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How We Help Students Learn

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Abstract:
Three leaders in the field of using system dynamics in Kindergarten through 12th grades explain how young students can be taught the core principles and introduced to computer simulation. They will use many examples of classroom curriculum and relate personal experiences with students.

Key Words: education, pre-college, curriculum, elementary, middle, high, teachers

Introduction by Jay W. Forrester:
Pre-college education is under attack for poorly serving the needs of society. Unless a superior concept for improving education emerges, public displeasure is apt to result in still more of what is already not working. But now, a fundamentally new and more effective approach to education is emerging from advances in system dynamics. System dynamics offers a framework for giving cohesion, meaning, and motivation to education at all levels from kindergarten upward. A second important ingredient, “learner-centered learning,” imports to pre-college education the challenge and excitement of a research laboratory. Together, these two innovations harness the creativity, curiosity, and energy of young people. System dynamics allows reversing the traditional educational sequence in which deadening years of learning facts

have preceded use of those facts by introducing synthesis (putting it all together) at an early stage in a student's experience. Such synthesis can be based on facts that even elementary school students already have gleaned from life. Learner-centered learning reverses the process of a teacher lecturing facts to resistant students. Learners have the opportunity to explore, gather information, and create unity out of their educational experiences. A "teacher" in the new setting acts as a guide and participating learner, rather than as an authoritarian source of all wisdom. *

* excerpt from "System Dynamics and Learner-Centered-Learning in Kindergarten through 12th Grade Education" by Jay W. Forrester, December, 1992

The Early School Years: Ms. Jan Mons

Dr. Forrester gave us quite a task many years ago when he asked us to bring Systems Dynamics into K-12 education. He has explained the reason and any teacher who has worked with students using SD has seen the light in their eyes grow brighter. Recently a third grader, while working to create a model, said ,"This is fun!". Later we asked her to repeat the statement and she said, " This is fun," then she paused and said, " No, it isn't fun; it's exciting!"

I first became involved in Systems Dynamics in 1992 when a gentleman named Barry Richmond came to Glynn County Georgia to train a group of teachers, a core team. The Glynn County's Integration of Systems Thinking, GIST, project had begun. In 1994 I heard Dr. Forrester speak for the first time. He asked if any of us had used a model that day. His speech " Learning through System Dynamics as a preparation for the 21st Century" at the 1994 ST/DM conference in Concord, MA, convinced me that I wanted to spend the rest of my career helping to spread the use of Systems Dynamics in K-12 Education. This was why I became a teacher.

In the fall of 1994, GIST became a Water's Foundation Project and I became a full time mentor. The struggle began. How do you teach SD to middle school, 6th to 8th grade, students and how do you train teachers? Over the years we reversed the question to how do students learn SD? Actually, it became how does anyone learn this? How do we learn anything? What did we learn in order to appreciate Shakespeare? What did we learn in order to write a dissertation? What did we learn in order to understand Calculus? We had students and teachers using SD activities but there was something missing.

It is said that "Everything I needed to know I learned in Kindergarten". The problem was that we were not teaching the basic SD skills in Kindergarten. In Kindergarten we started our learning process with the 3 R's. Reading, Writing and 'Rithmatic. We learned letter sounds so that we could eventually read and appreciate the quality of Shakespeare's work. We learned how to form letters so eventually we could write a dissertation. We learned how to count blocks so eventually we could understand Calculus. What should we have learned in elementary school in order to help us participate in building and understanding a dynamic model?

In the spring of 1999, I faced my first group of Kindergartners to do an SD activity. It was then that my learning on how to help students learn SD began. It was the beginning of the creation of what we call the "4th R". In order for anyone to learn something new, they need to attach it to something they have already learned. In Education we use the word SCHEMA. Dr. Forrester talks about Mental Models. Our task has been twofold: to create a method to teach and promote SD tools use, and to create an atmosphere in the classroom that promotes sharing and independent thinking. To reap the full impact of Systems Dynamics in K-12 Education one must integrate the style of teaching with the use of the SD tools.

We now refer to the “4th R” as “Reflexive Thinking”. It started in the fall of 1999 when four elementary teachers, Mary Jo Davis, Rebecca Hill, Clelia Scott, and Eugenia Taylor, became interested not in the Dynamic Modeling but in the discussions and sharing that occurred during an activity. They knew what students should learn in elementary school and recognized that SD would help students achieve these objectives and become more responsible for their actions.

