that the student has acquired new knowledge and adjusted the mental model(s) being employed. The "war stories" add to student engagement and enthusiasm.

Research has also pointed out the performance differences in group vs. individual simulation scenarios (Richardson, (1996), Morecroft and Sterman, (1994), Schoen (1983), Argyris, (1983)). In effect, [simulations] are "practice fields" for managers and teams. Little learning would be possible for the sports team without regular practice, or for the symphony orchestra or theatre troupe without rehearsal. The continuous movement between practice and performance enhances individual skills, group understanding…" (Issacs and Senge, (n.d.). Learning in teams is well documented. Having someone else to "bounce" your thinking off, and with whom to reflect upon performance, is a valuable component to increasing understanding.

At this time, little systematic, formal assessment of the impact of simulations has been published. Work within 28 school districts in the Waters Consortium, a group whose mission is to introduce systems thinking and dynamic modeling into the K-12 arena, indicates the need for formalized assessment. This work remains to be done.

Conclusion

Our increasing understanding of mental structures, brain-based learning, and the role of mental models in concept formation leads to the potential for utilizing computer-based simulations to increase student learning. The ability to approximate real-world behavior and structure, compress time horizons, provide "play" with decisions and the decision-making processes, and foster holistic, systematic thinking support the use of simulations for increasing student understanding.

Afterword: web-Based Simulations

Interactive, web-based dynamic simulations are just being to appear on web sites. Powersim Corporation (www.powersim.com) has several demonstration "web-sims" at their site. These are based on the Powersim modeling software, and can be run individually, or "players" can log into a continuing simulation with other players. The well-known simulation, "Beer Game," a supply/demand simulation (the basis for Sodagame cited above) developed at MIT, places the player in one of several possible roles: wholesaler, producer, or retailer. High Performance Systems has just released "Otterville," an urban policy web-based simulation in STELLA (see http://www2.hps-inc.com/otterville/). Widespread use of interactive web-based simulations, however, has yet to become a reality.

This document, with a list of works cited, is available from the CLE and the web site <clexchange.org> catalogued under Systems Education as SE2001-04ChangingStuMentMod.

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Systems Education

SE2001-04ChangingStuMentMod **Computer-Based Simulations as Learning Tools: Changing Student Mental Models of Real-World Dynamical Systems.** Will Costello

This paper explores current theory of mental model formation and its role in student understanding. It describes the potential of computer simulation to enhance student learning, here defined as a change in students' mental models. [Systems Education, K-Adult] ($1.00)

SE2001-04SDFoundationOfST **System Dynamics: the Foundation under Systems Thinking.** Jay W. Forrester

A commentary which originally appeared in Reflection, Journal of the Society for Organizational Learning, Vol.1, No. 3, Spring 2000, published by the MIT Press, as a response to "Systems Change in Education" in that issue by Peter. M. Senge, this paper discusses system dynamics as a solid systems core in K-12 schools. [Systems Education, K-Adult] ($1.00)

Social Studies

SS2001-04FutureOilSupply **A Systemic Exploration of future World Petroleum Production.** Steve Kipp

A Waters Foundation mentor works in a whole-class, teacher facilitated discussion to construct a STELLA model of world petroleum reserves and production. [Social Studies, Dynamic Modeling, High School] ($1.00)

Systemic Exploration of Future Petroleum Production

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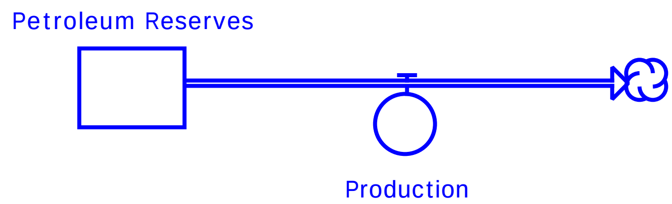
rarely as clear-cut as it is often presented in school.

As a Waters Foundation Mentor, I recently had the opportunity to use ST/DM tools and concepts in a learner-centered approach with students in Laura Ragland's Introduction to Technology class at Brunswick High School, in Brunswick, Georgia. Laura and I had previously introduced her students to the use of Behavior over Time Graphs (BOTG), Stock/Flow Diagrams, and pre-made STELLA models in a unit on the resources that make technology possible. Afterward, she approached me with the idea that she wanted her students to have the experience of using "data from the real world to build mathematical models." Given the central economic importance of petroleum as a source of energy and raw material, we decided to look for data that could be used in construction of a STELLA model of world petroleum reserves and production.

