System Dynamics: The Classroom Experience
Quotations from K-12 Teachers

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1 SYSTEM DYNAMICS

System dynamics, which has been under development at MIT since 1956, and now at many other places, deals with how things change through time. That covers a great deal of what most people find important.

System dynamics was first developed as a management discipline to understand how the policies of corporations produce successes and failures. What is it in decision-making policies that produce growth or decay; what policies make huge fluctuations of employment, as seen in some corporations that work seven days a week and overtime one year, and two or three years later have half the people laid off?

Later we realized that system dynamics was not limited to the field of management, and there were excursions into larger social systems. Work I did with former mayor John Collins of Boston became my *Urban Dynamics*[1] book dealing with how cities grow and then stagnate, and how national policies for dealing with cities often lie between neutral and highly detrimental, both for the city as an institution and also for the low income, unemployed residents.

Then system dynamics extended further in work with an organization called the Club of Rome that resulted in my *World Dynamics*[2] book and *The Limits to Growth*[3] by Meadows. These two books produced vastly more public reaction than any other computer modeling in the social sciences. Since then, I have applied system dynamics to understanding better the dynamics of national economies.

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[1] Forrester, Jay W. (1969). *Urban Dynamics*. Waltham, MA: Pegasus Communications. 285 pp.

[2] Forrester, Jay W., 1973. *World Dynamics*, (2 ed.). Waltham, MA: Pegasus Communications. 144 pp.

[3] Meadows, Donella H., Dennis L. Meadows, Jørgen Randers, and William W. Behrens, III. (1972). *The Limits to Growth*. New York: Universe Books. 205 pp.

2 SYSTEM DYNAMICS IN EDUCATION

This paper discusses the most recent frontier in system dynamics—its use as a foundation underlying a dramatically different kind of education in kindergarten through 12th grade.

The dynamic, computer-modeling approach provides a foundation that is transferable from field to field. There are several dozen K-12 schools now doing excellent work, and several hundred doing something. Pioneering schools are scattered over the United States, and extend into The Netherlands, China, and other countries.

System dynamics uses computer simulation models to reveal how known structures and policies often produce unexpected and troublesome behavior. The computer models are constructed from descriptive information that usually is already known. Such information relates to who is striving to do what, the information that each person has available, time delays in taking action, and what individuals will do under a variety of pressures. The same approach carries over to physical change and nonhuman systems in nature.

In K-12 education, system dynamics modeling has been applied to mathematics, physics, social studies, history, economics, biology, and literature.

3 LEARNER-CENTERED LEARNING

In the more successful schools, system dynamics is combined with a classroom reorganization we call "learner-centered learning." Such a project-oriented approach goes by various names in other proposals for K-12 education, but is especially powerful when coupled with system dynamics. Learner-centered learning focuses on solving significant problems. Teachers are no longer lecturers, no longer the source of all wisdom, not even necessarily authority figures. Teachers become advisors and coaches to students who are doing projects that may lie beyond the teacher's experience. Indeed, moving to learner-centered learning can be traumatic for some teachers who feel they must be in command of all that the students are doing and learning.

A junior high or high school classroom can become much like a university research laboratory. Students address projects with real-world significance for which they have not been given the necessary background and techniques. They start by facing the challenge of learning what they need to know in order to accomplish the project. Such an approach departs from the highly unrealistic format of most education that is found all the way up through college.

Education in most schools could hardly be more unrealistic. Students, when they are given a problem, can usually assume they have been taught everything needed to solve the problem. How many in real-life situations find that challenges come pre-equipped with everything for a solution?

In the full use of learner-centered learning, if a student asks a specific question, the teacher may not know the answer, but, even if the teacher does know the answer, rather than answering, the better approach is to discuss how the student might find the answer.

4 QUOTATIONS FROM TEACHERS

In preparing this paper, I sent out email messages to teachers asking each for a quotable paragraph that captures how system dynamics is being used in their schools. I give here some of the responses.