Our first efforts were connected to behavior. “Rules to Grow By” was created to help students gain a shared understanding of items such as “using time wisely” and “accepting responsibility”. We gave students “grades” in these areas but we found they did not really understand what it would take to “fill their TUB” and get a satisfactory. The activity “Sticks and Marbles” was used to help students track their positive and negative behaviors. While graphing the accumulation of STICKS (negative behaviors) and MARBLES (positive behaviors) over several weeks, the students discovered that on Wednesdays they accumulated more STICKS. In a class discussion they shared their ideas of why and were soon able to change their Wednesday pattern. The students and teachers were not using the formal vocabulary of SD at this time, but it gave them something to tie the formal vocabulary to when they began a formal study of SD.

With both the teachers and students interested in learning more, the question became “How do you teach the concepts and vocabulary of SD to second grade students?” The answer was you don’t. One aspect of elementary learning is using manipulatives and hands on learning. We allowed the students to experience the concepts and tools within regular classroom activities and then attached the vocabulary. When teaching a tool, we use activities such as the In and Out game developed by Carlisle Waters Project and Nancy Roberts, ”Picture Kit” to help make concepts as concrete as possible.

We have allowed students to explain a concept in their words, connecting it with their mental models, and we have given them the vocabulary word that they defined. An example of this occurred after the students drew Behavior Over Time Graphs of sharing in the story <u>Rainbow Fish</u>. We discussed how one character’s sharing led to the other’s sharing. I then drew a Causal Loop and labeled it Reinforcing. The teacher blanched when I put the word up, but I simply asked the students if they had ever heard the word before. One small hand went up and a student said it had something to do with the army. I paused, trying to make the connection, and asked him to explain how it was used in the army. He explained that it happened when an army brought more men in to fight. We then discussed the Reinforcing Loop involved when armies brought in reinforcements. The students had an understanding of the army term and we built on that knowledge to assist in their understanding of how to identify a Reinforcing Loop.

. The study of system dynamics became for all of us a way to help build better mental models by learning how to use the tools correctly. You must learn how to use a hammer before you can build a birdhouse. You must learn how to use SD tools and concepts before you can build Dynamic Models. I carry a toolbox with me for introductory SD lessons with K-5 students. A concrete item for an abstract concept. We discuss banging our thumb and bending some nails in the process of building. We talk about why people build model cars and I introduce SD as a way to build mental models so we can test them and make them better, but we have to share our thinking and work together. We can create a better model of the structure of the systems we study and how they change over time. This serves as an example for both students and teachers and sets the atmosphere in the classroom that we are all learners.

An aspect of elementary learning is drill and practice. One teacher designed a daily calender activity to practice recognizing Causal Loop Diagrams. Once a week she puts an if/then

statement on the board. Their task is to identify the pattern,
A-B-C-D or A-B-A-B of the statement and classify it as a cause/effect, A-B-C-D, or a causal loop, A-B-A-B. If it is a causal loop relationship, then they draw it and name it as balancing or reinforcing. The discussions generated by their sharing are rich with thinking and they often disagree with the teacher and offer valid reasons.

We continue to adjust our list of things students can do and understand at different age levels, but at this point we have had the following experiences:

Pre-K, Kindergarten, and First grade

Desired Results:

- Recognize that things change over time and everything is not right now.
- Recognize large and small growth
- Draw BOTG to show change
- Recognize that the slope of the line indicates the rate of change

Activities:

Moving Sand - Students pour sand into and out of a clear picture. The amount of sand is measured and a bar graph is created. As the activity progresses, students begin to predict what will happen with the next scoop and the bar graph becomes a line graph.

Car Racing - Students take turns letting a model car roll down a cardboard ramp. As the activity progresses, they begin to predict whether their car will roll down faster or slower than the last person's. They gain an understanding of the relationship between speed and the slope of the ramp.

Melting Ice Cube - The students observe the accumulation of water from a melting ice cube and graph the amount of water. They then were able to draw changes that would have occurred if the ice cube had been put outside or in the freezer.

Story BOTG - Even 5 year olds can participate in drawing a class BOTG. The stock in the beginning is usually happiness but the discussion on what changes happiness and the connections is still filled with good thinking.

Second and Third grade:

Desired Results:

At this level we begin a formal study of the tools and concepts. SD is used in a variety of regular classroom activities just as reading and writing are.

Students should be able to use the tools in a variety of activities and recognize concepts such as delays and leverage points in their regular studies.

We have used the following basis activities in our teaching of SD:

In and Out game, developed by the Carlisle MA. Water's Foundation Grant Project

"The Picture Kit", developed by Nancy Roberts

Graphing Daily Temperature, Bulletin Board Pieces, Walmart Stockroom, and Making Stone Soup which we developed.

