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THE FUTURE OF SYSTEM DYNAMICS AND LEARNER-CENTERED LEARNING IN K-12 EDUCATION

A Report from the Planning Meeting in Essex, Massachusetts, June 23 - July 1, 2001

Prepared by Debra Lyneis and Presented at The International System Dynamics Society Conference, Palermo, Italy, July 2002, by Lees Stuntz and George Richardson

Today's schools were designed to meet the needs of a dawning industrial society in America. They prepared students to be productive workers in the factory system, and the schools themselves were fashioned on the principles of mass production, ideas that were sweeping change across the country. In these schools, an efficient assembly line process aimed to educate graduates of consistent uniform quality. Teachers, who were also cogs in this process, could dispense to their students all that they needed to know at each grade along the way. It was a system suited to the needs of the time.

Now times have changed. We live in a rapidly changing global economy where information and its accessibility are burgeoning and communication is instant. No longer can we fill students up with all that they need to know and send them off to predictable jobs. Now students need a much broader set of skills to thrive in today's volatile economy. Even more important, they also need deeper understanding, courage and compassion to effectively deal with the increasingly complex social, political, economic and environmental problems facing all of us. It is time for us to notice the winds of change and design our schools to meet today's needs. Our children's futures will not wait.

INTRODUCTION

In June 2001, a group of educators and system dynamicists met in Essex, Massachusetts to envision the future of system dynamics in kindergarten through twelfth grade (K-12) education in the United States. System dynamics is a disciplined way for students to understand the causes of change in the ubiquitous systems that surround us. For example, students explore how things work in systems as diverse as:

- The growth of a population of people, or bacteria, or fish
- The development of character and plot in literature
- The escalation of a conflict between individuals, groups, or nations
- The rise and fall of a revolution
- The spread of a disease or rumor
- The accumulation of money in the bank
- The building of their own self-confidence

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MURDOCH MIDDLE SCHOOL, Part II

By Dan Barcan

A year after the teachers at the Chelmsford Public Charter School (CPCS—now called Murdoch Middle School) first met Steve Petersen in the hectic days leading up to the school's opening, five of them once again sat before him in a Stella training class. They had signed up for a five-day version of the basic training of which they had seen parts the year before. This time, CPCS was paying for their training—Petersen had come to them, at the school, for free, the last time—in a lecture hall at the University of New Hampshire with a mix of teachers, professors, and managers from various industries among the students.

Again, Petersen poured water from cup to cup. Again, the students built tiny models and unleashed the dynamite on their mistakes. Again, there were varying levels of comprehension and frustration. But this time, there was no book ordering—the school and its office manager, who now handled such things, were miles away. No seventh-graders came through the lecture hall to meet the teachers. The teachers took notes, sketched stock-and-flow diagrams, and generally began to put together what they had learned, in bits and pieces, over the last year.

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UPDATES…

De La Salle North Catholic High School

From Tim Joy in Portland, Oregon, wearing his second hat as vice-principal of the newly formed De La Salle North Catholic High School

De La Salle North Catholic, a new work in the 300-year tradition of the Christian Brothers, is in its second year of operation under the revolutionary education model pioneered by Cristo Rey Jesuit High School in Chicago. At De La Salle, all students work one day a week in an entry-level position for a Portland area corporation; in addition to gaining valuable life skills, students also earn two-thirds of their own tuition, giving themselves access to a Catholic college preparatory education.

All incoming students take a class called *Connections*, a semester course that introduces students to systems thinking. In this course, students work on a series of systems problems that include gaming simulations such as Fishbanks, physical models, behavior-over-time graphs, stock and flow diagrams and computer models. Students in Integrated Science, another Ninth Grade course, receive some systems instruction in chemical concentrations.

Catalina Foothills School District

From the Waters Grant Project in the Catalina Foothills School District, Joan Yates writes in answer to the question, "What are you excited about?"

One thing I'm excited about is the scope of the systems work in the district. Because we've been putting our documentation matrix together for a Waters Foundation report this month, I've seen "latest numbers" and know that from Jan 02-May 03 there are 99 lessons with explicit systems concepts and tools being used to help students in our seven schools learn district-designated curriculum.

The middle and high school mentors and teachers are very excited about the questioning and thinking students have been doing as they work with classmates on the Fishbanks, OPEC, and stock market networked simulations. The students have been questioning their own strategies as they've worked through the simulations. This questioning, in turn, has lead to questions regarding the operations of these systems in the world. No better way to learn than to question.

We're also excited about the initiative that district teachers are taking in bringing systems applications into their classrooms. More teachers than ever before are working with each other, independent of systems mentors, to create systems applications for use in their classrooms. The teachers are the classroom experts and so any time they can supplement their classroom and curriculum expertise with systems concepts and tools, we think the students have an incredibly rich thinking and learning experience.

EDITORIAL

As the days now begin to lengthen, we in the Northeast are buried under more than a foot of snow (*great* for snow-shoeing!) and the heart of the school year is in process. At the CLE, we are looking at this year to renew our focus and to concentrate on the future of system dynamics in K-12 education. Since our next conference is more than a year away (see page 4), we have the luxury of some extra time for organizational fine tuning.

