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

Lees N. Stuntz, Debra A. Lyneis, and George P. Richardson
Creative Learning Exchange, 1 Keefe Road, Acton, Massachusetts 01720, USA
978-287-0070 stuntzln@clexchange.org, lyneisd@clexchange.org
Rockefeller College of Public Affairs and Policy
University at Albany – SUNY, Albany, NY 12222, USA
518-442-3859 gpr@albany.edu

ABSTRACT: For a week in June 2001, a small group of schoolteachers and professional system dynamicists convened in Essex, Massachusetts under the guidance of Jay Forrester to plan the future of system dynamics in kindergarten through twelfth grade (K-12) education. Based on early experience in schools, the group articulated a vision of what an education based on the principles of system dynamics could provide to students. The group then drew up a strategy to achieve that vision and a detailed plan to implement the strategy. The participants of the Essex session and co-authors 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. The following report on the session outlines how system dynamics can fundamentally improve K-12 education.
Key words: system dynamics, K-12 education

PURPOSE

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 deal effectively 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, 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 or social movement
- The spread of a disease or rumor
- The accumulation of money in the bank
- The building of their own self-confidence
- 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.

The participants in the week-long Essex session 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. Others who also contributed generously to the process were: 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.

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 interdependencies, 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 nurtured 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 in order to bring the benefits of systems education to many more students across the country.

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.
    - Dynamic Thinking –seeing patterns of change over time rather than focusing on isolated events.
    - System as Cause Thinking – recognizing that problems, and their solutions, arise within a system, not from outside. They are endogenous.
    - 10K Meters Thinking – being able to step back and see the big picture.
    - 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.
    - Closed-Loop Thinking – recognizing feedback: any action has consequences that can influence that action again.
    - Non-Linear Thinking – knowing that feedback loops interact to produce changing responses over time.
    - Quantitative Thinking – being able to consider and include all variables, even those that cannot be measured in standard units.
    - Scientific Thinking – recognizing that all models are working hypotheses to be built, tested and refined rigorously.

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

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

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.
- 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

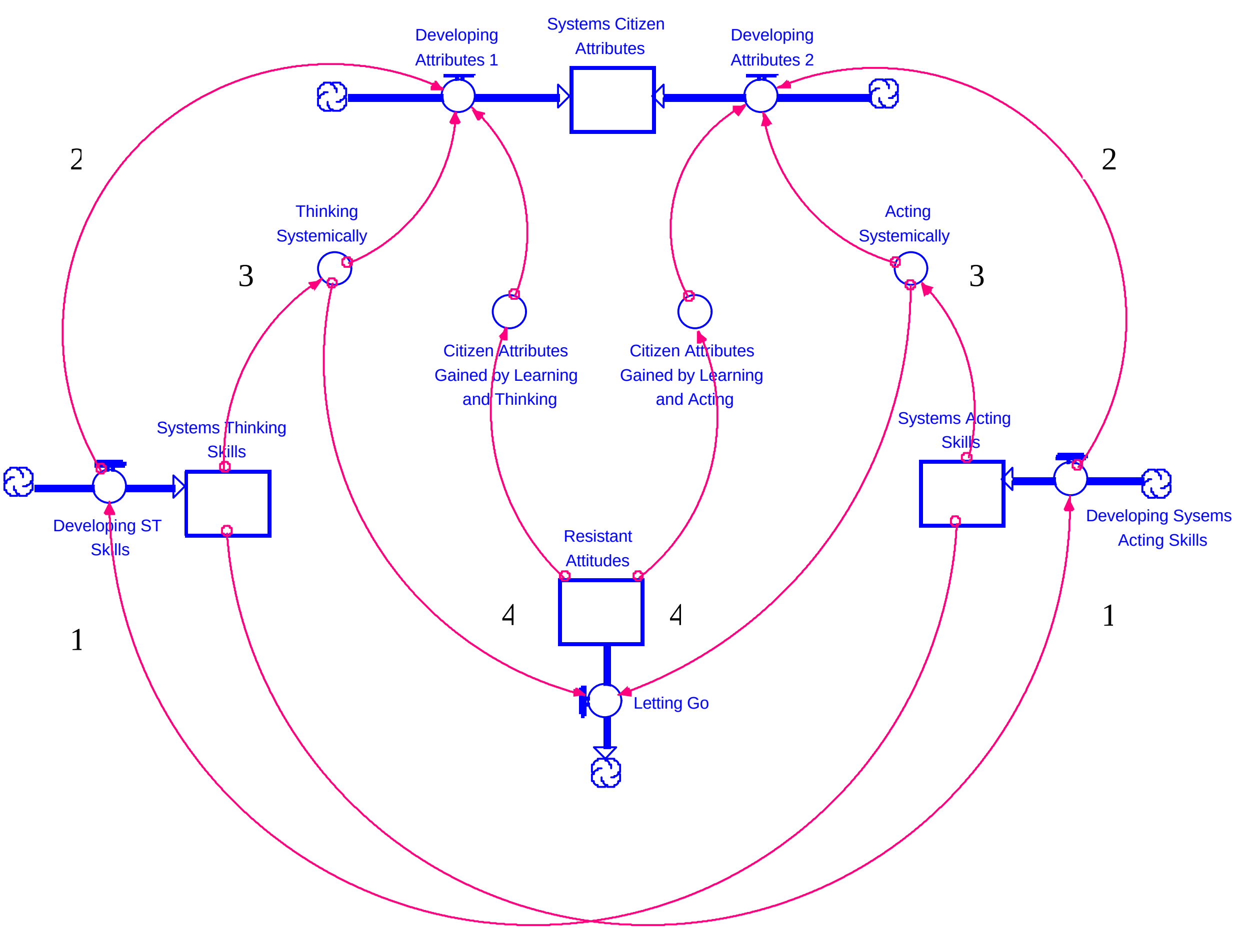
System dynamics is not taught for its own sake as a separate class, like Algebra I, for example. Instead it is seamlessly woven into the fabric of a school's curriculum and structure. An analogy might be the introduction of information technology in schools. "Computers" is not a separate subject. While 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.