The group of students with which we started working in the fall of 1999 as second graders are now in third grade. Their teachers have integrated SD use throughout their teaching. In second grade they did a unit on the study of habitat and interdependence. They graphed animal populations using S-curves, J-curves, and Oscillation and discussed what created each type. They have used pre-built two stock STELLA models and gained an understanding of CLD involved. This year they are working in groups studying the three ecosystems in our area. Their final presentations will include a CLD or Stock/Flow diagram of their ecosystem.

In a health unit they were studying infectious diseases. We adapted the epidemic game and all three classes played it and graphed the results, discussing different patterns. The gifted students from those classes then created a STELLA model of the game. Our plan was to create a simple two stock model because it was their first hands on modeling experience. Their knowledge base allowed them not only to tell the story, but to identify the pieces necessary to create a model. As they discussed different diseases they put the variables in that will enable all classes next year to use the model to examine the pattern for a variety of infectious diseases.

Fourth and Fifth grade:

By this time elementary students are applying the fundamental skills they learned in earlier grades to a more in depth study of all subjects. We use SD tools to assist in this study.

In science they use the Mammoth Game, Carlisle Water's Foundation Project, to study extinction. They then apply it to what is currently happening to the Manatees and discuss possible solutions to save this endangered species. The gifted students created a STELLA model to examine possibilities.

In their study of American History, we have used a series of activities using CLD and STELLA models originally developed for eighth grade to assist in this study. The activities have students to role play different views from the past and experience events rather than memorize them. They become involved in history and gain an understanding of why things happened and discuss what changes would have avoided wars and other tragedies from the past.

Sixth to Twelfth grade:

We continue to use activities in these grade levels but as students get older it is harder to break the traditional style of education. They have become "right" answer thinkers and because of the pressure of standardized test scores, the teachers are less willing to break from traditional styles of teaching. The walls of the box are stronger and it is harder to move to "out of the box" thinking.

As we enter our third year of elementary work, our desired result is to let the infection model on SD use work it's course. More teachers are asking questions about SD activities and willing to learn as they see the exciting things going on in other classes. The third graders we have been working with are moving on to fourth grade and new teachers. We hope to be able to answer questions such as:

Can students "force" teachers to adopt the use of SD and adapt their teaching methods to the student's style of learning?

Can this group of third graders, who have been immersed in SD use for two years, continue their growth as they change teachers and move up through the grades?

Only time will tell us the answers to those questions. We feel we are only beginning to discover what K-3 students can do with SD. We will continue to explore the possibilities in the future. We are only at the beginning of our story of growth and change and look forward to the next chapter.

Middle School Studies: Will Costello

I am a teacher. I am really not sure when or where it finally hit home for me. I had sensed it for years as a nagging "background noise." Sometimes a whisper and at other times a growing crescendo, notably when sitting and talking with students, or when correcting a set of final exams, or addressing parent concerns in conferences. It was a shadow of discomfort, subtle, creeping, and usually held at bay by the insane day-to-day demands of the teaching profession. It can be easy to dodge reality when your dealing with 150 students a day, parent phone calls, the incessant clamor of e-mails and announcements form the office, flu epidemics, head lice, transportation issues, weather, and maintenance of vascular caffeine levels. But invariably the notion would fretfully explode into the forefront of my mind: I was not doing my job! I was not teaching!

Certainly my students could get A's, hit the honor roll with unfailing precision, write well, solve equations, and get into the colleges of their choice. But they could not think! They could not approach a real-world system that had more than two components, uncover the dynamic interactions in that system, or propose policies to impact the situation. They were unable to either significantly increase their understanding or solve a real world problem. Why should they? They were not being taught…and I was their teacher.

I am here today because I was lucky enough to encounter this "discipline of thought" that the first speaker baptized as "System Dynamics." It has sent me searching to Boston, Quebec City, Bergen and Atlanta to see and meet many powerful thinkers. It connected me with the profound foresight and magnanimous grace of Jim and Faith Waters. It provided me the chance to learn from great thinkers in a positive, collegial atmosphere I had only hoped for once. It brought me, most recently, to Worcester, Massachusetts to stand in awe as my 11-17 year old students discussed their work with Jay Forrester, George Richardson, Rich Karash, Ginny Wiley, and many others. Above all, it has taken me to new levels of excitement and enthusiasm for teaching children. It has molded me a teacher of thinking.

