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FUNDAMENTAL CHANGES IN HOW WE TEACH: A NARRATIVE ABOUT TEACHING SYSTEM DYNAMICS AND THE ART OF LEARNING

Timothy Joy and Ron Zaraza

When you think about it, it makes no sense. But in the United States, we've been doing it this way for well over a century—everybody in a single cohort is taught the same thing at the same time. Students quickly learn they may speak if they have a *good* question or the right answer. Teachers take courses in how to conduct courses such as these, learn the addresses of publishers and organizations that will sell them ready-made curricular materials, determine the clerical skills to compute grades, to track attendance, to keep classroom order. One might walk into any humanities room in any school in America and find roughly the same thing: rows of students, about 28, texts open, notebook ready, and a teacher lecturing. In the sciences, little changes except for the labs, but in many cases these, too, suffer from sameness. The prepared lessons, we all heard in graduate school, were made "teacher-proof"—so finely tuned, not even a novice teacher could mess it up. And students learned. As did the teachers. Students learned things but not ideas; teachers learned to manage but not to teach.

The accouterments of instruction have grown abundantly so that most schools hire someone to fix the broken equipment: overhead projectors, video machines, tape players, audio accessories. Nonetheless, teachers conduct themselves in much the same way as ever. Indeed, the old joke goes this way: if 18th Century American genius Benjamin Franklin were to return to the United States in the 20th Century, what would he recognize? Schools, of course, because they have changed the least. Longevity, however, breeds bureaucracy, and education has acquired a stirring strength to perpetuate itself just as it is. Significant forces in American education still call for "return to basics," a longer school day and year, increased discipline, and a national curriculum. In the face of such a monolith, change is daunting.

Nevertheless, as we in the CC-STADUS Project (Portland, Oregon, USA) have taught our classes based on system dynamics, we have witnessed change in profound terms, both personally and professionally. Some changes were welcome—a chance to teach what we loved and believed; some changes

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Problems in Causal Loop Diagrams Revisited

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A reemerging problem

Word-and-arrow diagrams (causal-loop diagrams, influence diagrams, cognitive maps, and the like) are enjoying widespread use in the system dynamics and systems thinking communities. It is increasingly common to see these diagrams with links labeled "S" and "O" to identify causal effects in the "Same" or "Opposite" direction to changes in the causing variable at the tail of the arrow. But therein lies an old problem in a new disguise.

An illustrative example

Figure 1 shows a pair of feedback loops representing the essential structure of the spread of a disease, diagramed in the style popularized by The Systems Thinker, Kim (1992) and others, and now much in vogue in the systems thinking and system dynamics literatures. The diagram has a serious flaw, the same flaw pointed out in Richardson (1986/1976) and corrected in the definitions in Richardson and Pugh (1981), but hidden here in the S's and O's: two of the links do not behave as their labels claim.

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Updates. . .

Maryland Virtual High School

The Maryland Virtual High School has negotiated a new grant to be funded by NSF. It is called MVHS CoreModels. Three regional centers will be created to work with teachers in using computational modeling to help students meet the Maryland Core Goals in Science and Mathematics. The leadership team, which includes the three center directors, two supporting teachers for each center, and myself, will select, adapt, and enact modeling materials within their classrooms. After a summer workshop for 12 participating teachers from each center, a mentoring approach will be used to help these teachers adapt these materials to their own classrooms.

This new project will benefit from our experience in enabling collaboration among teachers, in understanding classroom practices both that hinder and that promote authentic learning, and in determining the prerequisite skills needed for students to benefit from working with system dynamics and other computational models.

Since the formation of this group, I have started reading The Fifth Discipline, and am convinced that its principles can help form the MVHS CoreModels learning community.

In addition to the understandings mentioned above, I think I can bring to the meeting some ideas from science educators about effective methods for implementing project based learning and learning cycles.

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From the Editor . . .

Welcome back to what we hope will be a challenging and productive school year. I always regard September as the real start of the year rather than January, as I am sure many of you do also. This year at the Exchange promises to be a busy one. We are starting to plan the summer conference (see the box on page 4) and are getting excited about the possibilities. If any of you have suggestions or comments about its organization, who should speak, or what material needs to be presented—please tell us. We would love to hear from you.

During this year we will also try to continue to keep you updated about what is going on throughout the country (and even the world). As the use of systems education becomes more widespread, it becomes harder to keep track of everything that is happening. Please write and tell us about what you or others are doing. As always, give us references so we can include others on our newsletter list. Have a good start to the year!

Please note that we have a new area code—978. Until the end of the year, either area code will work, but after January 1, 1998, only the new number will be effective. That's 978-287-0070.

Lees Stuntz *(stuntzln@tiac.net)*

Spring Branch Independent School District

The Spring Branch Independent School District began its journey in organizational learning early in 1995. Our journey continues as we enter into our fourth year of implementing a multi-year organizational plan, the Learning Organization Initiative (LOI). The initiative is a series of learning opportunities for all employees, designed to develop high performing individuals who keep learning and who produce extraordinary results. This effort is firmly grounded in the contention that the district must focus on helping students to maximize their own potential through the continuous improvement of the staff.

The first phase of the LOI was the Edge Institute's *Increasing Human Effectiveness* (IHE) program. IHE is an active-participation training program that is based on the premise that the way people feel about themselves affects their performance in all areas of life. The program consists of a series of videotape presentations, class discussions, demonstrations, and learning exercises. A student program from Edge, *Unlocking Your Potential*, is also being used in the district.