The Essex report, the first half of which is presented in this newsletter, is a product of the discussion held in the summer of 2001. That discussion and what we do about it needs to be an on-going concern to all of us who are interested in revitalizing education with learner-centered learning and system dynamics. Any thoughts or input about what we need to do for the next steps would be greatly appreciated. Perhaps the best forum for that would be on the K-12 listserve (k-12sd@sysdyn.mit.edu.) I look forward to hearing from you.

Lees (stuntzln@clexchange.org)

When a Butterfly Sneezes…

The second volume of the Butterfly Sneezes book* is being published on the web, a chapter at a time. It is being sponsored by the Water's Foundation, and the first 3 chapters are up.... available on the web at watersfoundation.org. I'm hoping to get feedback from folks on the story summaries, and then, after 10 or 12 are written, compile them all in the next volume. This round has both picture and chapter books.

Linda Booth Sweeney, Harvard Graduate School of Education; e-mail: *Linda_Booth_Sweeney@harvard.edu* tel: 617-354-1390 fax: 617-812-8935

*The first volume is available from Pegasus at pegasuscom.com.

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- The increase in civility in their classroom
- The acceleration of a projectile in a science experiment.

In the process of exploring these systems, students learn to recognize similarities in patterns of change across disciplines and the common interdependent feedback structures that drive them. At its core, system dynamics is a computer simulation methodology, but in practice in schools it creates a template, a mental framework for weaving disparate disciplines into a whole cloth. It also hones a worldview that values inquisitiveness, creative problem solving, cooperation, clear communication, and a deep appreciation of each individual's responsibility as part of a larger system.

At the Essex meeting, our purpose was to appraise our experience thus far and build on it to articulate a clear vision of what an education based on the principles of system dynamics could provide to students and their communities. We developed a strategy to realize the vision and a 25-year plan to implement that strategy.

Classroom Experience

Several developments gave rise to the need for a unified vision and plan for system dynamics in education. The most important has been the dramatic success teachers have already experienced in classrooms with the systems approach. For more than a decade, we and many other teachers across the country have created lessons using system dynamics to enhance our curricula in the humanities as well as the sciences and mathematics – for students in all grade and ability levels. Early results have been exciting! We have found that the systems approach makes education more learner-centered, engaging and relevant for students – and teachers. Students ask better questions leading to a much deeper understanding of the curriculum material; often they are able to transfer that understanding from one application to another. They sharpen their problem-solving skills and eagerly take charge of their learning.

The benefits of the system dynamics approach extend beyond an enriched curriculum, however. As students take charge of their learning, the structure of the education experience changes. The teacher shifts from being the sole dispenser of all knowledge to being a guide, helping students develop the skills to construct their own knowledge. In a learner-centered classroom, teachers and students, together, pursue an idea, a skill, an understanding. The teacher leads as skills need refining, while the students lead as investigation and exploration go forward. As lessons naturally become more interdisciplinary, this fundamental change in the delivery of instruction permeates the structure of the school itself, revitalizing it. Learning together becomes the enterprise for everyone.

An added benefit of the system dynamics approach is broader still. The study of system dynamics equips students with the skills, perspective, courage and responsibility to deal effectively with the dynamically complex social, economic, and environmental problems facing them. It gives them the tools and common language to surface and openly discuss their mental models of complex thorny issues; it gives them a means to test possible alternative policies leading to informed decision-making. As students understand how systems work, they expand their own boundaries of time and space, gaining a keener awareness of the effect of their own actions and personal interactions within the systems surrounding them. They learn about interdependence, long- and short-term solutions, and that what they do makes a difference. In short, system dynamics educates good citizens.

Other Developments

In addition to promising experience with students, other influences spurred the effort to create a 25-year plan. First was Jay Forrester's role in the early development of the digital computer more than 50 years ago. Forrester, a participant in the Essex session, founded the field of system dynamics in the 1950's based on his earlier pioneering work in servomechanisms and missile guidance systems. In 1948, while Forrester was the director of MIT's Whirlwind computer project, the US military was considering the possibility of developing the first fast, reliable, multi-purpose computer. Forrester and his team proposed a detailed 20-year plan for the research, development and production of the digital computer, which was ultimately implemented with success. Reforming the education system and developing the computer are not quite the same, but the necessity of a clear plausible plan is evident to reach a goal. Seizing an opportunity can make the future happen.

Two previous education reform initiatives also informed the Essex process. In the 1950's, in response to Sputnik, the American science curriculum was completely overhauled. Teams of teachers and scientists worked together over several years to produce a more experiment-based curriculum. In the 1960's, teams of teachers and mathematicians also revamped the American mathematics curriculum. In Essex, we discussed these initiatives and recognized a need to learn from their experience.