A Conceptual Map of a Systems Citizen

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 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 defned.

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.

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 education 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 an expanded self 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.

THE STRATEGY TO REALIZE THE VISION

Fundamentally improving K-12 education through system dynamics is an enormous challenge, best approached in measured steps. The task is to create something new out of what is available.

Early experience indicates that the growth of K-12 system dynamics will follow the "infection model," a process also described as spreading by "word of mouth" or "grassroots." The systems approach is introduced into a school through the curriculum. It starts when a few innovative teachers are drawn to the approach because they see that it can benefit their students. As these teachers experience success in their classrooms, their colleagues try it also, and the idea slowly spreads. The stock of teachers using system dynamics grows as teachers perceive its need, try it, observe its benefits for their students and voluntarily change the way they teach. The strategy is to foster the steady "infection" of system dynamics within schools until the change gains widespread acceptance and sustains itself.

To initiate and sustain this strategy it is essential:

- *To determine what K-12 students have been able to accomplish in system dynamics so far and build on that experience to outline what students could plausibly achieve.* Currently, only a few schools across the country have embraced the system dynamics approach, and none of these has yet achieved the level of the envisioned ideal school. To effect change, it is important to have a plausible, clear, explicit description of the end product for students.
- *To develop extensive curriculum materials of demonstrated benefit that are ready for teachers to use.* Until now, teachers have had to create their own classroom materials. It is important to learn from the most effective lessons and develop more materials across the range of grade levels and disciplines. Since a shortage of good materials is a constraint, this is an early priority.
- *To focus on teacher training and support.* Teachers need training in system dynamics and on-going support as they use it with their students. To this end, it is necessary to develop effective teacher-training materials and train the teachers who will then be using the materials to train and support others. We need to build on our past system dynamics training experience and broaden the cadre of teacher-trainers because this is another bottleneck. Our goal must extend beyond simply transmitting computer-modeling skills, however. In the process, we must help teachers become systems thinkers too. Training is equally crucial for school administrators.
- *To maintain high standards of quality for curriculum materials and training* because an erosion of standards will undermine credibility and sustainability. It will be important to enlist the help of system dynamics professionals throughout the process for help with quality control.
- *To acknowledge that system dynamics can be difficult to learn at first* because it requires looking at things through a new frame of reference. It will be up to skilled teachers to devise ways make system dynamics accessible to a broad audience. Meanwhile, we all need support and patience.
- *To assess student progress continually* in order to demonstrate that a systems education can deliver its claimed benefits. Assessment will also be important for the on-going

evaluation and refinement of curriculum materials and teacher training. It will be necessary to engage experts in assessment because we do not currently have that expertise and because we can benefit from their feedback.