By the year 1999, SBISD will have offered training in Covey's Seven Habits, contributing to increased effectiveness in the workplace. By the year 2000, we will have offered training in Vertical Leadership Training, resulting in self-managed work teams. And, by the year 2001, we will have offered training in Organizational Learning, using Senge's Five Disciplines, resulting in applying systems thinking.

We have developed a video which presents an overview of Spring Branch's Learning Organization Initiative. We welcome observations and possible networking opportunities with other districts and organizations embarked on a similar journey of indi-

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Fundamental Changes in How We Teach, continued from page 1

were necessary—what worked before would no longer do; some changes were painful—the students needed to take more control.

A striking similarity among successful teachers in the CC-STADUS project is interest in ideas *outside* one's field. This may be what drew teachers to the project in the first place—teachers were predisposed to see things differently, to defy the norm and take students beyond the delineations and dissections of Cartesian methods. We can not overstate this crucial piece of our success: *teachers must see the world systemically before they teach it so.* However trite this sounds, it is critical. Merely carrying a single system dynamics activity into a biology classroom, but having no insight into the connections to other disciplines or the manifest feedback in an organic system, will only lead to student and teacher confusion. This is why some portion of training time at CC-STADUS is given to this idea; ultimately, though, the teacher will have to go the intellectual distance to reframe the world in her mind. This takes time. And some courage.

Though system dynamics and the use of STELLA lend themselves felicitously toward the sciences, the Humanities remain difficult to penetrate not so much for lack of models but for lack of willing teachers. Of all disciplines, none is so entrenched as the Humanities. One need only look back a century to the rise of science to recall the enmity the arts harbors for natural sciences—Matthew Arnold and Thomas Huxley argued poetically and pointedly over this issue—and the split remains deep, not just in world view but also in how each discipline prepares its cadre of instructors. Science teachers are predisposed for labs and computers and individual instruction. Using a computer in a Humanities course, however, borders on a deadly sin. Since the computer is the primary tool of system dynamics, computer literacy has been a major obstacle and represents a deep chasm Humanities teachers must cross. Even when willing, there is much to learn.

In a recent class, Sophomores gathered in a computer lab to work through *The Rulers*, a STELLA model on population control that puts teenagers in charge of a desperate country for a century and they must fix it. In ten minutes, disaster struck. The instructor, not prepared for the permutations eager students might exercise in a computer model, found himself barraged by questions, freezing screens, illogical graphs, and utter student chaos. Moving to another classroom to use unfamiliar equipment was no trivial matter, as this instructor found. In time, though, a more natural flow of one-to-one questioning and responding emerged as well as a clearer sense of when to focus the whole class on one idea; even such minute details as where to stand and what to point at when presenting with a computer and a projection panel can place an experienced Humanities instructor on novice ground.

Without a room full of computers, one teacher with one computer and a projection panel can still lead a deep discussion as the whole class creates a model through the interaction. A very useful discussion in a basic Biology class, especially as an introduction to systems, takes a broad shape and then a deep clarity as stocks and flows are identified and then connected in front of the entire class. This critical moment helps students delineate that most crucial distinction: what is a stock and what is a flow. Even so, the teacher must eventually get students before their own machines and building their own models; it is in this arena that quantum leaps occur.

The nature of system dynamics demands some measure of independence for its devotees. If we wish students to fully study, then we must grant them some intellectual independence and allow their curiosity to lead them. In Physics and Biology labs using STELLA, opportunities abound. In this new setting, the teachers grant the questioners primacy. A teacher might introduce some conceptual material on acceleration, and then allow students to work through a series of increasingly difficult models that test some of the conceptual material as well as some equations and precise data. More advanced students are free to experiment and test their own well-educated notions, each time receiving immediate feedback that redirects their personal search. Even so, the instructor, no longer bound to a text all must do at once, is free to pose ever more complex and thoughtful problems, each suited to a particular student need or capacity to raise questions about an expanding idea. Likewise, the struggling student can receive such thoughtful, prolonged attention from the teacher who knows the other students are well engaged. No longer one question for the many, but a myriad of questions, each appropriate, for the multitude.

As the modeling reaches deeper realms, the teacher and student explore together—a student's curiosity and imagination teamed with a teacher's wisdom and experience. This intellectual intimacy, brief on a daily basis, but profound over time, conjures the mas-

. . . the teacher will have to go the intellectual distance to reframe the world in her mind. This takes time. And some courage.

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ter-apprentice models of earlier times. For the students of average ability, this relationship bears much fruit. Many of these students have languished through course work, doing what's required but retaining little over time, just enough to pass or a bit better; many of these students are lost in the vast crowds of American education. But the visual aspect of system dynamics engages students both *conceptually* and *pragmatically* so that many more students are drawn into this question-rich learning. This dialectic mode of instruction is far more endearing to these students for whom teachers were oft viewed as authoritarians rather than mentors. Because the computer model makes explicit what heretofore was unknown in a student's mind, the teacher and student now have very clear venues for questions and suggestions. The best teaching and the best learning still take place at this primary level—the intellectual intimacy of teachers and students breeds trust, curiosity, imagination. It is not that this didn't happen before; it was just rare. System dynamics creates more possibilities for this as it enjoins minds in deep ways: students solve complex problems and teachers instruct directed minds.