Finally, impetus to get together and draw up a plan came from our growing sense of having reached a critical mass. Enough early evidence had indicated that system dynamics has the potential to fundamentally improve K-12 education at a time when the public is clamoring for better results from their schools. Teachers who have had success with the systems approach are eager to move forward and share its many benefits with other teachers and their students. Much of the early progress has been fostered with the generous support of the Waters Foundation, which has nur-

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GORDON STANLEY BROWN FUND

To support preparation for distribution of materials for using system dynamics in K-12 education

The Gordon Stanley Brown Fund has been established to promote system dynamics and an understanding of dynamic behavior in feedback systems in kindergarten through 12th grade schools. The Fund will focus on making teaching experiences available to others. Small and medium sized proposals are encouraged.

The Gordon Brown Fund can support teachers for:

- Released time or summer time used to put into transmittable and usable form materials and methods that have already been used in schools and that could be of help to others,
- Communicating experiences that did not meet expectations so that others can be forewarned.

Work supported by the Fund is to be available for distribution through the Creative Learning Exchange and any other channels that the author arranges.

The Fund honors Gordon Brown, who pioneered the theory and practice of feedback dynamics and engineering control systems at MIT in the 1940's. Brown went on to be head of the Electrical Engineering Department and Dean of Engineering at MIT. During retirement, he devoted energy and skillful leadership to bringing system dynamics into the Catalina Foothills school system in Tucson, Arizona.

Address applications, with an outline of the proposed project, to:
Lees N. Stuntz, Creative Learning Exchange, 1 Keefe Road, Acton, MA 01720

2004 Systems Thinking and Dynamic Modeling Conference
June 30 - July 2, 2004
Dolce Skamania Lodge
Stevenson, WA

Next year we return to Skamania Lodge in the beautiful Pacific Northwest, site of the 2000 conference. Make plans now for the sixth conference on systems thinking and dynamic modeling in K-12 education.

Please consider ideas for presentations or sessions you would like to see included, and share them with us. More information will be available in future newsletters and on the web site at clexchange.org.

Meanwhile, mark your calendars to save these dates for a stimulating conference amidst the waterfalls and rocks of the magnificent Columbia River Gorge. Those of us who attended in 2000 are excited to think of returning.

ICSD to be held July 20-24 in New York City

The 21st International Conference of the System Dynamics Society will be held July 20-24, 2003, in New York City.

Works may be submitted from January 2, 2003, to March 23, 2003. Materials should be submitted on line through the Society website www.systemdynamics.org or they may be emailed to ISDC@albany.edu.

For more information, please contact Roberta L. Spencer, Conference Manager
System Dynamics Society
Milne 300 - Rockefeller College
University at Albany, State University of New York, Albany, New York 12222 USA
system.dynamics@albany.edu

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tured system dynamics and organizational learning in dozens of schools across the country for more than a decade. Jim and Faith Waters have ably demonstrated that outside support can effect change in schools. Now the time has come to enlist the participation of many other reform-minded citizens to bring the benefits of systems education to many more students.

THE VISION

The Student

What are the skills, attitudes and behaviors that a citizen with a system dynamics education will possess?

- **Systems Thinking Skills**[1] **–** learned in the context of the current curriculum.
  - o Dynamic Thinking – seeing patterns of change over time rather than focusing only on isolated events.
  - o System as Cause Thinking – recognizing that problems, and their solutions, are endogenous: they arise within a system, not from outside.
  - o 10K Meters Thinking – being able to step back and see the big picture.
  - o Operational Thinking – understanding how the structure of a system causes its behavior, and that the same basic structures apply to all systems. Understanding stocks and flows.
  - o Closed-Loop Thinking – recognizing feedback: any action has consequences that can influence that action again.
  - o Non-Linear Thinking – knowing that feedback loops interact to produce changing responses over time.
  - o Quantitative Thinking – being able to consider and include all variables, even those that cannot be measured in standard units.
  - o Scientific Thinking – recognizing that all models are working hypotheses to be rigorously built, tested and refined.

- **Systems Thinking Attitudes and Behaviors –** developed in the process of learning and practicing the principles of system dynamics within the curriculum.
  - o The ability to work together to solve real world problems.
  - o The willingness to examine and change one's own assumptions and conclusions. Meta-cognition.
  - o Openness to the mental models of others. A tolerance for productive disagreement.
  - o Patience and persistence in problem solving. Using systems thinking skills to dig deeper and keep learning.
  - o The willingness to be wrong and learn from mistakes. An ability to take considered risks.
  - o An acceptance that often there is no one right answer.
  - o An expanded sense of self. Seeing oneself as an integral part of a larger system with a shared responsibility for the common good.
  - o Empowerment. Using an understanding of a system to act upon its problems with courage, confidence and hope.
  - o An extended time horizon. A suspicion of the short-term easy solution based on an understanding that short-term policies are detrimental in the long run, and vice versa.
  - o An ability to relate the past to the present and the present to the future. An ability to read across the present and recognize patterns.
  - o An internalization of all these principles that informs actions and interactions with others.