- *To let students be ambassadors.* Students who have studied system dynamics can eloquently and enthusiastically express what they have learned. They always impress adults with their poise and depth of understanding of complex issues. Keeping students out front not only wins converts but also reminds all of us that students are the reason we pursue this.
- *To recognize that system dynamics does not stick if it is mandated from above or pushed too fast.* Teachers, administrators and communities need time and patient support to digest and accept these ideas at their own pace.
- *To value the vital role of administrators in effecting school change.* A supportive administrator can encourage and facilitate the spread of system dynamics within a school, especially if the administration embraces the principles of organizational learning, creating a climate of continuous improvement and collaboration.
- *To engage local communities in their schools.* Everyone benefits when schools, community members, businesses and other institutions work together to improve K-12 education. Outside initiative, feedback and support are vital needs.
- *To work with the growing number of educators around the world who are also introducing system dynamics into their schools.* It will be important to share experiences and learn from one another.
- *To acknowledge that any effort to change K-12 education will naturally engender resistance.* It is necessary to use the tools of system dynamics to look for leverage points and work within the system rather than against it.

WHAT CAN STUDENTS DO?

Based on early experience in classrooms, teachers are frequently surprised that students can do more than they would have expected. Students have demonstrated that they can do the following: (These are specific cumulative system dynamics skills, but they are all used to deepen understanding of topics within the context of the current curriculum. Examples of actual lessons are briefly described in the Appendix. Grade levels and activities may shift as we move forward and learn more.)

Kindergarten

- Recognize patterns of change
- Identify accumulations
- Participate in classroom simulations, games.

Grade 1

- Understand behavior over time graphs
- Understand a basic stock/flow diagram with one stock
- Plot data on a line graph from an activity
- Discuss causes of change
- Discuss delays

Grade 2

- Compare slopes of behavior over time graphs with different rates of growth
- Graph stories from literature with behavior over time graphs
- Discuss feedback and simple causal loops
- Identify balancing and reinforcing feedback loops
- Discuss patterns of exponential growth

Grade 3

- Use a simple system dynamics computer model based on a classroom simulation and graphing activity
- Discuss the concept of a model as a representation of reality
- Use behavior over time graphs with two variables and infer causality
- Create simple feedback loops from stories
- Analyze graphs from newspaper articles

Grade 4

- Build one-stock linear models in teams with direction
- Make predictions before running a model
- Generate behavior over time graphs independently in many applications
- Distinguish between linear and exponential growth patterns in graphs and structure
- Recognize oscillating patterns

Grades 5 and 6

- Build one-stock linear and feedback models independently
- Explore the relationship between structure and behavior
- Explore transferability of structure; notice that the same basic structure appears in different contexts
- Draw multi-loop causal loop diagrams independently; label balancing and reinforcing loops
- Use graphical functions to capture non-linear relationships, with direction

Grades 7 and 8

- Use/construct 2- to 3-stock models
- Apply simulation to the consideration of global issues
- Discuss how loop dominance affects behavior
- Use behavior over time graphs and causal loop diagrams to organize a term paper and presentation
- Use graphical integration to understand simulation
- Use pencil simulation to understand solution intervals, *dt*

Grades 9 and 10

- Explain functioning of behavior segments of larger models
- Suggest and justify policies based on models using writing and presentations
- Apply an existing simple to moderate level model structure to another discipline or problem; recognize and transfer learning across disciplines

- Predict the behavior of the system by looking at the structure
- Use modeling language to describe and explain the dynamic structure in news articles
- Use group model building to collaboratively address real world problems

Grades 11 and 12

- Identify a real community issue and apply system dynamics methodology to its solution
- Present results and insights to an audience outside of school
- Advocate policies based on analysis and insights
- Re-examine policies and models in response to criticism

And More…

Above, we have listed activities that students are actually doing now in pioneering schools across the country. They represent only a beginning. Following are additional system dynamics threads that we also envision for students. Students will:

- Study economics in the framework of system dynamics, beginning in elementary school with the study of bank balances and money management and progressing through the grades to the study of national economic policies.
- Use models of growing scope, starting with a very simple structure in younger grades and adding complexity as the depth of study of a topic increases through the grades. The study of revolutions and social movements is an example.
- Study a set of exemplary generic system dynamics models that address significant problems and illustrate the general characteristics of complex systems. (These are "gem" models.) Advanced students will also study classic literature, e.g. *Introduction to Urban Dynamics* by Alfeld and Graham, *Urban Dynamics* by Forrester, and more.
- Welcome outside expert review and criticism of their work as a way to learn from mistakes and grow – also as a guard against complacency with internal quality.
- Develop the ability to read and evaluate the models of others.
- Study and learn from "bad" models.
- Develop a culture of raising quality by reviewing others' work and learning how to give and receive constructive criticism gracefully. Make error creative.