Among the pleasing surprises of this enterprise have been teachers reaching outside their disciplines. This occurs primarily when the model is simple and teachers as well as students readily identify its application to other areas. We all realize that a key concept in system dynamics is archetypal structures, a recurring pattern of behavior that is consistent or, at least, recognizable within *and* across disciplines. Gregory Bateson called it "the pattern which connects." In these archetypes, teachers find some common ground. The oscillation that occurs in a watershed through winter rains also occurs in the Israelites relationship with Yahweh in *Judges*, albeit for different reasons. Students with a propensity for mathematics find their way into a model through equations, while those of a more aesthetic sensibility find openings on the diagram level. At one school, social science, English and science instructors will team teach one course; at another school, Biology teachers often send their students with model in hand to ask an English teacher for help. Classroom and faculty-lunchroom conversations flourish as this cross-pollination widens. People read outside their standard academic discipline. All of these people are confronting information from a radical perspective; whereas they once thought they saw disparate things, they are actually viewing the same, large phenomena, but now through the same lens. One can imagine that the traditional idea of "academic department" will likely evolve, but ought not include a *system dynamics department*.

An English teacher reads science books and wonders about the ratio of food per person over a twenty-year time period. A Physics teacher creates social science models or teaches a Literature class on *Lord of The Flies*. A Mathematics teacher assists students with bear populations or increasing disorder in Van Gogh's paintings. In such experimentation, students have been gracious and willing subjects. They have found themselves advising school boards, local voters, governmental councils; they receive job offers and scholarships to major universities; and they help us teach a bit more brightly, a bit more effectively, and a bit more courageously. Ultimately, the whole project comes down to what the students are doing. Within the CC-STADUS project schools in Portland, Oregon, USA, students and their fortunate teachers find themselves charting new intellectual territory.

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1998 SYSTEMS THINKING AND DYNAMIC MODELING CONFERENCE

June 28 - June 30, 1998

New England Conference Center
University of New Hampshire
Durham, New Hampshire

The summer conference for 1998 will be held on the lovely wooded campus of UNH. Durham is just a little more than an hour north of Boston. The Center itself affords excellent meeting facilities with comfortable rooms and delicious food. Look for your registration brochure coming soon.

Student/Teacher Mentor Program in Modeling and Simulation

Susan Ragan

Half of the one-semester Modeling and Simulation course taught at Montgomery Blair High School is devoted to system dynamics as expressed in STELLA. Although the upperclassmen in the course have used STELLA during their freshman year to model systems in physics, they have not had the opportunity to explore it in depth. In this course, not only do they have the opportunity to see a wide range of examples of STELLA models, they also are given the freedom to choose a system of interest to them for which to develop a model.

First, we study causal-loop diagrams as presented in Introduction to Computer Simulation by Nancy Roberts, et al. We translate some of our diagrams to STELLA, exploring appropriate built-in functions. We also study the numerical integration methods, Euler and Runge-Kutta, comparing their results using different step sizes. This leads us to the recognition that the modeling of discrete events versus continuous ones requires different integration methods. For example, if a student is modeling the action of a savings account earning interest quarterly, Euler's method with a step size of 0.25 must be used. On the other hand, the modeling of a physical or chemical reaction which changes continuously over time requires the use of Runge-Kutta with a small step size.

Once the students have designed and mastered a variety of models, they are ready for their independent projects. They are required to choose a problem for which a model would be a useful teaching tool. Then they must find a teacher who would like to use this model in classroom instruction. This requires them to explain STELLA to the teacher and to work with the teacher to choose an appropriate problem. At a faculty meeting before making the assignment in class, I announce that the students will be approaching their teachers so that they are not taken by surprise. The students then submit a written proposal to me describing the system to be modeled, the resources to be used for data and information collection, and the name of the teacher-mentor. I reserve the right to approve or change the topic if I feel it is either too easy or too difficult for the student.

The students then have two weeks of class time to work on their models. During the design of their model, they are required to meet with their mentor to verify the causal relationships in their model. When they have completed their models, they write a report in which they state the problem, give the background information needed to understand the concepts behind the model, explain the model itself and

Mentors *continued on page 9*

Maryland Virtual High School of Science and Mathematics

In October 1995, Montgomery Blair High School was awarded a three year grant totaling over $1,500,000 from the National Science Foundation for an innovative program to extend Blair's expertise in computational science studies and Internet use for science resources, mentoring and collaboration to schools throughout Maryland.

High schools located in Anne Arundel, Garrett, Washington, and Wicomico counties, and Baltimore city joined the Maryland Virtual High School of Science and Mathematics as charter schools. In September 1995, additional schools located in Baltimore City, Carroll, Cecil, Charles, Frederick, Harford, Queen Anne's, St. Mary's, and Washington counties were added to the project. Each school is provided with a direct connection to the Internet through a dedicated 56kbs line or a frame relay 128kbs line. This connection allows students to search and communicate on-line simultaneously through local area networks attached to the school Internet hub.

The grant fosters use of powerful computer systems and software tools to solve problems through computational science techniques. The selected teachers from each school receive training in the computational science paradigm and its place in science curriculum, as well as instruction on math and science software. They plan and field test collaborative computational science projects.