This discipline of thought has forced me to become an ardent student of brain and learning research to understand what I was missing, what I was not doing. There is currently a wealth of "new knowledge" about how the brain works and how kids learn. The marriage of this research and the field of System Dynamics has brought me into an entirely new family. It has changed the nature of my work. Yes, schools have yet to change significantly, and the process of renewal will be lengthy and, at times, discouraging, but if we proceed with conviction and precision, our kids *will* be able to think. As for me, I really will be able to teach.

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. These 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).

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 (internal)

Systems thinkers operate to see the larger "chunks", the context, and have a systematic framework to "store" their understanding (deeper knowledge). Crucial research also demonstrates that the brain exhibits the capacity to process parts and wholes together (Cain and Cain, 1991). Systems thinkers do this: they simultaneously see the "forest" and the "trees", looking through complexity to see and understand the underlying system structure generating change (Senge, 1994). Even physiological research on rat brains supports the notion that a natural, complex environment results in the greatest brain functioning. Fascinating new research, conducted with nuns in convents, shows how lives led in enriching environments, complex in content, actually increases the mass of the brain, retards the process of aging and resists the development of Alzheimer's Disease.

Clearly if educational reform is to make substantive changes in the lives of children then this research must be incorporated into practice. The methodology and tools of System Dynamics are fundamental components of this change.

Like most K-12 teachers and administrators who have embraced System Dynamics and are attempting to instill it within their particular educational environments, I have a long story of self-discovery, false starts, frustrations with getting discipline-specific teachers engaged, successes with kids, continued discovery, and lots of hard work. The trajectories of all of these stories is similar and material for another time. I wish to focus here on current efforts underway at a middle school in my district where System Dynamics is becoming "part of the culture."

Williston Central School (WCS) has always been a "little bit on the edge" in our 5-school district. They formed mutli-aged teams 15 years ago, they structured team activities around a "kiva" concept over 10 years ago. WCS evolved the use of personalized learning plans, individual contracts for learning that are designed, monitored and evaluated with the children and their parents in 1990. They set a policy of student access to technology, including student internet access and student e-mail in 1991.

Not surprisingly, when the opportunity arose to learn about System Dynamics, systems thinking, and dynamic modeling, with the potential for improving student's lives, they "came around" first. That was in 1996. They have evolved though a typical progression beginning with individual teacher training, two teachers getting engaged and excited initially, trained by a mentor supported by the Waters Foundation. This led to episodic use of systems tools and lesson plans centered on a systems applications within a single team. That spread, by word of mouth (teachers and kids!), to a second team, and then a third…. Whole-team, multi-disciplinary applications later emerged as experience increased and benefits to students became evident. The principal became engaged and traveled to a Waters Foundation meeting. Use began to expand as the "infected" principal encouraged others to learn about systems. This remained the norm for several years, until 1999, when teachers pushed it to the next level. System Dynamics, and its tools, they believed, needed to be a fundamental component of all learning at WCS.

In 1999, we shifted the focus to the "WCS System Dynamics Project." Our experience with systems and kids, as systems thinking often does, led us to a number of better questions.:

What if we viewed SD/ST as essential as language and math?

Doesn't SD have its own, unique language?
Doesn't "system thinking" involve changing your perspective, your world-view?
Aren't traditional roles and rules of engagement now different?
Don't we expect to see new "habits of thinking" emerge?
Shouldn't it be a part of every area of content study where dynamics were observed to occur?
Aren't the tools, BOTG's, CLD's, stock-flow maps, and simulations useful and instructive in most curricular areas?

It was becoming clear that we needed to move away from episodic, lesson-by-lesson approach and begin looking at System Dynamics as a core curriculum structure that became the scaffold for the teaching of thinking in the school.

We established a training experience that re-focussed our work. We went about learning and re-learning the tools of systems study (BOTG's, CLD's, etc.) with the objective of establishing the use of these tools in every content area. We began a comprehensive study of the SD Methodology as described in Randers (1980) and Richardson and Pugh (1981). Applications and student guides were developed that assisted students in making this significant shift in ways they "attacked" problems. I, as the Waters Foundation mentor, worked with teachers in delivering information within this new framework.

Social studies groups began studying the impact of population change on a national and local level, monetary systems, the impact of rural development, the interplay between population and resources in a limited environment, and the national election process. Math classes studied the power of compounding, the nature of savings, linear and non-linear systems, probability, and complex problem solving. Science students examined the dynamics of liquid cooling, the growth of bacterial populations, the impact of alcohol on the body, nuclear decay, and cycles in nature. Literature groups did detailed analyses of the Dust Bowl and the dynamics of nuclear power accidents after reading award winning children’s books on these topics.