THE PLAN

With a vision and a strategy in hand, the work of the Essex meeting turned to developing a 25-year implementation plan. Where do we start? What steps must we take to bring the vision to fruition? What resources will we need? Our goal was to develop a plausible, practical plan to guide the effort. Although the details of the proposal may continuously evolve, at any point in time it is important to have a clearly articulated goal and plan for achieving it.

Several tools aided the process of identifying necessary resources and plotting their growth over the next 25 years. A spreadsheet matrix displayed the specific needs for each resource year-by-year. A spreadsheet model computed costs based on those projected needs, and a PERT chart provided a visual representation of the matrix. A preliminary system dynamics simulation model examined how system dynamics innovation spreads within schools; its purpose is to identify leverage points and obstacles to progress. [Summaries of these are in the Appendices.]

Resources

Infusing system dynamics into K-12 education is a process that will start on a small scale and require increasing outside resources to support it over the next 25 years until it can eventually sustain itself in school systems. Following is a list of the required resources. In systems parlance, these are the stocks, or accumulations, that will need to grow and be monitored over time.

- **People Actively Involved**
    - Students
    - Teachers
        - Using SD curriculum
        - Developing curriculum
    - Professional system dynamicists
    - School administrators
    - Evaluators
    - Content area experts
- **Training Programs**
    - Summer and in-service training programs for teachers and administrators
    - Pre-service training (teacher education programs)
    - Training materials
    - On-going support for teachers and administrators
- **Curriculum Materials**
    - Teaching materials infusing systems thinking/system dynamics concepts and tools throughout the K-12 curriculum
        - Single discipline
        - Interdisciplinary
    - Administrative models and materials
    - 'Gem' models – elegant classic generic system dynamics models illustrating systems principles
- **Assessment Capabilities**
    - Professional assessment resources (schools of education, etc.)
- **Getting the Word Out**
    - Promoters
        - People who raise money
        - People who build networks
    - Publicity materials
    - Strategies for overcoming resistance
    - Citizen Champions
- **Project Management**

The Matrix

The resource list became the spine of a matrix that plotted specific needs over the next 25 years in each area. This was a challenge because all of the strands are intertwined, interdependent. It soon became apparent that the two most pressing needs are to develop quality curriculum materials and to establish good training materials and programs for teachers. Initial efforts will focus on these because success in all other areas depends on them. These are highlights of the discussions:

Curriculum creation, review & refinement

The first task, already underway, is to sort and improve the materials currently available through the Creative Learning Exchange and to establish processes for the creation and review of new materials. Moving forward, curriculum materials will be developed in two ways. Continuing the current practice, lessons will be created, written and tested by teachers and mentors in their own classrooms. Curricula will also be developed in more intensive summer curriculum writing workshops involving teachers, subject area specialists and system dynamicists. Curricula will be tested with students during the school year, refined the following summer, and field tested again before publication. An example would be developing high school biology units that teachers could use separately or as a complete course. (Since all freshmen study biology, it is a high-leverage starting point. There are many other such points in the current K-12 curriculum.) Writers and editors will assist in preparing both the site- and workshop-generated materials. There will be on-going review of the materials and the development process. The eventual goal is to build a comprehensive K-12 curriculum.

Costs associated with curriculum development include released time and remuneration for teachers who write lessons during the school year, plus the expenses of conducting the summer workshops, including stipends, travel and housing costs for participants. (See Appendix B for a more detailed plan.)

Training resources

Proper training and support are crucial needs. Training consists of developing and refining training materials, training the trainers who will use them, and actually setting up training opportunities for teachers. Some training, especially introductory sessions, will continue to be held in-service, in schools, conducted by local mentors and teachers. There will also be a need for more intensive and advanced programs at system dynamics teacher-training centers. Such a center could be housed at a college or university where system dynamics experts and teachers could prepare and sponsor summer training workshops and ongoing teacher support throughout the school year.