As the project matures, the schools in Maryland will be linked together solving 'real world' problems. Students from different age groups, with varying mathematical and scientific backgrounds, with all levels of computer expertise, and from schools geographically distant from one another will collaborate on problems of common interest. Students will no longer wonder why they are learning disjointed facts nor will they wait impatiently to see the uses of their high school education. Instead, they will be motivated to learn because they are solving 'real' problems now.

Currently, teachers and students are investigating a wide variety of topics, including change of state, measurement of earth size and movement, and environmental issues, such as air quality and the Chesapeake Bay ecosystem.

Problems in Causal Loop Diagrams Revisited, continued from page 1

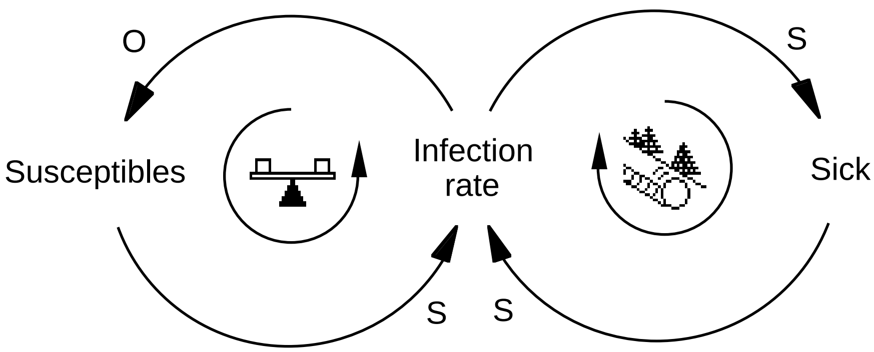

Figure 1: Causal loop diagram in "S" and "O" notation, capturing the balancing and self-reinforcing loops inherent in the spread of a disease.

The story intended in Figure 1 is that a few people infected with the disease (Sick) make contact with people who can catch the disease (Susceptibles), resulting in more people becoming sick, so still more Susceptibles become infected. This self-reinforcing process continues (in this simplified picture) until the stock of Susceptibles falls low enough to slow and eventually halt the spread of the infection. (A stock-and-flow diagram for such a system is shown in the notes, along with a graph of typical behavior.)[1]

The link from the susceptibles to the infection rate is labeled "S," meaning, according to the current characterizations (e.g., Kim 1992), that as the susceptible population changes, the infection rate changes "in the Same direction" (ceteris paribus). Similarly, the link from the infection rate back to the susceptibles is labeled "O," meaning that as the infection rate changes, the susceptible population changes "in the Opposite direction." The labels on the other arrows in the diagram have analogous interpretations.

Yet it is clear that two of the characterizations of these arrows are false. Consider the link from the Infection rate to Susceptibles. If the infection rate were to decrease, as it does in the later stages of the spread of the disease, the susceptible population would not increase (move in the opposite direction) as its "O" label suggests — susceptibles in this system would continue to decrease as more become sick. The link from the Infection rate to the Sick population has a similar problem: when the infection rate decreases, the sick population does not decrease (move in the same direction) as the "S" label suggests — it would continue to increase. We know very well the reason for these behaviors: the infection rate always *subtracts* from the susceptible population and *adds to* the sick population. The populations are stocks, and the infection rate drains one stock and pours into the other. In this diagram, the susceptible population always decreases and the sick population always increases, whether the infection rate is increasing or decreasing. Thus, the "S" and "O" labels rather fundamentally mischaracterize the meaning of two of the links in this simple structure.

Moreover, as pointed out in Richardson (1986/1976), such misbehaving links will occur at least once in every causal loop that a modeler would draw to capture complete system structure, because there must be a stock in every loop in a system dynamics model. Hence, at least one of the arrows in every feedback loop in an accurate loop diagram must be an additive or subtractive influence for which the S and O notation is incorrect.[2]

At least one very experienced modeler uses the S and O notation by very carefully defining each label in terms of an increase or decrease from what *would have occurred* without the change in the causing variable. For example, he would define the link from Infection rate to Susceptibles by saying "if the Infection rate increases then the Susceptibles will be *less than they would have been* had the Infection rate not increased," thus justifying the O for Opposite. This sort of definition solves the problem, but unfortunately most of us are not this careful in the definition and usage of these labels. The definitions published in every issue of *The Systems Thinker*, for example, say S and O indicate "change in the same direction," and "change in the opposite direction." Furthermore, the problem is "solved" by the more sophisticated definition by covering it up (see Richardson 1986/1976, 161-162). The real problem is not subtle wording but rather that Susceptibles is a stock and the Infection rate is a flow — that the process of infection moves people by subtracting from the pool of susceptible people and adding to the pool of sick people — and any correct reading of the word-and-arrow diagram requires recognizing that fact.

The result is very general: in any word-and-arrow diagram that contain concepts that should be interpreted as stocks (levels, accumulations) and flows (rates), the S and O notation fails to capture for the reader the structure of what is really occurring.