The School

What will the school look like? A school built around the principles of system dynamics and learner-centered learning will have the following characteristics:

- Lessons will be designed allowing students to construct their own knowledge and understanding with the teacher as a guide and coach. Instruction will be learner-centered, focused on active learning for students and teachers.
- System dynamics will be infused into the curriculum. It will not be an added course; nor will it supplant all current instruction. Instead, it will provide the tools and framework to integrate and energize the current curriculum.
- Problems will come first. Instead of presenting students with a problem only after they have learned everything necessary to solve it, students will face the problem first and seek to learn what they need to solve it – as in real life.
- Teachers will have 30% of their time (without conflicting assignments) available for learning, collaboration, and lesson refinement.
- Classrooms will be openly accessible to parents, other teachers and students.
- Students will work on interdisciplinary projects with real world relevance to their own lives, issues in their communities, or larger current events.
- At all grade levels, disciplinary boundaries will be softened.
- Students will work on projects in multi-age groups, learning from one another.
- Students will be involved in their communities, contributing to the solution of problems. Community members will be involved in their schools.
- Students will have access to system dynamics and subject experts.

[1] Richmond, Barry, "The 'Thinking' in Systems Thinking: How Can We Make It Easier to Master?" *The Systems Thinker*, Vol. 8, No.2, Pegasus Communications, March 1997

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- The governance of the school will be shared.
- The administration will facilitate collaboration, risk-taking, open communication and continuous improvement – it will be a learning organization.

What System Dynamics in Education is NOT

System dynamics is not taught for its own sake as a separate class, like Algebra I, for example. Instead it is seamlessly woven into the fabric of a school's curriculum and structure. An analogy might be the introduction of information technology in schools. "Computers" is not a separate subject. While schools might offer some specific instruction on how to use/program computers, computers are primarily a tool employed throughout the school in service of its curriculum and management.

System dynamics uses those computers, and other supporting pedagogic tools, to unify the current curriculum by teaching students about the universal system structures that underlie all disciplines. It can provide the framework for all social studies, science, and math instruction because these subjects examine patterns of change over time and focus on problem solving. Students will not be sequestered at computers; they will be using simple pencil and paper activities, and eventually computer models, to shape, refine and communicate their mental models in a more disciplined way than they do now. Students will still learn to read, study foreign languages, participate in the arts, and enjoy other endeavors that are not primarily based on system dynamics (although there are some applications in these disciplines). In all areas, however, teaching will use the broader systems approach, which is learner-centered, inquiry based, and collaborative.

Teaching system dynamics to students is like teaching them to read. It is a process that takes time and many different approaches through the grades, but it is a gift that opens their minds to new worlds of ideas. Reading is a tool that students employ throughout their lives, one that they could not imagine going without. Just as today's citizens need reading and computer literacy, so do they also need the skills and confidence to address today's constantly changing dynamically complex social, economic and environmental issues. They will need a systemic perspective and a disciplined way to meet these challenges. They will need to be life-long learners who can work together.

AN OPERATIONAL VISION

The vision of the ideal school and the student it educates has been presented in the form of lists, the customary approach. However, lists do not illuminate how the system actually works. In reality, the systems thinking skills are not discrete – they are fluidly interdependent, continuously reinforcing one another. The systems thinking attitudes and behaviors are also not isolated. As students develop the skills and use them in a wide range of curriculum applications, they begin to internalize the attitudes and act upon them. In that way, system dynamics not only changes what students learn, but it also teaches them to think and act systemically.

An informal stock/flow map, used as a talking tool, begins to shape an operational vision. (Start near the bottom at "1" by the flow "Developing Systems Thinking Skills" on the left and the corresponding flow "Developing Systems Acting Skills" on the right.) As students develop systems thinking skills through system dynamics lessons, practice and other classroom interventions, they accumulate a stock of systems thinking skills. These skills are dynamic thinking, closed-loop thinking, endogenous thinking, scientific thinking and the others previously listed and defined.

As they gain systems thinking skills, students are also developing Systems Acting Skills (on the right). These include communicating and listening skills, the ability to work together, patience and persistence in problem-solving, tolerance for differences in opinion, learning from mistakes and others previously listed. Building systems thinking skills and building systems acting skills are mutually reinforcing (as shown by the connecting arrows across the bottom of the map.) For example, as students practice system dynamics in the curriculum, they also learn to work together to solve problems, thus further enhancing their systems thinking development. As they examine and refine their own mental models, they become more open to those of others and more tolerant of productive disagreement, which in turn helps them further refine their own ideas, and so on. Thinking and acting, growing and learning, are inextricably bound.

As students develop systems thinking and acting skills, they simultaneously develop Systems Citizen Attributes by internalizing the ideas that they have learned. (See "2" on the map.) These are the attributes listed earlier as Systems Thinking Attitudes and Behaviors. Students know, for example, that often there is not one right answer, that actions have unintended consequences, and that short-term solutions often exacerbate problems in the long run and vice versa.