The basic concepts about systems can be introduced as early as kindergarten, as described by an elementary school principal:

> *We are introducing kindergartners to the concepts of stocks and flows and the idea that behaviors can be graphed over time. Beginning in first grade students are mapping larger sets of information and working with causal loops to explain cycles in nature and everyday events. Students continue working across the curriculum, strengthening their understandings of behaviors over time, causal loops, and simulations mediated through a systems approach. By fifth grade, students are manipulating simple computer models that integrate into their curriculum.*

In the above quote, kindergarten students go through their environments identifying stocks and flows, the fundamental building blocks of system.[4] They are beginning to see the fundamental structure of all systems in their surrounding world.

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[4] Forrester, Jay W. 2009. Some Basic Concepts in System Dyamics. Concord, MA: Forrester Personal

Again from an elementary school principal:

> *Teachers, especially at the elementary level, have found it very easy to integrate systems thinking across their curricula. It is not another subject to be added, but instead it integrates and supports our work with… composition… use of technology… science and mathematics… and … interdisciplinary projects in all areas.*
>
> *At this point we have students, teachers, parents, and the larger community working toward a better understanding of the use of systems thinking in school programs, parenting issues, and as a tool for understanding the changes we are facing. This has been a grass-roots effort with support that continues to grow as we learn more.*

One can include in a formal model anything that can be described explicitly in words. To say, "We want life to be better," is not explicit, it has no operational content. However, to say, " We want more income," or, "We need more free time," is coming closer to a concrete statement. Modeling forces a person to go from empty statements to ones with operational content.

From a sixth grade math teacher, promoting interdisciplinary work:

> *My most fruitful experiences occur when I discuss classroom discipline systems. We have both students and teachers build a discipline system together so that all parties will know what the system is capable of producing. When we do this many students have an "Aha!" experience and state that they now understand how a teacher's frustration can accumulate over time. Teachers have their own insights as well—they begin to understand how they have often built discipline systems that were "preprogrammed" to result in unpleasant situations.*

From a high-school chemistry teacher:

> *My favorite vignette is one that occurred while three girls were working in a chemistry lab predicting shifts in reaction rates, concentration, and mass action values as a chemical system is repeatedly stressed. I overheard one student ask her partner what would happen if they plotted all of these variables together on a single graph. Her partner said, 'Let's do it!'.... and they did. Upon observing the graphs evolving together, one said, 'What a mess!' Her*

> *partner then exclaimed, 'But look! Everything's happening at once!' This last remark piqued my curiosity. I asked her what she meant by it. Her reply: "First we studied rate changes. Then we looked at concentration changes. Then we did the mass action behavior. I thought that first one thing happened… then the next: and then the next. But it all happens at once! Everything depends on everything else!"*
>
> *"Here we had a linear thinker who made a quantum leap towards more systemic thinking. It's interesting to note that her overall class performance also took a quantum leap from that moment forward (C all the way to an A).*

Those comments from teachers remind me of a TV producer who was filming opinions, insights, and discussions among parents, teachers, and students who were involved in a school using system dynamics. The TV producer turned to one eighth-grade boy and asked, "What has all this meant to you?" The immediate answer, "I am much better able to deal with my mother."

4.1 Models of Plots in Literature

System dynamics modeling can enhance almost every activity in K-12 education. Some applications have surprised even those of us who already had high optimism.

To illustrate going from a written description to a system dynamics model, English teachers have created models to show social and psychological pressures that cause plots in literature to unfold. Thus far, most such models may be overly simple, maybe even naive; nevertheless, they point a direction and provide a vehicle for intensified discussion of a book.

One such model by a high school English teacher arose from Golding's *Lord of the Flies.* About this model, the teacher writes:

> *I honed two models for Golding's novel; one based on the boys' declining civility, another describing how the boys' loss of hope drives the increasing power of the beast…*

I was left with how to introduce system dynamics and the STELLA[5] *software to 135 sophomores within the guise of an English class.*

Graphs in hand, the students were arguing positions before I could take attendance, peering over books and tables, pointing out misjudgments and omissions.

This simple model was readily understood by most students. An amount of civility is transformed, through isolation and turmoil, into savagery. It was not until after running the model that some sophomores saw the model's weakness.

Students were not ready to accept their first attempt. Indeed, quite a few wanted to redo it. Some asked for more time to run another graph on a different boy. Others were just plain dissatisfied and came after school, on Friday no less, or the following Monday to finish the work. This was a new experience for me.