As diagrams like Figure 1 have grown in popularity, the form of the diagram shown in Figure 2 has gone out of favor, yet it has a very desirable property that Figure 1 lacks. When polarities are labeled with positive and negative signs, links can be defined as *either* additive or proportional influences, and the notation works well semantically in either case. One can say that a positive arrow from A to B means that *A adds to B,* or, *a change in A causes a change in B in the same direction* (resulting in a positive correlation or direct variation). For a negative link from A to B one says *A subtracts from B,* or, *a change in A causes a change in B in the opposite direction.* Such definitions and interpretations have been commonplace since Richardson and Pugh (1981). Their applications in practice are easy, for the creator or describer of a word-and-arrow diagram knows the meaning of the concepts in the diagram and thus knows when a link is adding or subtracting versus when the influence described is proportional.

Unfortunately, in the current "S" and "O" notation, no analogous definitions or interpretations are possible. We'd have to say "S" can mean "adds to" and "O" can mean "subtracts from," neither of which makes any intuitive sense.

The motivation for "S" and "O"

I conclude that the current fad of using S's and O's to label the polarity of links in influence diagrams is seriously flawed. It does have two desirable properties, however, which are presumably the reasons it was introduced in the first place. First, it helps to prevent the mislabeling of the polarity of links that beginners sometimes create when tracing around the loop the up-and-down implications of a change in a variable. When one comes to a link and says "when C drops then D tends to rise," some beginners have a tendency to put a positive sign on the link, signifying "rise," instead of a negative sign indicating "change in the opposite direction." The solution to this erroneous tendency is straightforward, however. Suggest that beginners assign link polarities by going to each link separately and always determining the implication of an *increase* in the variable at the tail of the arrow; then the direction of change in the variable at the head matches intuitively the correct polarity of the link: "If C increases, the D tends to *decrease,* so the link is *negative.*" Once the link polarities are correctly established individually, one can then get the polarity of the entire loop and tell its self-reinforcing or goal-seeking story.

The second desirable property of the "S" and "O" notation is that it strives to sidestep any nonmathematical tendencies of folk we are trying to reach with systems insights and thereby strives not to put them off. It thus enables a superficial following of lines of reasoning in a systems thinking exercise. Unfortunately, that very superficiality runs completely counter to the purposes of systems thinking consultants and clients because it reinforces tendencies to not think deeply or clearly. If one does think clearly in any instance of a diagram with additive or subtractive influences, one either becomes confused by the "S" and "O" notation, or one realizes the letters do not capture what is actually happening in the system.

There is a third possible motivation — to use "S" and "O" notation to avoid thinking of "positive" and "negative" as "good" and "bad," but I doubt this is a significant motivator since the issue is so easily dismissed by simply mentioning it. In any case, I suggest that none of these properties of the "S" and "O" notation outweigh the dramatically undesirable property that the notation is simply wrong at least once in almost every loop one would construct to capture causal structure accurately.

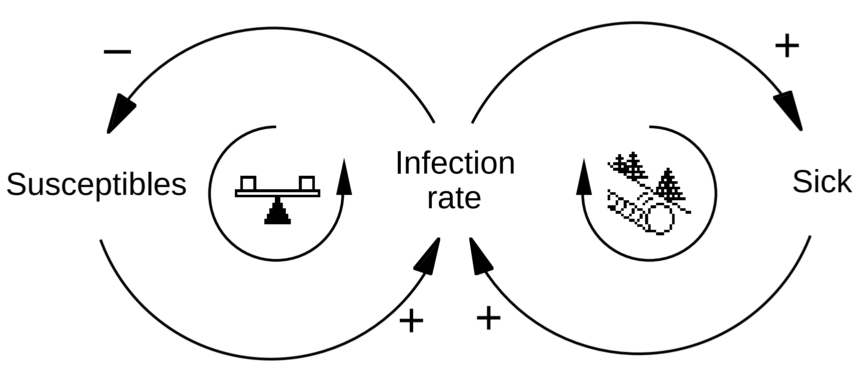

Figure 2: The loop in Figure 2 shown in arithmetic sign notation, where the signs on the two top links would be interpreted as addition and subtraction, while those on the bottom two links represent proportional change.

Rekindling motivation for "+" and "–"

Teachers learn that if there is a subtlety in a line of reasoning, and for the sake of efficiency or misplaced compassion they hide the subtlety, someone is sure to become either confused or disenchanted. Both reactions are possible with "S" and "O" notation from folk who think deeply enough to see the problem and who note that it is not being addressed. Confusion can be dealt with moderately easily: we can point out the double meaning we require in polarities in causal loop diagrams, note that S's and O's don't really do the trick, and suggest either positive and negative signs or full stock and flow representations to cure the problem. We could even combine the S and O notation with the + and - notation, reserving S's and O's for proportional change links and using +'s and -'s for

Problems *continued on next page*

Problems in Causal Loop Diagrams Revisited, continued from page 7

additive and subtractive links. But disenchantment is more difficult to deal with, for it usually results in rejection of the enterprise — in school, dropping out of a course that persists in such glossings over; or in our case, abandoning a serious systems thinking effort.

We have three viable options for our word-and-arrow diagrams: 1) use plus and minus signs for all links to indicate link polarity; 2) use plus and minus signs for additive and subtractive links, preferably with boxes drawn around the stocks they point to, and use S's and O's, if one must, for the other links, which would represent proportional links for which the S and O notation works correctly; 3) show explicit stocks and flows (as tubs and pipes) with the remainder of the links labeled with either plus and minus signs or, if desired, S's and O's. Any of these options can yield a logically consistent diagram. Taste can dictate the choice. Personally, I favor number 1 (with boxes around the obvious stocks) and number 3, depending on the audience, but I suspect one can find merit in any of these three options.