Using whole-class, teacher-facilitated discussion, we constructed a simple one stock, linear diagram to describe the basic structure of any renewable or non-renewable resource. (See Figure 1.)

We then labeled the non-renewable diagram to represent oil reserves and production. (See Figure 2.)

Figure 2. Stock/Flow diagram of petroleum production.



We had only two class periods to work with, so we decided to provide students with the necessary data instead of having them spend time searching.

To find recent estimates of numbers they could "plug in" to their models, pairs of students were handed copies of the *2001 World Almanac and Book of Facts*, and turned to tables titled "World Crude Oil and Natural Gas Reserves, Jan. 1, 2000" and "World Energy Consumption and Production Trends, 1998." They were bemused to discover two different published estimates for world oil reserves, one labeled "OGJ" and one labeled "WO," causing them to question,

"Two different numbers… OGJ… WO… what's going on here?"

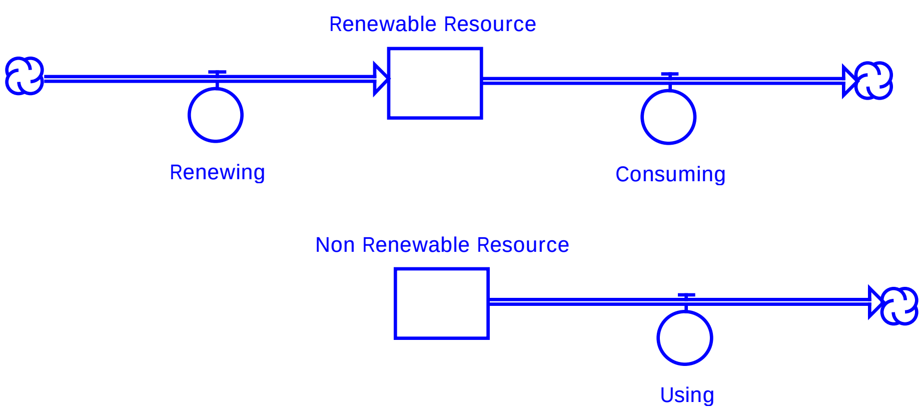
Further investigation of the fine print revealed that the estimates came from two different trade journals, *Oil and Gas Journal*, and *World Oil*.

"You mean we don't know for sure how much crude oil is left? Which number should we use? Let's average them," they said.

"OK. But how can we use 2000 reserves data with 1998 production data?"

Since oil production has increased at about 2% per year for the last decade, we estimated 2000 production by increasing the 1998 production number by 2%, twice. So now we have a linear stock/flow diagram and some data to plug into the STELLA model. Bell rings—end of class.

Figure 1. Stock/Flow diagrams of renewable and non-renewable resouces.



The next day, I guided pairs of students on individual computers in constructing a STELLA model of the linear stock/flow diagram. They ran it from 2000 to 2050; petroleum stocks ran down linearly until running out around 2036. Just the experience of watching simulated world oil supplies drop to zero in their lifetime had a visible effect on students. Now they needed some positive re-direction.

"But let's not dwell on gloomy thoughts of life after oil, let's focus on improving our model; we've left some things out. What's wrong with this model?"

The students responded:

"We didn't increase the production every year like the world has experienced for the last decade," and

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"As the stock of crude oil gets down low, we won't be able to get it as easily, and production might actually decrease."

"So the rate of production might increase for awhile as it has been doing, then production might decrease as we begin to run out."

Now they were ready for more of the story.

Many petroleum scientists use the United States as a case study of how the rate of production increases, then declines, in a "mature oil field." In the US, when the ratio of reserves to production (R/P) reached 10, production began to drop so that the R/P ratio of 10 was maintained as oil stocks declined (Energy Information Administration, 2000). In other words, when the reserves drop to about 10 times production, production begins to decline as reserves continue to drop, maintaining the R/P ratio of about 10. In the US, this peak and decline in production happened about 1970. Many experts expect a similar pattern to happen globally, where R/P ratios are currently about 50.

We did not have time as a class to develop the R/P ratio idea into a working STELLA model. So I had previously created a model based on the R/P 10 principal that allows experimentation with two input variables: 1) different initial stocks of petroleum (since we don't really know how much is left—more on that later) and 2) different yearly rates of increase of production (since we don't know how that will play out in the real world either).
(See Figure 3)

We gathered 'round the computer projection screen, and, as a class, explored several alternative scenarios of future world petroleum production. Yearly rates of increase of production (until R/P 10) ranged from 0-3%. The initial value of petroleum reserves is a more complex matter.