I taught writing and literature for 13 years and always suspected I was party to some intellectual crime. Why is it that so many students thought the world of language began and ended at the door of the classroom? Then I discovered system dynamics.

System dynamics has a logic-based grammar, a universal language that students can readily learn and manipulate to create meanings. What have I found? Creating "meaning" results in bolder QUESTIONS, whole new views which do not house traditional understandings.

In some ways, it's been terrifying. I have to give over some portion of the direction and instruction of the material to their own instincts and inquiry. It's slower at the start, but the curve steepens as we discuss and build models. For instance, I have changed the phrasing of questions in literature--we speak of influences (change of rate) to character motivations (levels or stocks), we focus on whether one defining moment is greater than another (in essence, it's a mathematical discussion on a literary event). Let's face it, reading a

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[5] STELLA is the system dynamics software most commonly used in schools, although Powersim and Vensim are also being adopted. STELLA is available from isee systems, Lyme, NH; Powersim from the PowerSim Corporation, Bergen, Norway; and Vensim PLE is available free from Ventana Systems, Harvard, MA.

Charles Dickens' novel is to plunge headlong into a very complex system; STELLA provides a means through it.

I'll never be the same teacher, never go back to teaching only one thing. When I think of living, I just can't recall a time when ONLY ONE THING happened; lots of things happen, all the time, each in differing degrees. What happens in a classroom ought to prepare people for those realities.

I still teach writing and literature but it's changing radically. We use STELLA (software) at all levels and in many disciplines: Physics, English, Government, and Economics. This year we'll add models in Health and Biology.

Pamela Hopkins, 11th grade English literature teacher, in the Desert View High School, Tucson, AZ:[6]

The Hamlet model was used with my students… Teaching Shakespearean drama has traditionally been difficult… a high crime area… drug-related activities are ever-present… many of our students are members of dysfunctional families… The lower socioeconomic level of the students further complicates the issue… students are distracted by financial difficulties… tired from working part time… Shakespeare fails to draw their attention.

When we used a STELLA model which analyzed the motivation of Shakespeare's Hamlet to avenge the death of his father in HAMLET… The students were engrossed throughout the process… The amazing thing was that the discussion was completely student dominated. They were talking directly to each other about the plot events and about the human responses being stimulated. They talked to each other about how they would have reacted and how the normal person would react. … My function became that of listening to their viewpoints and entering their decisions into the computer. It was wonderful! It was as though the use of precise numbers to talk about psychological motives and human responses had given them power, had given them a system to communicate with. It had given them something they could handle, something that turned thin air into solid

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[6] Hopkins, Pamela Lee. (1992). Simulating *Hamlet* in the Classroom. *System Dynamics Review*, Vol. 8 (1, Winter), pp. 91-98.

ground. They were directed and in control of learning, instead of my having to force them to keep their attention on the task.

Hopkins also said the students would tell her in quantitative terms how to change the personality of a character to alter the plot and to see who got killed instead. Students found that fascinating.

4.2 Teachers and Classrooms

The project-oriented organization of the learner-centered-learning classroom shares with students the role of teaching. One of the best ways to learn is to explain a subject to another person. A high school teacher reported student reactions in his chemistry classes:

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CHANGE IN NATURE OF CLASSROOMS

LEARNER-CENTERED LEARNING

PROBLEMS COME BEFORE SOLUTIONS

RELEASING STUDENT INITIATIVE

TEACHER BECOMES COACH AND ADVISOR

INTERDISCIPLINARY

STUDENT ENTHUSIASM AND CAPACITY

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Figure 1.

Working in groups was incredibly effective. Often it is easier to understand concepts when they are explained by a peer."

I feel that everyone is heard and, therefore, the people are more willing to contribute to the discussions and admit to being uncertain about a concept.

The graphs and simulations brought the concepts to life.

I found myself explaining concepts to people in other classes. This has never happened to me before. I think they would have benefited just as much as I did if they had had the opportunity.

Being a visual learner, it really helped to see the reactions in easy schematics. The graphs produced were even more helpful. My father and I spent long hours discussing the graphs and talking about what was the initial change and what was the reaction to that change.

This was a great lab! Using the computer made it easier for me to understand what was going on in the reaction.