Costs associated with training include teacher and trainer stipends and expenses for summer workshops, plus the costs of establishing and staffing several national training centers over twenty-five years. (See appendix C for a more detailed plan.)

The Development Office

A professional development staff, part time at first, will raise the funds necessary to support the program. The first need in this category is the seed money to establish a development office and hire a professional to run it. The staff will create publicity materials and explore funding resources. In the outlying years, as K-12 system dynamics spreads and demonstrates its effectiveness, the need for outside funding will diminish when local school districts begin to absorb their own costs.

Laboratory Schools

These are schools at which many of the curricular and training ideas will be tested and implemented. Each laboratory school needs:

- One systems mentor – a full time teacher with systems thinking and system dynamics expertise who helps colleagues learn and implement skills in their classes.
- Released time for several classroom teachers to collaborate, develop curricula and mentor fellow teachers as the need arises.
- Funds for curriculum and administrative support.
- Extensive summer training for classroom teachers and administrators.
- Availability of professional system dynamics expertise.
- (There is overlap among the curriculum, training and laboratory school categories.)

Helpers

This includes teacher mentors in other schools across the country supported by system dynamicists as a resource to help sustain the quality of their work. Experience, primarily through the Waters Foundation, has shown that teacher mentors are a high leverage means to train and support teachers in schools.

Assessment resources

It will be essential to assess student learning to inform our continuous improvement and to demonstrate the benefits of the systems approach to others. Professionals will devise and administer appropriate assessment tools and programs with the guidance and oversight of experienced teachers and mentors. Graduate research on the effectiveness of system dynamics curricula will also be encouraged. Assessment will be conducted in the laboratory schools and at other schools. Assessment is a challenge because, although students gain a deeper understanding of the current curriculum, many of the broader skills and perspectives also gained through systems education are not readily measured on today's standardized tests.

Project Management

Initially, the Creative Learning Exchange, a non-profit organization, will provide central coordination and financial management. Another structure may emerge as needs expand.

THE CHALLENGES

System dynamics and systems thinking hold great promise for fundamentally improving K-12 education at a time when schools are under intense pressure to do a better job preparing students to thrive and contribute in a rapidly changing global economy. System dynamics can revitalize schools and unify the curriculum. It can prepare students to deal effectively and compassionately with dynamically complex social, political, environmental, and economic problems facing them.

A clear vision and a strong partnership among committed individuals with diverse backgrounds and skills will move us forward. But the path will not be straight and easy. An early challenge will be to widen the circle of people who are involved so that the work can be accomplished in a timely way. Another challenge will be to maintain high standards of quality in curriculum and training as we grow because diluted quality can discredit and derail any progress. To avoid eroding quality, we need to nurture a culture of continuous improvement and carefully monitor the pace of growth.

A further challenge will be adapting our programs to the needs of the market. Teachers drawn first to the system dynamics approach will be the innovative teachers who are already seeking change. They are easy to win and tolerant of the uncertainties that accompany pioneering. The challenge will be to move beyond these early adopters and reach the larger majority of teachers who will change only when they are convinced that a program is established and successful. We will need to be mindful of the "chasm" between these two groups.

A final challenge, of course, is funding. Effecting change in schools is an ambitious undertaking. Although our effort will start small and grow slowly, it will still require substantial financial support. There are countless innovative teachers and administrators across the country who are ready for change, but local school budgets are stretched thin just trying to meet day-to-day challenges; there is little money left to break free and try something new. Systemic improvement in K-12 education will need the help of reform-minded citizens and institutions willing to support these innovators in new ways. It is an investment in our future. The time is now.

APPENDIX A

EXAMPLES OF SYSTEM DYNAMICS IN THE K-12 CURRICULUM

System dynamics is currently used in the curriculum across all subject areas and grade levels, kindergarten through twelfth grade. Many lessons have been developed by teachers in their classrooms and written up for other teachers to use. They are available on the Creative Learning Exchange website at www.clexchage.org. Following are just a few examples in grade level order. (Use the search feature on the site to download these and many other lessons.)

The In and Out Game, a Preliminary System Dynamics Modeling Lesson, by Alan Ticotsky, Rob Quaden and Debra Lyneis. K-2 students learn about stocks and flows by playing a classroom game and graphing the stock as players move in and out. Older elementary students build simple computer models of the accumulations. Middle school students manipulate the models.

The Friendship Game, by Peg Clemans. As part of a discussion on social behavior and classroom rules, primary grade students play a classroom game and use a causal loop diagram to understand how friendliness (and unfriendliness) can spread in their class.