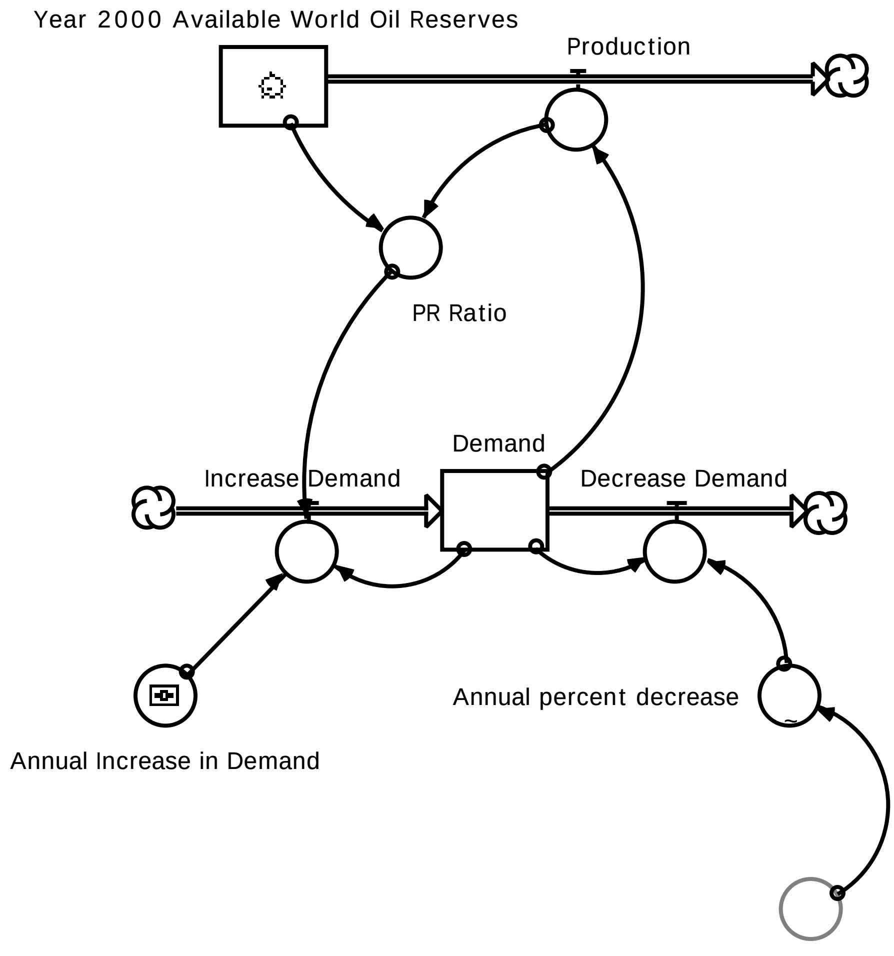

Figure 3

The average of the two different reserves estimates in the World Almanac is about 992 billion barrels (BB) of oil. An often-quoted study by Laherrere (1998) estimated about 900 BB. A recent study by the US Geological Survey (2000), which gives tremendous optimistic weight to recent advances in drilling and extraction technologies, paints a different picture. They estimate "ultimate recovery" as follows in the chart below:

So the USGS proposes a 95% probability that there are 1348 BB of crude oil "left", and a 50% probability that there are 2103 BB "left," the latter being over twice the other World Almanac and Laherrere estimates.

What are we to do? Try 'em all. Try 'em all with different initial production increases. The results of three key runs are shown on the graph in Figure 4,

Probability	Ultimate Recovery (BB)	Ultimate recovery minus production to date of 900 BB
95%	2248	1348
50%	3003	2103
5%	3896	2996