From the report at a teachers' conference:

> *Models provide a common language with which to engage learners with diverse learning styles and interests. Simulations are especially engaging, and draw out many who might not otherwise participate in more traditional discussions and activities.*
>
> *Models are extraordinarily powerful for helping to convert abstractions into concrete realities. A learner's ability to 'see' a system—what goes into a stock, where feedbacks exist—and then to run a model and ascertain how the system operates under varied conditions, renders abstractions into real meaningful, concrete terms. This discovery is true for students at all levels.*
>
> *Models provide a vehicle through which students see issues as involving trade-offs rather than having one or two sides (as in the debate format). Positions move from being simplistically labeled 'good' and 'bad' to being seen as much more multi-faceted.*
>
> *Models, which deal with real issues in student's lives—such as financial and interpersonal—render learning especially meaningful.*
>
> *Participants agreed that many of the greatest benefits of a systems approach are in disciplines like literature, the arts, and history. A great work like 'Animal Farm' expands from a piece of writing into a powerful vehicle for learning more about general human behavior.*
>
> *Kids' enthusiasm for learning carries over into other classes and leads other teachers to express interest in learning about systems.*

The above report mentions discovery being true "for students at all levels." And one can add for students of all academic rankings. Evidence is accumulating that there is no correlation between how students have previously been ranked as fast or slow learners and how they do in the system dynamics setting. Some top students remain at the top. But some top students have ranked high only because they learn and repeat facts but without deep understanding of the meaning of the facts; such students may do poorly in the systems framework. On the other hand, some students who have been graded at the bottom of their classes may be there not for stupidity but because they see the academic work as irrelevant and not engaging; they often blossom when given the chance to bring their real world into a focused systems context.

From an education specialist volunteering in a classroom:

> *Last year I was asked to help with a large 6th-grade class project on Africa. The class had discovered that diseases play a major role in the culture and customs of the peoples. I was asked to build epidemiological template models of several diseases for the students to use. The students wanted no part of that, so they, with help of myself and a graduate student, researched the literature and built models from scratch. One student even located one of the authors on the Internet and corresponded with him through email. The project was so successful that the 6th grade kids presented an 'epidemiology conference' to a group of epidemiologists from Duke University. Without a doubt, the kids clearly understood the mechanisms involved in the various diseases, and used the models to make some interesting observations about Africa's future.*

An 8th grade biology teacher wrote:

> *Our classrooms have undergone an amazing transformation. Not only are we covering more material than just the required curriculum, but we are covering it faster (we will be through with the year's curriculum this week and will have to add more material to our curriculum for the remaining 5 weeks) and the students are learning more useful material than ever before. Facts are now anchored to meaning through the dynamic relationships they have with each other. In our classroom students shift from being passive receptacles to being active learners. Our jobs have shifted from dispensers of information to producers of environments that allow students to learn as much as possible.*
>
> *We now see students come early to class (even early to school), stay after the bell rings, work through lunch and work at home voluntarily (with no assignment given). There are essentially no motivation or discipline problems in our classrooms.*

From Ellen Mandinach, Educational Testing Service, Princeton, NJ and Director of the Systems Thinking and Curriculum Innovation Project involving some eight schools in different parts of the country:

The teachers in the STACI Project perceive the systems thinking approach to be both an effective instructional strategy and a professional development opportunity. Many of the project teachers have altered completely the way they structure their classroom activities. Both students and teachers benefit from the systems approach. For teachers, it is the stimulus for changing the fundamental role of the teacher to facilitator, coach, and mentor rather than the purveyor of information and facts.

A facilitator after a summer training workshop for teachers:

Last summer we assembled middle and high school teachers who use system dynamics and STELLA in their classrooms. Again, we learned a phenomenal amount from them. Perhaps the most important message relates to the degree that middle school and high school teachers are at fundamental odds with one another. Innovative middle school people, seek to expose their students to 'real world' models, which demand involvement and choice, with the conscious desire to 'empower' kids to view themselves as active players in decision-making. High school teachers, sadly, seek to inculcate discipline-based knowledge. We need to rethink this system.

When we engage in modeling, we move beyond the traditional boundaries of disciplinary 'turf' and seek to develop common ground upon which to better communicate the workings of the real world, a world that too often refuses to respect the simple disciplinary borders of the academic specialist.