Only the fourth option — labeling all links in a word-and-arrow diagram with S's and O's — is logically flawed and must be ruled out. I submit that our current enthusiasm for S's and O's is significantly misguided and needs to be curbed. Positive and negative polarities stand up much better to the deep thinking we are striving to facilitate in and about complex systems.

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Notes

1 To keep the picture simple, in Figure 1 the Sick unrealistically never get cured. A full stock-and-flow diagram of the structure, together with typical model behavior, is shown in Figure 3. Note that the two links from the Infection Rate in Figure 1 become a single pipe in the stock-and-flow diagram.

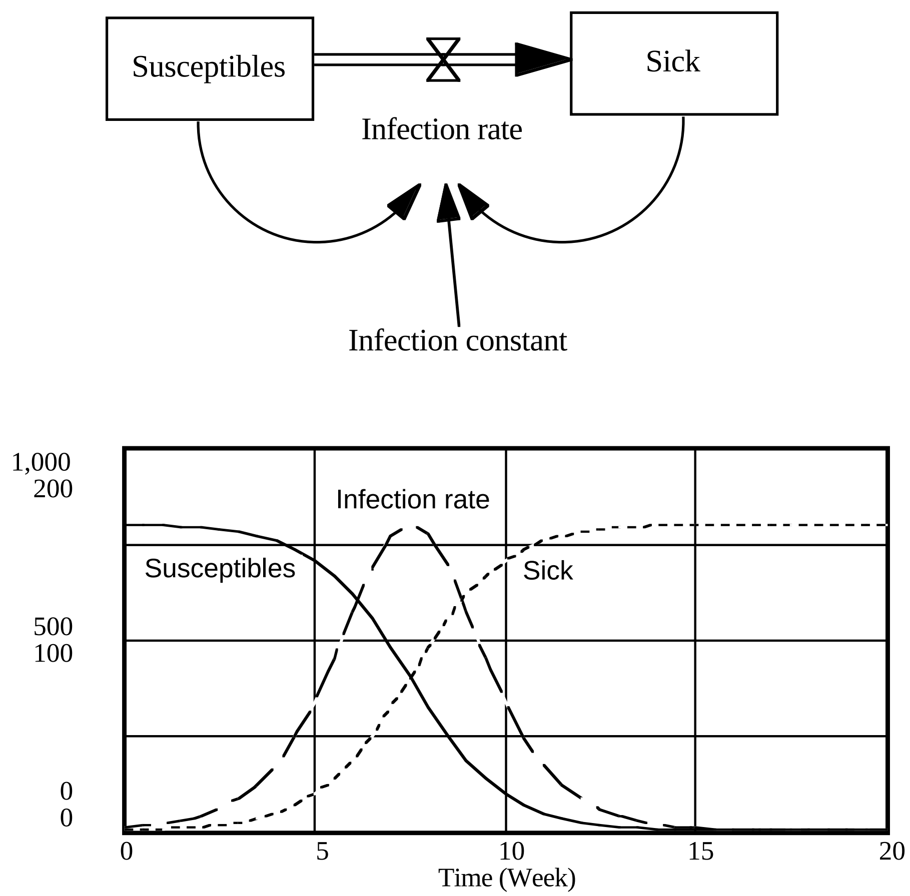

Figure 3: The structure and behavior of a trivial system dynamics model fitting the causal loop diagram in Figure 1. The Infection Rate is modeled simply as a constant times the product of the Susceptibles and the Sick populations.

The graph in Figure 3 makes it clear that the Infection Rate moves, at different times, in both the Same and the Opposite directions as the two stocks — the S and O notation fails completely here for the links from the Infection Rate.

The structure here is a variant of the "limits to growth" archetype (Senge 1990, 95-101) and is related to diffusion models such as the Bass model of market development (Bass 1969).

***Problems** continued on next page*

For a more complete epidemic model see Richardson and Pugh (1981, 95-98).

2 One can draw word-and-arrow diagrams that do not contain concepts one would model as stocks, and in such cases the S and O notation itself causes no problems. However, such diagrams would be incomplete from a modeler's perspective and probably tell at best only a loose story about the dynamics of the system. In any case, usage of the S and O notation has not been limited to "no stock" causal loop diagrams so such special cases do not solve the problem.

This article, PROBL2GR, is a variation of Problems with Causal Loop Diagrams *by George Richardson and Colleen Lannon which originally appeared in Vol. 7, No. 10 of* The Systems Thinker™ *Newsletter published by Pegasus Communications, Inc. It is available from the CLE with an appendix which consists of some comments made about points raised in the text and further explanations by Mr. Richardson. The article in its entirety is also available on the website—http://sysdyn.mit.edu/*

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verify the correctness of the model's results. They then invite their mentor to their presentation in which they explain the model to their classmates and demonstrate the results. If the mentor is unavailable during the classroom presentation, the student must schedule a lunch-time or after-school time to present to the mentor. All audience members, classmates, teacher and mentor, participate in the evaluation process.

The most difficult part of this project is model verification. If the student chooses a topic which has known mathematical relationships, it is fairly straightforward to insert given values into the model and verify that the results match those expected mathematically. On the other hand, if the data regarding the system is limited to trends and observations, it is more challenging to validate the results. It is easy to tell when a model is clearly wrong, but a model with errors in it can appear to give logical results.