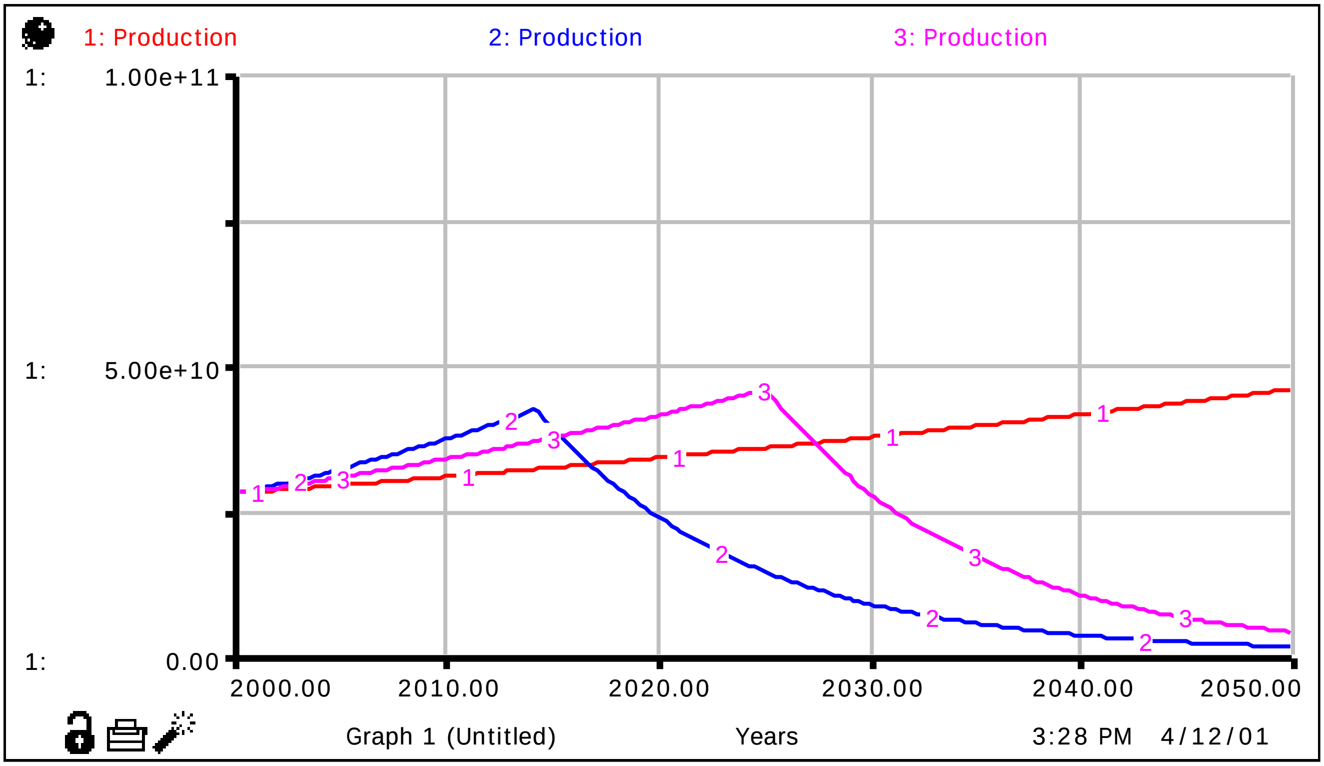

Figure 4

and this table:

	Reserves Estimate		Initial increase in production	Production Peak Year
1) Good case:	USGS 5%:	2996	1%	2062
2) Bad case:	Laherrere:	900	3%	2014
3) Likely case:	USGS 95%:	1348	2%	2025

These students, packed with hormones, minds often ready to leap to the slightest distraction from the hard work of learning, were paying attention. The question is not "When will we run out of oil?" A better question is "When will the production peak make petroleum so expensive as to be economically nonviable as the energy foundation of civilization (especially transportation)?" The answer, still, is no one really knows. But based on the assumptions of R/P ratio 10 and continuation of some sort of yearly increase in production demand in the near term, one safe answer seems to be "Sometime in your lifetime, kid."

The room is very sober at this time. But it's not very useful to worry people with gloomy future scenarios, and then dismiss class. This can have a paralyzing, disempowering effect. Now was the time to go on to alternative energy sources, an area where there have been some major advances recently, especially in the areas of energy from biomass (lawn clippings, tree limbs) and from fuel cells. These students ARE now eager to learn about alternative energy...but that's another story.

References:

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Senge, P.; Cambron-McCabe, N.; Lucas, T.; Smith, B.; Dutton, J.; & Kleiner, A. (2000). *Schools that learn: A fifth discipline fieldbook for educators, parents, and everyone who cares about education.* New York: Doubleday.

This article is available from the CLE and the web site catalogued under Social Studies as SS2001-04FutureOilSupply.