But we had yet to move fully beyond the "lesson" notion and into the use of systems as an underlying framework to thinking and learning. This year, WCS teachers, as a group, have taken the next step. Systems, they came to realize, really is a way of seeing the world, a perspective, a language, and a way of thinking about things, simple or complex. This implies going beyond mere pedagogic tinkering and delving into significant "cultural" change. After all, they reasoned, a culture is defined by it language, interactions, beliefs, and habits (customs). Systems thinking and dynamic modeling was obliging them to fundamentally rethink their school culture.

Now that the tools of systems had become familiar to kids and teacher fluency had improved, the teaching teams felt the need to also develop a formalized process to employ the tools in efforts to research, study, and propose solutions to problems and questions. A better question arose from our work to date:

Isn't the System Dynamics Method a comprehensive way to examine both simple and complex systems, and simultaneously teach kids how to think about them, examine leverage points, and craft policies to alter or reinforce the behavior of the system?

Timing is everything! The System Dynamics methodology, once previously studied, was now presented to them as a way of thinking, of planning, of researching, and of solving problems and answering questions. Teachers related quickly to it as a "scientific method" with broad application in many aspects of learning. Several noted it to be a preferable scientific method as iteration was a fundamental component of the method. The traditional "scientific method" as taught in schools is a linear process where some teachers *might* mention the notion of the process leading to "better questions" thus dictating further inquiry or research, but usually as an aside or afterthought. The SD method obliges the student to practice learning as an iterative process, where each step in the method intuitively feeds back upon the other steps in the process. Once I begin the Formulation stage, I will probably find information that causes me to rethink my initial Dynamic Hypothesis. Policy tests might reveal a weakness in my Formulation. Each step in the process and each time I cycle through it, I find a greater depth of understanding and a wealth of "better questions."

Work began in developing ways to use the methodology in global studies classes. Students were given a structured outline in class that took them through the steps in the process. The initial emphasis was on the process of focusing the question and problem articulation (Conceptualization). Students, indeed learners of any age, have a habit of addressing too large a problem, or they lack clarity regarding the purpose of the model. To get students to develop a habit of "standing back" and patiently exploring many of the facets of a dynamic problem before "jumping in" and rushing to the Formulation stage, requires a clear, structured approach, guiding students through several questioning cycles before beginning to focus on any aspect that might lead to further analysis and eventual model development. The student guide is purposeful in questioning students about their concepts, selected variables and articulated problem. Emphasis is placed upon the *understanding of the behavior of a single, critical variable over time*. Students are then instructed in ways to clearly describe their question or problem, including the time frame in which the situation will be explored. Supportive behavior over time graphs and causal relationships must be included. Students are provided a visual scaffold to link the key variable of interest to other, influential variables. Causal diagrams could emerge from this process. At first, these causal diagrams are often single-loop structures. Students, however, soon see the inclusion of the key variable in more than one loop and this naturally leads to multiple-loop diagrams. These diagrams form the basis for describing feedback and delay relationships that exist within the system. A written description of the BOTG and the causal diagrams must be included with the proposed question/problem. The feedback dynamics and the presence of significant delays must be indicated in the description.

Student teams then meet with the teacher to discuss if, when, and how to proceed to the Formulation stage. This results in very simple 2-3 stock models that address a very narrow aspect of the student's question, but leads the student to additional, better questions, as well as an increased understanding of the system under study. In some cases students do proceed with more complex model structures but in each case these are built upon simpler structures. A final written summary must detail the student's original mental model, the explorations that led to the problem articulation, and an analysis of what has been learned about the system, and what "better questions" are generated by the work. Student products are generally viewed by the entire class or, in cases of notable work, by the entire team in a Kiva session.

Concurrently, teachers realized the need to infuse the language and tools of SD throughout the curriculum in a more comprehensive and formalized way. The vehicle for accomplishing this is the "Current Events" curriculum. Teams generally spend 1-2 periods per week in Kiva exploring current topics of interest. Students use newspaper, magazine and online sources to select news stories and present them to the team. Listeners are responsible for writing synopses and adding their perspective and comments. A student guide is used to prompt students for specific information. Any news story must be examined in a systematic way. Students use BOTGs to describe the current behavior of the system under study. Also, efforts must be made to do research resulting in a BOTG of past behavior. Students are prompted to include their best approximation of the future behavior of the system. Time scale is arbitrary but must be defendable in terms of length and justified based upon their current thinking.