Getting Started With Behavior Over Time Graphs, by Gayle Richardson and Debra Lyneis. Fifth graders use behavior over time graphs to examine change in literature and social studies applications. They use the graphs to ask, "What is changing?" "How is it changing?" and "Why is it changing?"

The Mammoth Extinction Game, by Gene Stamell, Rob Quaden, Alan Ticotsky. Third graders use a dice game, graphing and a simple system dynamics population model to understand the demise of the wooly mammoths and sharpen math skills.

Everyday Behavior Over Time Graphs, by Gene Stamell and Debra Lyneis. Third graders use behavior over time graphs throughout their curriculum to think more carefully and express their ideas about a wide range of topics from current events, to science, to poetry.

It's Cool, An Experiment and Modeling Lesson, by Alan Ticotsky, Rob Quaden, and Debra Lyneis. Fifth graders conduct an experiment to record and graph the cooling of a cup of boiling water. They discuss the feedback affecting the cooling rate and build a simple computer model of the system.

An Introduction to Models of Linear Change: Using STELLA to Solve Word Problems, by Rob Quaden, Alan Ticotsky, and Debra Lyneis. Students in grades 4-8 begin to build simple computer models of change over time without feedback, e.g. $d = rt$, etc.

Stress on the First Day of Middle School, by Jan Mons. Sixth graders use behavior over time graphs as an objective way to discuss their concerns, observe their progress and ease their transition into middle school.

Behavior Over Time Graphs as Literature and Writing Tools, by Frank Draper. Middle school students use graphs to analyze character and plot development in several novels.

Focus on Folk Tales and Fairy Tales, by Tori Christopher and Anne LaVigne. Students read folk and fairy tales and use systems tools to analyze the events, patterns, structures and mental models within them.

Tuck Everlasting: System Dynamics, Literature, and Living Forever, by Carolyn Platt, Debra Lyneis. Sixth graders use graphs to explore the themes of a novel and build a simple population model to see what would happen if everyone could live forever.

Banzai Barbie! STELLA Model Building and Graph Analysis in Math and Science, by Mary Memmot and Becky Hadden. Using a system dynamics model and then designing an actual bungee jump, students take Barbie bungee jumping.

Let It Roll! An Interdisciplinary Middle School Math Science Unit Using a STELLA Model of the Physics of Motion, by Rob Quaden, James Trierweiler, Debra Lyneis. Students experiment with cars on ramps and model the results.

Using Computer Models to Apply Concepts in Math, by Tad Sudnick. High school students use system dynamics computer modeling to link math concepts to science instruction.

Understanding the Tragedy of the Sahel, by Corey Lofdahl. This is an analysis of the Sahel famine through the tragedy of the commons and computer models.

Dynamic Models for Instruction and Exploration in Chemistry, by Albert Powers. Students use a series of interactive computer models to understand the dynamics in Le Chatelier's principle, chemical equilibrium, thermal decomposition of a metal carbonate, and more.

The Cooling Cup Packet, by Albert Powers and Celeste Chung. High school chemistry students build models of a cooling cup of coffee.

Soda Bottle Water Rockets: Build the Rockets and the Models, by Martha Lynes and Debra Lyneis. Students construct and launch rockets and build a series of computer models to capture and understand their behavior.

APPENDIX B

A PLAN FOR CURRICULUM DEVELOPMENT

At the Essex session, a team of teachers and system dynamicists drafted a plan for developing a comprehensive curriculum using system dynamics across all disciplines and grade levels, K-12.