Since models vary in difficulty, some students are not going to be successful in their attempts to validate their models. This leads to a dilemma. Should all students be assigned systems for which the validation will be absolute? Or, should more challenging systems be allowed so that the students experience the difficulties of real-world modeling? I choose the latter within reason. Usually the more able students gravitate toward more challenging problems, and I encourage them in their efforts. I believe that they will learn more from a system that frustrates them than from a system that is transparent to them. Ideally, the student will seek and get help from the mentor; and most do. Unfortunately, the reality of busy schedules and the unfamiliarity of the mentor with STELLA impacts the amount of assistance the mentor can give.

The student/teacher mentor program benefits both parties. The student gains a better understanding of both STELLA and the subject matter chosen as a result of having to work through a model independently. The teacher sees a new way to present material to a class. Those teachers whose models are flawed may ask to have another student attack the problem the next year or may elect to learn STELLA and fix the model themselves. As a result of this process, teachers who never heard of system dynamics consider using STELLA models as an instructional tool in their classrooms.

This article, MENTORSR, is available online—http://sysdyn.mit.edu/ — or from the CLE. In its entirety, it includes the following 5 appendixes:

- *Appendix 1 — a sample of a unit test.*
- *Appendix 2— a sample worksheet.*
- *Appendix 3 — the project description form and sample project ideas.*
- *Appendix 4 — the presentation evaluation form.*
- *Appendix 5 — the evaluation form used by the mentor to critique the overall quality of the student's work.*

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***

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

ASSESSJP ***Assessing Progress in Systems Thinking and Dynamic Modeling: Some Thoughts for Educators.*** Jeff Potash & John Heinbokel

From Triniity College of Vermont. A discussion of the methods and building blocks which help educators achieve success in introducing and understanding system dynamics. [Overview, Systems Education, Adult] (50¢)

FUNDAMTJ ***Fundamental Changes in How We Teach: A Narrative about Teaching System Dynamics and the Art of Learning.*** Timothy Joy and Ron Zaraza

From CC-STADUS. A brief summation of the changes in teaching style among successful teachers in the CC-STADUS Project. [Implementation, Adult] (50¢)

LEVERARZ ***Introducing System Dynamics into the Traditional Secondary Curriculum: The CC-STADUS Project's Search for Leverage Points.*** Ron Zaraza and Diana Fisher

From CC-STADUS. A discussion of the single-subject natural "entry points" for system dynamics—areas where systems ideas and models are natural topics. Examples are given for physics, biology, mathematics, social sciences and literature. [Implementation, High School] ($1.00)

MENTORSR ***Student/Teacher Mentor Program in Modeling and Simulation.*** Susan Ragan

From Maryland Virtual High School. A description of the Student/Teacher Mentor Program in the Modeling and Simulation course taught at Montgomery Blair High School, with samples of a unit test, worksheets, project ideas and evaluation form. Funded by the Gordon Brown Fund. [Implementation, Systems Education, Dynamic Modeling, High School] ($1.00)

PROGRARZ ***The CC-STADUS Training Materials: A Program for Developing Models and Modelers for the Pre-College Environment.*** Tim Joy, Ron Zaraza, and Scott Guthrie

From CC-STADUS. A summary of the CC-STADUS Project training program funded by the National Science Foundation, including a schedule and description of the 12-day program. [Systems Education, Dynamic Modeling, Adult] ($1.00)

CROSS CURRICULAR

ACTIVISS ***System Dynamics Activities Adapted from The Systems Thinking Playbook.*** Scott Suter

From Catalina Foothills School District. Fifteen activities adapted from *The Systems Thinking Playbook* to be integrated into various academic units. [System Dynamics, Cross Curricular, Elementary School, Middle School] ($1.00)

MATH

EULERSJB ***Dynamic Modeling and Euler's Method.*** Judith Bishop and Nanette Dyas

From Maryland Virtual High School. The objective of this unit is to use and understand Euler's Method to predict future populations of the grey squirrel under a variety of hypothetical conditions. The student will see how continuous change may be approximated using discrete time units. Funded by the Gordon Brown Fund. [Math, Dynamic Modeling, Simulation, HighSchool] ($1.00)

SEAMLEDF ***Seamless Integration of System Dynamics into High School Mathematics: Algebra, Calculus, Modeling Courses.*** Diana Fisher and Ron Zaraza

From CC-STADUS. A report on the introduction of system dynamics concepts into the mathematics curricula, including sample models. [Math, HighSchool] (50¢)

SCIENCE

CRITTEMM ***Student Guide to Computer Critters.*** Mary Memmott

From Acton-Boxboro School District. Worksheets comprising a Student Guide to "Computer Critters," for students working in the computer lab to try a computer simulation from "Eatordie Island." See EATORA-K in Cross-Curricular. [Science, Dynamic Modeling, Middle School] (50¢)

CELLULEG ***Cellular Respiration.*** Elaine Goldberg

From Maryland Virtual High School. Cellular respiration is one of the most difficult topics for first year biology students to grasp. Designing a computer model compels students to analyze relationships and enhances modeling skills while reinforcing the crucial concept that ATP production is the ultimate goal of cellular respiration. Funded by the Gordon Brown Fund. [Science, Dynamic Modeling, Simulation, System Dynamics, High School] ($1.00)