Other influences upon the variable in the BOTG are then explored (via group conversation) and listed. Possible causal diagrams are developed based upon these conversations. Feedback structures and dynamics are noted. Significant delays in the system are indicated and the impact of the delays is noted. In some cases stock-flow (level-rate) maps are developed. A final news summary is crafted using the BOTGs and CLDs as supportive material. A reflective piece, often from the perspective of “How does this system influence my life?” completes the activity.

This is our structure for addressing issues in the classroom, whether it be basic economics, environmental studies, the nature of revolutions, learning how epidemics spread, what population dynamics are impacting our local community, or the impact of missed assignments upon overall student performance. A logical, clear, iterative process for determining the components of a system, how they relate to each other, what the system produces in terms of behavior, and how the system could be impacted, modified, or altered by changes in structure or policy, gives students a framework for addressing a system and increasing their depth of understanding about that system.

The outcome of these initiatives is that a group of multi-age, middle school students are developing fluency with the language, tools, and methodology of System Dynamics. Students at WCS are "residents" of 1 of five multi-age "houses." Houses define the student's teachers and curriculum. We began this effort by engaging 2 teachers in one house in 1996. Currently 2 houses have begun the "culture" shift and it continues to be a challenge. The three other houses have begun the process or training and exploration. At Dynami**QUE*ST*** 2001 last May, WCS was represented by students from each of the five houses. BOTGs and CLDs now become part of almost every learning experience. Students initiate the inclusion of graphs and diagrams into many aspects of their day-to-day schooling. Students “see” and “point out” the behavior over time, causal loops and feedback/delay dynamics in their curricula. Dynamics that have always existed, but have been unobserved in the past!

This represents a beginning in a process of reform that will take many years to see fruition. To bring WCS to the point where systems education of all of its children is ingrained in the culture is still 5+ years away. Difficulties arise as teachers are inundated with new state and federal mandates around the notions of testing, standards, and accountability. As discussion rages in Washington and state legislatures, and proposals a floated or leaked to get public response, teachers struggle to "keep their eye on the ball." One teacher modeled the impact of mandates and now sees his classroom straining under the unintended consequence of spending 32% of the school year mired in assessments, testing, and evaluation, often redundant, whose results are little-read after the headlines are forgotten, and which results in less time for kids. In light of these demands, I cherish educators who can extend themselves, when confronted with the power of systems thinking, and undertake new learning which comes with a significant learning curve, but which, also, significantly enhances the thinking of their students.

Grades 9-12th: Ron Zaraza

Like the proceeding authors, the transition to my current work in System Dynamics was born out of a dissatisfaction with how I was teaching and what my students were leaning. However, I had no clear vision of where I was going and was most surprised when I got there. It was a place that I didn't even know existed when I started. In many respects, that is a good description of the evolution of the use of System Dynamics at the high school level (grades 9–12). Whether looking at the work of Al Powers at Carlisle High School, Frank Draper's efforts to develop models for use in high school, or the work done in the Pacific Northwest by the people who ultimately emerged as the National Science Foundation funded CC–STADUS/CC–SUSTAIN Projects, we initially see a very narrow vision of system dynamics. The work focused on the use of dynamic models built using STELLA to teach specific topics within content areas.

The files of the Creative Learning Exchange are full of those early efforts. Their use was characterized by episodic application of system dynamics, but no vision of system dynamics as a unifying tool, a unifying discipline. In the last ten years, this other, more powerful vision of System Dynamic's place in education, has gradually replaced the earlier one. This is probably most obvious in the Pacific Northwest, which boasts the largest concentration of secondary teachers who have received training in System Dynamics and the largest group of users of system dynamics at the secondary level.

The earliest users of system dynamics tools in Northwest developed simple models for use in physical science, physics, and mathematics classes. These models were designed to either teach topics that were beyond the reach of the mathematical techniques normally accessible to their students, or to teach topics already covered, but in a more visual way. Student response was mixed. The greatest success was achieved with students of average or lower ability, particularly those identified as "at risk". The models provided them with an alternate approach to the development of concepts. They could experiment. "Wrong" answers could be corrected once they identified why they were wrong. There was more emphasis on understanding than on correct or incorrect answers. The process of learning was lived out during class. The most able students, who were very comfortable with traditional mathematical approaches, were more resistant. They didn't "need" the other approach. The focus was using models, not system dynamics.