I have attended eight conferences of between 150 and 200 K-12 teachers involved in system dynamics. Widely divergent views were evident. Some teachers felt they would need to devote a full introductory term to teaching system dynamics and modeling before the ideas could be introduced into normal subjects. Others had already demonstrated that students could pick up what they needed on their own in a few days. Several teachers commented to me, "I never realized that the students could do so much."

In fact, the students, if given a chance, may be the leaders in an educational revolution. A computer science teacher describes their experience:

We have a group of experienced student modelers and a collection of student-developed models. Our next step is to get these models actually integrated into the curriculum of other courses.

Our biggest problem to date is getting our staff to integrate system dynamics into their curriculum.… Our biggest success to date is having our students reach out to the teachers by asking the teachers to be their mentors in the development of models that could then be used within the teachers' classes. Given the personal touch of a student-teacher mentorship we hope to generate the teachers' interest and through one-on-one meeting we hope to demystify modeling for the teachers.

5 STUDENT PROJECTS

In both middle school and high school, students can undertake projects with important real-world meaning. Here are projects selected from classroom activity and from various science fairs in system dynamics:

What will be the Effect of the One-Child Policy in China?
How Bad Will Portland's Traffic be in 2040
Solutions to the Epidemic of Childhood Obesity
Influenza's Effect on the Population
What Effect Does Raising the Minimum Wage Have on Business?
The Arms Race
Federal Reserve Interest Rate Policies
The Future of Cod Fishing
Fourth Graders Saving for College
Ecological Problems
Immaturity Among Teenagers and Education
Drinking and Blood Alcohol
Quality of Our School

6 FUNDING FOR EDUCATIONAL INNOVATION

Some people have expressed concern for how the transition to education based on system dynamics can be funded. Teachers must have released time to learn. Teachers should attend conferences that allow them to hear what is being done in other schools. Some schools will need to add computers and software. A school system will make the most rapid progress if a more experienced system dynamics modeler can be hired as a mentor to assist teachers. Schools have solved these funding demands in various ways.

Substantial work will be required with cooperative groups of teachers and system dynamics experts to develop teaching materials.

Government can sometimes be a source of funds, but that is often blocked by cautious bureaucracies. However, the National Science Foundation did provide more than three-quarters of a million dollars for teacher training in system dynamics in Oregon. In Massachusetts, a charter school is based on system dynamics.

Many schools are overlooking the strong appeal that a persuasive new approach to education can have with private individuals. Several million dollars have thus far been given by individuals to foster system dynamics in a number of schools. Private funding is often easier to arrange, and is more flexible than money from government or large foundations.

A great national concern drives the search for better K-12 education. But many of the interventions have been futile, or even have contributed to making matters worse. Very often, the misplaced efforts for improvement have put additional stress on doing more of what is already causing the decline in education--more authoritarian control, more accountability, more testing, more pressure. Such misplaced emphasis removes the excitement and enthusiasm from learning.

One business man who thought he might devote personal time and money to system dynamics in education became involved after visiting a junior high classroom on a Friday afternoon. He was convinced when the final bell of the day and final bell of the week rang and not a single student got up to leave.

7 MORE ON SYSTEM DYNAMICS

Study materials are available from the Creative Learning Exchange. Many accesses to the K-12 information come from corporations that use the material for internal training. Exactly the same material can be used anywhere from the 5th grade to chief executive officers; it is new to all.

Creative Learning Exchange
http://clexchange.org
Ms. Lees Stuntz, Director
27 Central Street
Acton MA 01720

tel: 978-635-9797
fax: 978-635-3737
email: stuntzln@clexchange.org
Look on web site or ask about the list of available materials to be downloaded and the “Road Maps” self-study Guide

Also:
sysdyn.clexchange.org
for the assignments and solutions for the Guided Study Program in System Dynamics

Internet discussion group:

Send a message to listserv@sysdyn.clexchange.org with the line "subscribe k-12sd first-name last-name" as the only thing in the message's body (no footer, no signature, etc.) The subject line is immaterial. "First-name" and "last-name" are your first and last names.

System Dynamics books:
Pegasus Communications, Inc.
One Moody Street
Waltham, MA 02453-5339
tel: 781-398-9700
fax: 781-894-7026

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