Understanding these concepts is not enough, however. As students build stocks of systems thinking and acting skills, they begin to *use* them. (See "3" on the map.) They think and act systemically in ways that reach far beyond the curriculum activities in the classroom. Their knowledge informs their actions and in so doing further develops their systems citizenship.

As students act on their systems knowledge, they also begin to relinquish Resistant Attitudes. (See "4.") An edu-

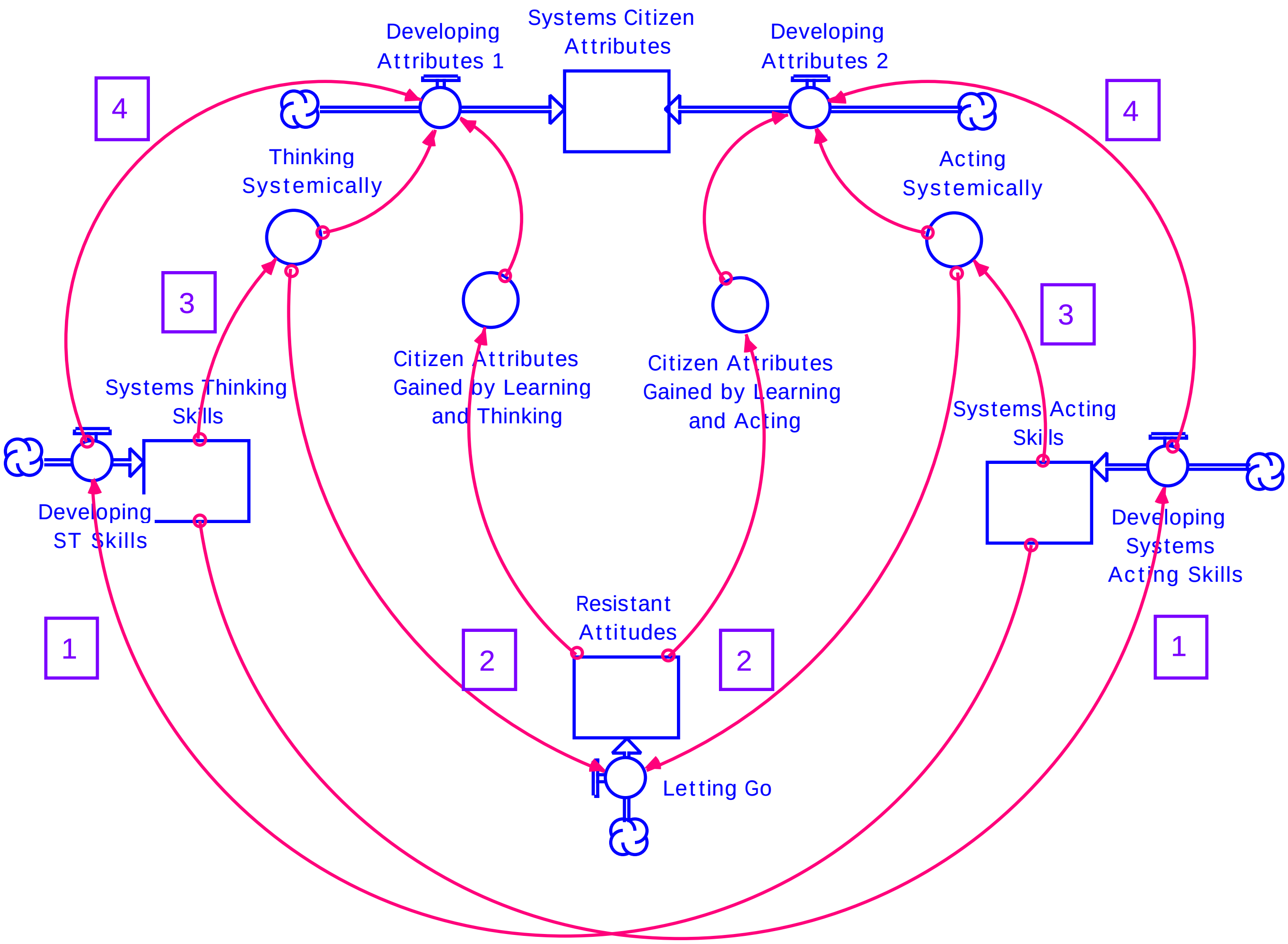

Figure 1. A Conceptual Map of a Systems Citizen

cation based on systems thinking and acting is a departure from the current paradigm. Students (and schools) who cling to more traditional views and approaches may have more difficulty internalizing systems thinking and acting skills. At the same time, however, the more they learn and experience success with systems education, the easier it will be to relinquish resistant attitudes and develop the broader systems citizen attributes.

Systems citizens see themselves as an integral part of a larger whole with a shared responsibility for the common good. They have the skill, understanding, courage, empathy, hope and commitment to get involved and tackle big problems together. They have an expanded time horizon and sense of self. These represent the highest, most cherished goals of system dynamics in education. They reside at the core of our efforts.