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Updates…

continued from page 2

I observed one lesson in which a group of students from these three classes were together in a class for the gifted. Previously, they had played a modified version of the Epidemic Game (CC1993-09EpidemicsGamePack). They had created, with Jan Mons, a simple stock/flow map of that game with two stocks (healthy people and sick people.) I observed as Jan and the third graders discussed and added death and recovery rates and delays to the map to make it into a running model. The discussion ranged from what a delay is to percentages and what they mean. Children built the model on their own computers, so it turned into a lesson in using STELLA to build a model as well. Two hours later, when the children explained why there were no healthy people (because they kept getting sick and eventually died) and said that what we really needed was a third stock—for the well people who couldn't get sick again—it was time to stop. Needless to say, there is plenty to do in a continuation!

Our discussions over the two days of my visit ranged around the perpetually interesting and vexing subject of how to get systems education firmly rooted in a school system. Certainly, encouraging teachers, like the ones I saw, who are using systems pervasively in their classrooms, is one of the key elements. Here are descriptions from three of the third grade students about what systems education has done for them:

"Sestus (systems) has helpt me lern and get buter grads in sinse."

"It's helped me lern about people. It helped me make a better grade. It helped me make a lot of better thigs to know."

"They make me smart. They make things easy. They explan the story. They explan my grades."

For more information on GIST, Margie Varnadoecan be reached by email at mvarnado@glynn.k12.ga.us

Resource Omissions

Debra Lyneis

Two important resources were inadvertently omitted from "Bringing System Dynamics to a School Near You" in the last issue of the *Exchange.*

The first is an early reference. From 1986 to 1994, the STACI[N] Project implemented and studied the use of system dynamics in K-12 education. The project was supported by the Department of Education, Apple Computers and Educational Testing Service, and it was directed by Ellen Mandinach and Hugh Cline of ETS. The project aimed to assess the potentials and effects of technology in education. Specifically, it focused on the effects of the systems approach on student content-learning and problem-solving skills, on teacher behavior and classroom dynamics, and on the functioning of the school as an organization. Work began at Brattleboro (VT) Union HS where several teachers had been working with Barry Richmond and others from High Performance Systems to introduce STELLA modeling to students. The project and HPS training expanded to include 100 teachers at eight schools across the country. The findings were many. The systems approach proved to be motivating and effective; it altered the way teachers taught while it made learning more learner-centered for students. However, the study also found significant hurdles to implementing such fundamental change in education. For more information read *Classroom Dynamics, Implementing a Technology-Based Learning Environment* by Mandinach and Cline, Lawrence Erlbaum Assoc., Hillsdale, NJ, 1994. Ellen Mandinach reports that several of the project teachers are "still going strong."

The second addition is a new resource for training in system dynamics. Paul Newton has set up a web site at StewardshipModeling.com to offer "project-based work/school partnership programs to help both budding organization leaders and educators become systems thinkers." Business or government organizations can sponsor a yearlong system dynamics training program for their employees and local educators. Participants work together to the benefit of both institutions. They attend training workshops and meet regularly to share their work. This is modeled after a course conducted during the 1999-2000 school year in Sturgeon Bay, WI for several high school students, teachers and community members interested in local sustainability issues. For more information, go to the www.stewardshipmodeling.com web site or contact Paul Newton at paulnewton@stewardshipmodeling.com.

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2002 Systems Thinking and Dynamic Modeling Conference
June 29 - July 1, 2002
New England Center, Durham, NH

Next year we return to the beautiful New England Center, site of the 1998 conference. Make plans now for the fifth conference on systems thinking and dynamic modeling in K-12 education. Please consider ideas for presentations or sessions you would like to see included, and sive us your ideas. More information will be available in future newsletters and on the web site at clexchange.org.

When a Butterfly Sneezes: A Guide for Helping Kids Explore Interconnections in Our World through Favorite Stories

Book review by Lees Stuntz

When a Butterfly Sneezes: A Guide for Helping Kids Explore Interconnections in Our World through Favorite Stories by Linda Booth Sweeney (co-author of *The Systems Thinking Playbook (I-III)* available from Pegasus Communications)

My immediate reaction to *When a Butterfly Sneezes* was that it would be a helpful tool for teachers in their quest for stories to emphasize system concepts, as well as an excellent beginning tool for teachers getting started with systems. This reaction was reinforced by a conversation I recently had with Nan Gill about a four-session workshop on “Using Systems Thinking to Promote Literacy” in Ann Arbor, Michigan. During the workshop, Nan and Shelley Bruder used the book as a starting point for a group of elementary level teachers who had already gone through beginning workshops but felt overwhelmed by the breadth of choice and extent of options in the use systems thinking (ST). *When a Butterfly Sneezes* offers a narrower entryway and creates a more comfortable segue into the field of ST.