General Guidelines

- Start by building on lessons that are currently effective and slowly build a complete curriculum.
- Use system dynamics to enhance the current curriculum, not as an add-on. Look for widely taught topics for high leverage. (Every HS freshman studies biology and world history, for example.)
- Maintain high quality. Include content area experts, system dynamics experts, teachers with system dynamics experience, teachers without system dynamics experience, and child development specialists in the curriculum development process.
- Assess student learning and use the feedback to inform curriculum development.
- Develop curricula to address the various needs/styles of students and teachers. Most lessons will focus on imparting curricular content using system dynamics, but some lessons will need to focus on teaching system dynamics skills themselves. Also, most lessons will present a complete subject area unit for teachers to use (like a lesson on mammoth extinction), while others will instead guide teachers in the use of a particular system dynamics tool that teachers then apply on their own (like behavior over time graphs).
- Field-test, revise, field-test and revise again all curricula before releasing it.
- At the middle and elementary levels, develop lessons that are interdisciplinary and that can be adapted to a range of grade levels. Start by developing many single lessons/units for a range of applications rather than focusing on one subject area.
- At the high school level, because of the established departmentalized structure, start by developing units that can build into a complete course. In time, develop courses in many disciplines, helping students and teachers make interdisciplinary connections and eventually soften departmental boundaries.
- Use curricula to help students build system dynamics skills sequentially. Pay attention to developmental appropriateness of system dynamics applications.
- Continue the current practice of experienced teachers developing curricula in their own classrooms during the school year, with added coordination, support and review.
- Add a process of also developing curricula at annual intensive summer workshops, eventually held at the system dynamics centers (see training plan).

2002

- Determine curriculum leverage points and choose topics. (6 people for 1 week).
- Complete the ongoing review and revision of curriculum materials currently posted on the Creative Learning Exchange website. Establish standards and procedures for new submissions.
- Continue encouraging experienced teachers to write up their effective lessons, K-12.

2003

- Hold summer curriculum development workshops.
  - High School (8 people for 3 weeks). Begin work on a grade 9/10 biology or world civilizations course. Develop 6-8 micro units (one or two class periods) with interdisciplinary flavor.
  - K-8 (8 people for 3 weeks). Develop strong single lessons for a variety of grades and subjects based on most effective current lessons. Aim to build curriculum strands and interdisciplinary units. Begin to determine a sequence for teaching SD concepts and skills throughout the grades based on experience in classrooms.
- To support on-site curriculum development during the school year, add a .3 FTE (full time equivalent) curriculum facilitator and a .5 FTE editor.

2004

- During the school year, field-test 2003 lessons. Suggest revisions.
- Continue to support on-site curriculum development and review.
- High school (11 people, 3 weeks in summer). Continue writing selected course – 6-8 more units. Review results of field tests, make revisions, and send lessons out for another field test.
- K-8 (11 people, 3 weeks in summer) Continue work on a sequence for teaching system dynamics concepts and skills throughout the grades. Add a developmental specialist to the team as a resource. Assess how current lessons fit the sequence and note gaps to fill. Review field tests of last year's lessons, make revisions, and re-test.

2005

- During the school year, continue to field test summer curricula and support the development, field-testing and review of classroom-generated curricula, with additional organizational and editorial support as needed.
- High School (11 people for 3 weeks in summer). Finish writing the first selected course, send new units out for field-testing, and make revisions on last year's units. Begin plans for writing another course.
- K-8 (11 people for 3 weeks in summer). Continue developing interdisciplinary lessons and curriculum strands. Continue developing a sequence for system dynamics skills acquisition and developing lessons to complete and reinforce the sequence.

2006 and Beyond

- At all levels, expand the process of assessing needs, developing and reviewing curricula, and widening the scope of system dynamics applications K-12.
- High school courses to be developed: algebra, biology, calculus, earth science, ecology, economics, English/literature, global studies, health, physics, social studies.

APPENDIX C

A PLAN FOR TRAINING TEACHERS

At the Essex session, a team of teachers and system dynamicists drafted the following plan for developing standard training materials and designing a sequential training program for teachers.

2002

During the school year (One person working for two weeks)

- Coordinate discussion questions for summer work.
- Gather current training materials.
- Generate a list of potential trainers available.

Creative Learning Exchange conference in June

- Train the trainers
  - Hold a 1-day session prior to the conference to train the trainers in an ongoing process of building system dynamics skills in experienced teachers and mentors. (George Richardson will teach the session on best SD practices.)
  - Video-tape sessions for wider use
- Build mentoring skills
  - Hold one session during the conference on mentoring skills

During the summer (Six experienced teachers, plus one system dynamics expert)

- Identify training goals for Level I, Level II, etc.
- Develop a generic framework for the training with listed topics to be covered and a collection of activities for trainers.
- Assemble current training materials that meet the goals.
- Identify gaps in the current materials.
- Create assessment instruments for training programs.
- Develop a strategy/incentive to attract participants and new trainers.
- Consider the need to develop training materials and programs for administrators.
- Throughout, emphasize personal mastery for teachers as well as how to use the approach with students.