DUNEC-C ***Succession from Sand Dune to Maritime Forest on a Barrier Island.*** Aili Carlson and Sarah Clemmitt

From the Maryland Virtual High School. By building a computer model of a complex dynamic system—the succession form sand dune to maritime forest on a barrier island—the student develops an understanding of the relationships among many contributing variables. The exercise deals with both modeling skills and the ecology of barrier islands. Funded by the Gordon Brown Fund. [Science, Dynamic Modeling, Simulation, System Dynamics, High School] ($1.00)

STREAMTP ***Stream Assimilation Capacity for Waste Material.*** Tran Pham

From Maryland Virtual High School. The unit objective is to develop a model which will simulate the biodegradable process of man-made waste released into a stream. Students can design, experiment, collect data, build a model, evaluate the model, and redesign it to produce a working model applying appropriate mathematics and chemistry concepts. Funded by the Gordon Brown Fund. [Science, Dynamic Modeling, Simulation, System Dynamics, High School] ($1.00)

SYSTEM DYNAMICS

BUILD1SA ***Building a System Dynamics Model Part 1: Conceptualization (D-4597) .*** Stephanie Albin

From SDEP. An in-depth examination of the steps of conceptualization of a model: purpose, boundaries and variables, behaviors of variables, and diagrams of the system's mechanisms. From Road Maps 8. [System Dynamics, High School, Adult, Dynamic Modeling] ($2.00)

OSCIL2KA ***Oscillating Systems II: Sustained Oscillation (Kevin Agatstein) (D-4602).*** Kevin Agatstein

From SDEP. A detailed examination of the structural causes of sustained oscillation. From Road Maps 8. [System Dynamics, High School, Adult, Dynamic Modeling] ($2.00)

PROBL2GR ***Problems in Causal Loop Diagrams Revisited.*** George P. Richardson

A discussion of the discrepancies which can result from the S (Same) and O (Opposite) notation commonly used to label links in word-and-arrow diagrams. [System Dynamics, High School, Adult, Dynamic Modeling] (50¢)

RMAPS8 ***Road Maps: Part 8, A Guide to Learning System Dynamics (D-4508).*** System Dynamics in Education Project

From SDEP. Part 8 in a series of 8. Includes a) *Building a System Dynamics Model Part 1: Conceptualization* (Stephanie Albin) (D-4597) An in-depth examination of the steps of conceptualization of a model: purpose, boundaries and variables, behaviors of variables, and diagrams of the system's mechanisms; b) *Mistakes and Misunderstandings: Use of Generic Structures and Reality of Stocks and Flows* (Lucia Breierova) (D-4646) A warning against incorrect use of a generic structure emphasizing the real nature of stocks and flows; c) *Oscillating Systems II: Sustained Oscillation* (Kevin Agatstein) (D-4602) A detailed examination of the structural causes of sustained oscillation; d) *An Introduction to Sensitivity Analysis* (Lucia Breierova and Mark Choudhari) (D-4526) The first in a series of papers on sensitivity analysis, containing 3 exploratory exercises which demonstrate the effects of various parameter and initial value changes on system behavior; e) *Learning through System Dynamics as Preparation for the 21st Century* (Jay W. Forrester) (D-4434-1) Transcription of Prof. Forrester's keynote address at the Systems Thinking and Dynamic Modeling Conference for K-12 Education given in June 1994. [System Dynamics, High School, Adult, Dynamic Modeling] ($10.00 [$20.00 non-educator price] in hard copy or $5.00 [$10.00 non-educator price] for a disk.)

SENSI1LB ***An Introduction to Sensitivity Analysis (Lucia Breierova and Mark Choudhari) (D-4526) .*** Lucia Breierova and Mark Choudhari

From SDEP. The first in a series of papers on sensitivity analysis, containing 3 exploratory exercises which demonstrate the effects of various parameter and initial value changes on system behavior. From Road Maps 8. [System Dynamics, High School, Adult, Dynamic Modeling] ($2.50)

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vidual and organizational growth and development.

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Ottawa Board of Education

Cathy Curry, a teacher, and her husband, Ian, who spend a year at the Sloan School at MIT, will be presenting on Systems Thinking and Dynamics at the Ottawa Board of Education's Professional Development Day in September.

Systems Education Consortium

This has been a busy summer for the schools west of Boston in the Systems Education Consortium (Harvard, Concord, Carlisle and Acton). During the past school year, the four middle schools joined with a charter school, Francis Parker, to work on a CESAME project in math and science. That project has proved to be a catalyst for more interest in systems education within the respective school systems. With the help of the Waters Foundation, both Harvard and Carlisle utilized the services of Jennifer Hirsch and Anne LaVinge, from the Catalina Foothills District, to present a basic systems thinking workshop at the end of the school year. Quite a number of teachers, especially at the elementary level, attended.

Later in the summer, again with the help of the Waters Foundation, a week-long workshop, which focused on both systems learning for teachers as well as integration of systems concepts into the curriculum, was held in Acton. There were attendees from Harvard, Carlisle and another charter school, the Chelmsford Charter, which has systems thinking and dynamics written into their Charter. With the help of the CESAME teachers, and Jeff Potash and Will Costello from Vermont, many of the teachers got a good start on new ways to incorporate systems into their existing curriculum.

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