As was the case with other practitioners, these teachers gradually became aware that they were only seeing the tip of the iceberg. Through reading and model building, they began to see the broader implications of system dynamics. In the case of the teachers doing this work in the Portland, Oregon area, this awareness ultimately culminated in the CC–STADUS and CC–SUSTAIN projects. These projects were officially intended to provide basic training in modeling for teachers while assisting them in the development of models for use in cross–curricular work and in their content areas. The real goal, as Diana Fisher often put it, was "to have someone else to play with", to have other people thinking "out of the box". The training they received gradually evolved to emphasize the unifying nature of System Dynamics, the power of system dynamics to enable teachers and students to see common patterns and behaviors across disciplinary lines.

The evolution of the training provided to teachers coincided with a shift in the use of System Dynamics by students. About the same students began to see computer models used in a few classes, the first modeling classes began to be offered. Over the next three years, the focus of the modeling classes shifted. Initially, they began by looking at causal loops, then converting these loop diagrams to stock–flow models. Success with this approach was very limited. Next, the approach abandoned causal loops and took on the nature of a traditional programming class. Finally, the classes developed into a form they still adhere to: learning the basics of computer model construction as a vehicle for developing the broader concepts and perspective of System Dynamics. Five years ago (five years after the first modeling classes) the first class was offered in which the use of system dynamics concepts and tools was at the core of content coverage. In this course, students used models, behavior over time graphs, feedback and causality discussions to learn concepts in a multidisciplinary course.

Today, episodic use of simple models for content teaching, use of models to explore more complex relationships, and instruction in model building, are taking place in secondary classes in the Portland area. By far the most common use of System Dynamics remains episodic use in individual courses. The type of use, however, has shifted from the practices of ten years ago. Mathematics use is an excellent place to see the difference. Initially, the STELLA models used reflected the mathematics nomenclature and labeling. The primary emphasis was exposing students to alternative approaches to understanding and exploring the patterns of growth that various mathematical functions generate. Connections with real world problems were often not explicitly made. Now, however, the STELLA models are use to explore linear, exponential, quadratic, periodic, and logistic functions in real–world applications. Algebra students use pharmacokinetic models to explore drug uptake and elimination as they learn about exponential functions. Calculus students use logistic models to deal with population problems. Predator–prey models are used to explore periodic functions and phase relationships. The output of simple models is used to help students develop the concept of slope, and to help them learn how to describe patterns of change represented by graphs. In short, students use systems tools and concepts to make a connection between behavior or patterns and problems outside of traditional mathematics.

This emphasis on behavior patterns and connections between disciplines, rather than the bare-bones content, is now fairly common where system dynamics is used in regular classes. In social science, chemistry, physics, biology, health, literature, and even theology classes, students explore content problems while at the same time identifying basic patterns of growth and the structures that produce them. Students develop a clearer understanding of the commonality of these patterns in multiple disciplines, especially where System Dynamics has more than one or two adherents in a school. The same pharmacokinetic models used in algebra are also explored in health classes and in biology classes, while exponential growth and decay are seen in biological populations as well as discussions of the problems facing third-world nations.

What may be most important about this use of system dynamics are the questions that arise. The very simple models used, whether built by students or simply run by students, often give obviously flawed results. For example, population models often predict huge populations in third–world countries. There is no way these populations could be realized – the system would collapse. Characteristically some students recognize the problem and bring it up. The student driven discussion develops a much clearer picture of the system and the various feedback loops, delays, and linkages, than would normally be presented. Depending on the teacher's mastery of modeling (or, in many cases, student interest in learning how to use the model) the model may be modified to reflect and experiment with the students' suggestions of a more realistic scenario. This extension of the "simple but wrong" answer through student action develops a pattern of probing answers in and out of class. The awareness that problems, systems, and answers are never as simple as they seem is a powerful gain that has much broader implications then the systems skills students acquire. Students learn to ask better questions and to look for linkages that complicate problems and solutions. They tend to bring these ideas to classes where SD is not used. In fact, they are sometimes “recruiters” for systems training programs.