The informal stock/flow map suggests how K-12 system dynamics can teach students to think and act systemically, to become good citizens. It also suggests intervention points. Teachers can design lessons to augment any of the flows, thereby building the stocks of skills and attributes (or depleting resistance) over time. The stock/flow map proposes how things work and how to proceed toward a goal.

End of part 1. *The second half of the Essex report will be published in our next newsletter later this winter. It is available free of charge in its entirety, including appendixes, from the CLE website, catalogued under Implementation as IM2001-07FutureOfSDEssex.*

Participants at the meeting in Essex were: Dan Barcan, William Costello, Diana Fisher, Jay Forrester, Scott Guthrie, John Heinbokel, Debra Lyneis, Jim Lyneis, Jan Mons, Jeff Potash, Rob Quaden, George Richardson, Barry Richmond, Lees Stuntz, Alan Ticotsky, Larry Weathers, and Ron Zaraza. They were assisted by Peter Bloniarz, Davida Fox-Melanson, Gary Hirsch, Tim Joy, David Packer, Pat Quinn, Eileen Riley, Khalid Saeed, Peter Senge, Stephen Stuntz, Ginny Wiley, Sherry Immediato and members of the SoL community.

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MURDOCH MIDDLE SCHOOL, Part II continued from page 1

Ruthann Graham (Ruthann Corbett at the time), a seventh- and eighth-grade math teacher, worked with a math teacher from a different school to build some models students could use in class. A pair of humanities teachers worked with a UNH philosophy professor to build a model showing the dynamics of the social movements behind Martin Luther King, Jr. and Malcolm X. The group wrapped up the week agreeing that they had made progress, that it was professional development money well spent, and that their new understandings would certainly improve their classes. But none of the models developed by the teachers at UNH ever saw use in a classroom at the Charter School.

And Sue Jamback, who served as the school's principal from its founding in 1996 until the end of the 2000-2001 school year, now thinks that perhaps that was as it should have been. "If I could do it over again," she says, "I would hand teachers a guide accompanied by materials and lesson plans." Though this statement might come as a surprise to those who witnessed the CPCS curriculum in action—the school used no pre-packaged materials, aside from a few math textbooks—Jamback says that she has seen a standardized curriculum work very well in the school she currently leads. "I have observed," she says, "that good teachers become great ones and mediocre ones become good ones."

Leah Zuckerman, one of the teachers who participated in the training, recalled, "I had a sense that I knew what the [stock and flow] diagrams represented and that I could understand the ideas behind the connections, but putting in the math myself seemed mystifying." Others echoed her sentiments—though they understood the algebraic functions when Petersen explained them, the group was not yet able to determine what formulas and figures belonged where in the design of the model.

This gap was made quite apparent by an early unit during the 1997-1998 school year. Though students worked primarily on interdisciplinary projects at CPCS, they also participated in what the school called "skill classes" for a few hours each day. These classes were designed more traditionally than the project classes. Students might learn math computation techniques or grammar rules in their skill classes, then apply those skills in an upcoming project. After the training in New Hampshire, the seventh and eighth grade team decided it would be useful to have one of the first skill classes (During that school year, each project or skill class lasted four weeks.) focus on basic model-building.

Out came the cups of water. Out came the sand tray and the tennis balls and marbles and paper towel rolls. The teacher and students drew endless boxes and pipes and arrows and circles on the white board. Days rolled by, and many students seemed to be making sense of the new language and icons. It came time for a final assessment, and the students were assigned to create small models of their own. The school owned roughly twenty-five computers scattered about the eight classrooms, and the students spent a few minutes sketching stocks and flows and then scattered themselves to get to work. It took roughly ten minutes before the first student ventured into a situation that required math beyond that which was required to simulate deer being born and dying or bathtubs filling and draining and began, as everyone involved would have hoped, to ask for help.

Had the assignment been a piece of writing, of course, or a scale model of an historical site, there would have been several teachers available to push even the most advanced student to the next level of success. In the medium of modeling icons, however, there was no help available for students who were venturing beyond what their teachers knew. The sort of statement about learning implicit in such a situation–"Please just stick to what I already know, or we'll both get frustrated."– could not have been further from what the faculty at CPCS was hoping to say to their students. While some students enjoyed the freedom provided by such a situation, many others started to lose interest—after all, who wants to work hard on something new, only to find out no one can tell you if you've done any of it well?

Other kids, like some of their teachers before them, found the whole exercise utterly confusing and clicked along with little success. Still others constructed wildly complex tangles that produced colorful graphs. Those models looked as much like correctly done assignments as any others. There were, of course, no teachers available who could provide any sort of response beyond something along the lines of, "Well, I don't quite think that graph makes sense." In other words, if all learning depends on feedback, there was not going to be much learning here.

Or was there? While the teachers were convinced that few, if any, students had picked up even the little that made it into their curriculum about *building* models, they also saw that some students definitely understood *something* about what they were studying. Ruthann Graham says that she thinks all students left "with an understanding of the big picture." Sue Jamback is more specific, saying, "We were very successful at teaching the Five Disciplines."