Nan and Shelley used the book as a jumping-off point to talk about the process for using ST to promote literacy. They discussed what kind of planning was needed to pick objectives both in literacy and in ST, and carry them throughout three or four lessons. Often, beginning teachers do one sample lesson and then stop, not knowing where to go next. Utilizing the stories in *Butterfly,* as well as others that they picked out, Nan and Shelley chose a few basic concepts, such as feedback and unintended consequences, branching out to the fixes-that-fail archetype. They found it was possible to use a story with basic concepts for younger children, and use more examples of causal loops from the same story for older students or more experienced teachers.

Because of the emphasis on literacy in the Ann Arbor Schools, the teachers were very excited about using the stories. They felt they were being given a tool to do the work they were already supposed to be doing. An unexpected result was that the teachers immediately, from the first story on, started relating what they were doing to other curricular areas, initiating the branching-out phenomenon that is often hard to facilitate. By narrowing the entryway, the workshop actually broadened the teachers’ horizons.

When a Butterfly Sneezes can be a useful book for teachers who want to utilize ST tools with literature.

In Linda Booth Sweeney’s own words: “I wrote *When a Butterfly Sneezes* as a guide for parents and educators who want to help kids see and understand the world of systems all around us. This volume (the first in a series) includes a discussion of 12 favorite tales from around the world—from Dr. Seuss among other authors—all offering powerful lessons about natural and social systems.” (Read more from Linda, and post your comments on the Pegasus Communications Systems Thinking for Kids Community Forum http://www.pegasuscom.com/cgi-bin/ubbcgi/Ultimate.cgi.)

When a Butterfly Sneezes is priced at $14.95; **free domestic shipping is available to people on the Creative Learning Exchange mailing list* until July 15, 2001.** If you’d like one (or more!) copies please contact Pegasus Communications, Inc. at 1-800-272-0945 or www.pegasuscom.com and mention **STK01FREE**.

*To register with the CLE, go to the web site (http://clexchange.org) and click on register on the left hand side.

CLE Materials Newly Available on the web at clexchange.org

CC1998-11FinanDreamInDesert **Financial Dreams or Budget Nightmares...in the desert.** Cindy Beckley

From Catalina Foothillls School District. A supplement to the original Financial Dreams cross-curricular unit. [Cross Curricular, Middle School, High School] ($1.00)

CC1999-09FinancialDreams **Financial Dreams or Budget Nightmares.** Jeff Giddens, Pat Stanford & Jan Mons

From the GIST Project, revised 2/99. This interdisciplinary unit looks at the relationship between a student’s actions and choices in school today and his future job opportunities. It is not about career choices but financial opportunities as they relate to educational needs and purchasing decisions in the “real” world. The learning environment includes four modules that impact an individual’s financial lifestyle: goal setting, job placement, decision making, and evaluation. The learning environment includes language arts, math, science, and social studies activities. [Cross-Curricular, Math, Social Studies, Science, English, Simulation, Middle School] ($15.00 paper only; $23.00 paper + models on 2 disks)—2 disk/web version includes most, but not all of the overheads, etc. available in the paper copy.

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<milleras@clexchange.org>

11th Annual *Systems Thinking in Action*® Conference "Harnessing the Power of Organizational Complexity" Sponsored by Pegasus Communications, Inc. Hyatt Regency Atlanta, October 24-26, 2001

In addition to the best in systems thinking, management innovation, and organizational learning for business and industry, the 11th annual *Systems Thinking in Action*® Conference "Harnessing the Power of Organizational Complexity" includes **Innovations in Education,** a workshop track important to all stakeholders in community education. Debra Lyneis, from the Creative Learning Exchange, will speak on "Lesson Plans for Teachers: Systems Thinking and System Dynamics in the Classroom." Representatives from school departments in Atlanta, GA; South Pasadena, CA; and West Des Moines, IA, will also present sessions. Friday morning forums include architect Stephen Bingler, who has energized school building projects using a community-based systems thinking approach, and education reform specialist Belinda Williams, speaking on the challenges of urban learners. Linda Booth Sweeney will discuss *When a Butterfly Sneezes* during Author's Night. A **Forum on Education** hosted by Mary Scheetz of the Waters Foundation, and a skill-building session on simulation modeling by Don Seville and Andrew Jones are among the post-conference sessions.

For more information, or to register, visit the Pegasus web site www.pegasuscom.com or contact the Conference Department at 1-800-272-0945 or 1-802-862-0095. If you are interested in team discounts, please contact Julie McCay Turner (781-398-9700, or juliet@pegasuscom.com).

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