In some respects, this approach to using system dynamics may be a “snap shot” of the far future. The system dynamics tools and concepts will be more a “tool kit” or language that students use to problem solve, rather than specific discipline taught in isolation. However, this will only be true when the use is far more widespread in a school. Until then, courses explicitly dedicated to teaching system dynamics modeling remain a key element in the growth of system dynamics at the secondary level. Next year, at least seven high schools in Oregon and Southwest Washington will offer dynamic modeling courses, all using STELLA. At least two of these schools offer a second–year course, and two offer an independent study third–year course. Most schools offer these classes to students in grades 9-12, although a few restrict the course to juniors and seniors. These courses have changed dramatically, particularly in the last three years. Assistance and recommendations from some of the professional System Dynamists, particularly Jay Forrester, George Richardson, Barry Richmond, and Andy Ford, have resulted in shifts in content. These courses, while still very much modeling courses, spend more time on broad general system dynamics concepts than before. All work keeps at the forefront the idea that the course is not a programming course, but a course in understanding and explaining systems with dynamic modeling as the primary tool used. This means a conceptual focus dominates rather than a mechanical proficiency in modeling. The courses have been influenced by both Road Maps series and the MIT Guided Study Program. The second year courses, in particular, address several topics presented in those programs. At all levels, students spend more time than a few years ago looking at existing models, such as the basic models George Richardson presented at the 2000 Skamania Conference. By both building models and exercising pre-built models, students learn more about good modeling and good analysis of problems.

The students in these modeling classes are expected, each year, to develop a significant project in which they model a problem that interests them. These range from analyzing population policy or zoning problems to literature models. What they have in common is creative, original work that seems well beyond what would usually be asked of 16-18 year olds. The students in these classes are often not the “honors” students in their school. Some of the best students and most interesting work has been done by students who do not do well in traditional classes.

The newest work in system dynamics at the secondary level has been the development of cross-curricular content courses in which SD tools form the framework of all problem analysis. The first of these courses was offered five years ago at Wilson High School in Portland. Developed by a social studies teacher, Megs Patton, and a science teacher, Scott Guthrie, with assistance from John Heinbokel and Jeff Potash of Trinity College in Vermont, the Science, Technology, Society/World Issues course looks at important changes in culture and civilization and their connections to other developments and changes. The course has continued to evolve, changing focus a bit each year. Current topics include population characteristics, urbanization, disease dynamics, agriculture, natural resource utilization, World Dynamics, energy development/standard of living, revolution, and the national drug policy. In each of these areas, the students examine what is understood about the problem and work toward identifying effective policies that were, could have, or could be applied to the problem. While students learn basic modeling skills, the focus is more on modifying and exercising existing models or using existing models to explore problems. Modeling is the tool, not the focus. This opens high level application of system dynamics concepts to students who do not want to become modelers. This is consistent with the long term view accepted by most involved in 9-12 system dynamics work that the large scale understanding and use of models is more important that the building of models. Being able to understand and interpret the results of models, while recognizing the assumptions and limitations of models, is probably the major educational goal we are working toward.

This approach is also reflected in the newest course developed at Wilson, giving it a four-year systems based program. The Environmental Science/Ecology Using Systems course also emphasizes use and modification of models. It combined a fairly traditional Advanced Placement style Environmental Science course with the recently published "Modeling the Environment" (Andy Ford). Students use models to develop deeper understanding of systems that ecologists have described and studied for years using other methodologies. They have the option of doing original field work and modeling.

These last two courses may represent the first "mature" use of SD at the secondary level. A sufficient collection of models exist or can be easily built to take traditional topics and explore them from a systems perspective. This systems perspective, inherently interdisciplinary, fits well into social science and environmental science, both also naturally interdisciplinary. The courses focus on understanding systems and how policies affect them. They reflect how we hope the students will us system as they become the decision makers of the future.

This use of system dynamics was pushed still further this past March. Activities like Model United Nations and Harvard Model Congress have been in the high schools for years. Students in these role–playing activities function as ambassadors, legislators, cabinet officials, and others involved in making important decisions in the real world. By simulating their roles, students learn about both the roles and the problems inherent in high level decision making.

Twenty–three students from three Portland area high schools, under the direction of five teachers, served as the local Crisis Management Team for a simulated natural disaster in the greater Portland Metropolitan area. For thirty consecutive hours, they combined internet research, building, and running dynamic models as they tried to cope with an outbreak of smallpox. Systems tools, including, but not limited to models, were used to define and explore the problems, model potential outcomes, plan and test policies. They used models to a degree that an actual management team would not have been able to, because they lacked the background and capacity. The students applied their systems skills to a situation new to them, and succeeded to a degree that was quite unexpected. Projected deaths were between 40 and 250, compared to a potential 600,000 if no actions had been taken. The students used what they had learned about systems to deal with a complex problem where any action had to be carefully weighed, where each decision triggered multiple results. In some cases, for example, the use of quarantines, they discovered that the sources they used gve wrong recommendations in the light of their particular problem. In short, they worked through a difficult problem using system dynamics as their guide. May they and others continue to do so.