Perhaps, then, as the staff became more and more literate in the language of feedback, causality, and stocks and flows, that language began to appear in more classroom conversations. In the months that followed the UNH training, the staff had begun to make greater use of causal loop diagrams and the language of the Five Disciplines in their weekly meetings. Few of their drawings would have translated easily into working simulations, but they served to help the staff better explain the thinking behind various ideas. For example, that school year the teachers spent a great deal of time monitoring a portfolio system that was the primary determinant of whether students were promoted from one grade to the next. Drawing ideas with stocks and flows helped the staff ask questions like, "Are you saying that simply spending more *time* on work helps students learn more, or is there something else we need to have them *do*?"

These questions led to systems with better, or at least more deliberate, designs. Ruthann Graham remembers using similar language with her students: "I think the most effective teaching tool [that used systems thinking and system dynamics] may have been a processing form that steered students back to the causes and effects and consequences of their behaviors."

Sue Jamback, though, isn't convinced that the staff didn't bring on those same behaviors themselves. "We taught many raging adolescents to question authority," she says, referring to an early attempt to teach students the definitions of each of the Five Disciplines. The students seemed to know they were important, but the phrases were truly just vocabulary words until the teachers reduced the terms to a few simple examples and, within days, all 154 students had an idea of what "mental models" were. The working definition among students, remembers Leah Zuckerman, became something like, "Any idea you used to have that you just realized you would be better off without."

Suddenly, annoying customs ranging from showing up on time to not being allowed to play football at lunch just because you were a girl were exposed as the social constructs they were. "Teaching them about mental models before we were completely ready to do it," says Sue Jamback, "was like giving them a match and dynamite. I think they were distracted by it all."

After a few months during which nearly all of the systems thinking and system dynamics exposure came through such discussions—why it's important to clean up graffiti, why hitting people doesn't tend to stop them from teasing you, why the fact that homework is part of the prevailing mental model about school doesn't mean that we ought simply to abolish it—the seventh and eighth grade team attempted to integrate dynamic modeling into the curriculum yet again. "We had to," says Graham. "It was in the charter and…we owed it to the creators of the school and the students who were attending."

Enter Gary Hirsch. Hirsch had first visited CPCS one year earlier. He was one of a few system dynamics professionals who had volunteered time to help the new charter school get its ST/SD curriculum up and running. The first steps, however, had been halting, as teachers figured out how to best integrate the contributions of experts with the daily realities of middle school: varied levels of comprehension and self-control, limited technological resources, and so forth. Like Steve Petersen before him, Hirsch says, "It was a bit chaotic." The plan this time, however, was different. Rather than simply having Hirsch plan a lesson and teach it to the students, he would spend several weeks planning with two teachers before he would ever appear in class.

> …everyone—the principal, the teachers, the trainers, the system dynamicists—had agreed that the best lever for improving system dynamics instruction for students was increased system dynamics instruction for the teachers…

With this new approach, the three seemed to be moving along a promising path. Having guest lecturers had proven ineffective and everyone—the principal, the teachers, the trainers, the system dynamicists—had agreed that the best lever for improving system dynamics instruction for students was increased system dynamics instruction for the teachers, coming in the form of exactly this sort of collaboration. The intention was for the team to create a simulation for student use and fully integrate it into a curriculum unit.

And so, one winter afternoon before the upcoming Journalism Project, a pair of teachers —Leah Zuckerman and Dan Barcan—sat talking with Hirsch. He stood at a whiteboard smudged gray with the group's revisions and translated everyone's thinking—in this case, about the dynamics of running a small newspaper—into a rough causal loop diagram. Though the initial ideas came from the teachers, and though the topic came from one that the school would have covered with or without system dynamics, the work of turning ideas into loops and, eventually, models, was led by Hirsch. Those materials, in turn, would become part of lessons planned by the teachers, in which Hirsch would participate right through the assessment phase. All involved could lead in their own areas of expertise, help students in class, observe their progress, and help decide what to teach next.

A few weeks later, after another meeting and some e-mail contact, Hirsch returned with a working model of a small newspaper business. Players using the

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flight simulator could adjust staffing levels to hire more writers, editors, and ad salespeople. They could also set the price of a copy of the paper. In the first meeting at which they had the finished model, the three simply played with it. The teachers saw firsthand how dynamic models provide little in the way of insight if the user doesn't predict the results first and then reflect upon what has actually happened after the simulation is run. They watched what happened when they entered extreme values—for example, having a staff of one hundred percent ad salespeople. They poked around in the stock and flow assembly itself to try to follow the causal and feedback links.

They also realized that, while Hirsch hadn't taught middle school students, he did have plenty of experience debriefing simulations with all sorts of other groups. And in direct contrast to Hirsch's experience the year before, the teachers were able to provide some guidance on what exactly he ought to do in the class while the students were using the model. Together, the three created some questions that would help students reflect on the simulation, and they talked about what sorts of insights students ought to be able to gain from different scenarios.[1]

After the students had written articles and created their own newspapers (the first three weeks of the unit), the teachers presented the model as the final part of the Journalism Project. The team adjusted its schedule so groups of twenty-three students could have two uninterrupted hours to play with the flight simulator. The eight temperamental computers on which the model was running all decided, for whatever reason, to work at the same time. Students looked at an overhead projection of the control panel for the simulator, made some predictions about what would increase their newspaper's bank balance, and hit the computers to test their assumptions. For the first time, students at the Chelmsford Public Charter School were learning their "content" —the stuff that normally comes from textbooks—as the founders had intended: with a working dynamic model.

> For the first time, students at the Chelmsford Public Charter School were learning their "content" —the stuff that normally comes from textbooks—as the founders had intended: with a working dynamic model... It was clear that all involved had seen a great deal of progress beyond what their efforts had produced the year before.

Hirsch and the teachers worked the room, asking questions as groups ran their simulations. If groups were simply changing variables and clicking "run" as fast as they could, they asked them to talk about the reasons why they were making particular choices. If a group seemed to be able to turn a huge profit, they steered them to the diagram of the stocks and flows itself and asked questions about what dynamics the students thought had led to their great wealth. (On one occasion, the answer to this one was, "Well, I saw a stock that was called 'bank balance,' so I clicked on it and just typed in a bigger number." Beware the simulation that looks as if it has a "scoreboard.")

After the students had "run the newspaper" for about an hour, the teachers began a group conversation about the dynamics of the model itself. Since they had drawn countless loops in the planning process, they were able to create simple causal loop diagrams as students explained their theories about what had gone on. Normally, teachers at CPCS would have students write for five or ten minutes to prepare to talk about the answer to a particular question. Here, they had the students sketch behavior-over-time graphs as they talked. The students quickly began to show their literacy in the language of modeling tools.

It was clear that all involved had seen a great deal of progress beyond what their efforts had produced the year before. Hirsch no longer felt like he had been hired as a substitute and "dropped in" to a classroom. He sensed that the kids were "learning the key lessons while having a good time. Exactly what education should be." And the teachers no longer felt as if they had been left in charge of some strange animal—Hirsch had vetted the model (indeed, he had built it) just as they had the actual lesson plan, though all three had seen both the model and the lessons develop from ideas to finished products. And his presence plugged the gap that had appeared earlier in the year, since there was a very slim chance of students encountering a situation he wasn't able to understand.

While it is easy to say that teachers, especially those centering their classes on a dynamic model, ought to get out of the business of worrying about whether they can answer all questions that come up and focus instead on simply asking more questions, in practice asking good questions probably requires a deeper understanding of the subject matter at hand than just providing answers. And while it wasn't Hirsch's purpose, *per se*, to be the "advanced teacher," the three adults in the room did wind up spending lots of time with specific groups of students. Hirsch

[1] See related article, model, and curriculum unit, by Deb Lyneis et al., on the CLE web site, catalogued as CC2000-10Newspaper

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wound up with a group that quickly understood the basic dynamics of the model, and he was able to push them much further than the teachers would have been able to on their own.

Soon after the kids had gone home for the day, one of the teachers went to a computer to investigate a question a student had asked about the inner workings of the newspaper model. The computer responded that the file had a deadly virus and wouldn't be bothered just then. But it had hung on long enough for the school to see significant progress in its ST/SD teaching. Teachers had collaborated with an experienced model-builder to create a piece of curriculum that did not exist before. What materials are out there for teachers to help seventh- and eighth-graders understand the dynamics of the newspaper business? It seems safe, despite the size of the textbook industry, to say that there are none. They had also been equipped with a deep enough understanding of the dynamics involved in the lesson to answer new questions as they arose. The teachers had, at the very least, become literate enough to teach this small part of a project using system dynamics tools.

This literacy, taken for granted in math and English and science and music classes, enabled them to explain things to students in a variety of ways, to assess student comprehension, to provide targeted feedback, and to offer

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modifications—such as a less complicated graph for a struggling student or a more nuanced question about feedback loops for a more advanced one. By working with someone who understood system dynamics in the same way the teachers themselves understood algebra or portfolios or other common middle school topics, they became much better equipped to not simply "have system dynamics" in the classroom, but to *teach* it as a real part of the curriculum.

The lesson from all this seems to be so simple that it wouldn't be worth writing if the stakes weren't so high. "If Jay [Forrester's] dreams are to be lived in more than just isolated pockets, there has to be considerable effort spent to standardize a program that can be mass produced and replicated," says Sue Jamback. (In fact, meetings have begun to do just that over a course of many years.) When the teachers at CPCS tried to teach subjects before they were ready—indeed, before they even really understood what "ready" meant in the context of teaching ST/SD, the results were disappointing. But when they took months to plan two days of instruction, with an expert working alongside to help create materials *and provide help understanding the dynamics illustrated in those materials*, the results were quite encouraging. The question was whether they would be able to repeat that experience and create more than just a newspaper unit quickly enough to teach their students more about systems, maintain enrollment, and have their charter renewed.

This article, catalogued as PH2003-01MurdochMSII, is available free of charge at clexchange.org.

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