During the year (One person for 2 weeks)

- Begin consideration of establishing SD Training Center(s).
- Explore possible sites: SUNY Albany, Worcester Polytech, Portland State …
- Explore costs/benefits.

Palermo System Dynamics Society 2002 Conference

- Offer a session conducted by George Richardson and teachers to recruit and coach professional system dynamics involvement with teachers and schools.

2003

- Further develop training materials, Level II.
- Use Level I materials – in-service and summer training.
- Further plan training/support for administrators.
- Further plan a system dynamics center.
- Begin planning on-site visit procedures from the training centers: who visits whom, what should be done during visits, etc. (System dynamics support/mentoring for local mentors.)
- Refine and use training program assessment tools and procedures.
- Consider distance-learning opportunities: MSST tutorial, e-mail question/answer sites, interactive web site, teleconferences, etc.

2004

- Revise Level I training materials/programs. Fill in gaps.
- Use Level II materials.
- Disseminate training packet curriculum to current and potential trainers.
- Establish a system dynamics center and offer summer workshops for teachers and administrators.
- Develop self-guided study packets focused on a particular system dynamics tool with curricular applications.

2005

- Hold regular training programs at the system dynamics center and at local sites as needed.
- Consider feasibility of distance learning programs from the system dynamics center.
- Offer on-site system dynamics support and mentoring from the center.

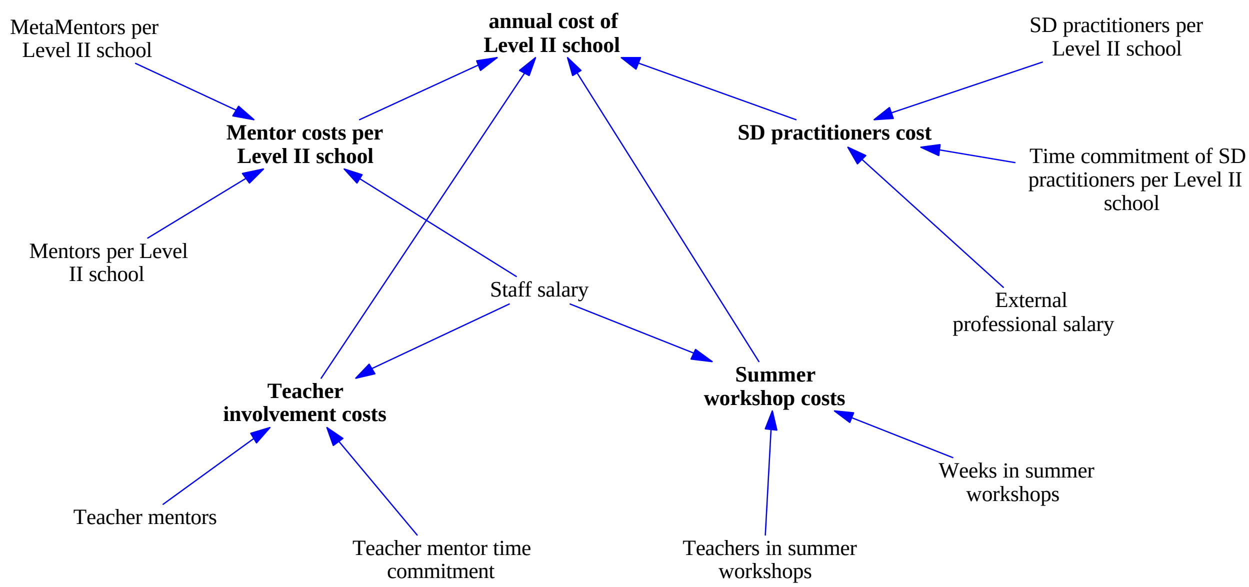
2006 and Beyond

- Continue to assess, refine and augment training materials and programs.
- Continue to develop training/support programs for administrators.
- Expand the system dynamics centers. At 5-year intervals, examine the need/feasibility of additional regional centers. Make necessary plans.
- Pre-service training – connections with university/college teacher-training programs.
    - Initially, hold informal conversations with institutions of higher education until a larger number of teachers and schools successfully using system dynamics can act as a leverage point for change.
    - After 5 years, form an internal study group to explore pre-service connections, possibly relying on the system dynamics centers for leverage.
    - After another 5 years, form an internal/external planning committee.
    - Use the flow of knowledgeable students moving into higher education as leverage.
- Throughout, be aware of the gap between early innovators and the larger majority of teachers who will adopt SD only when its effectiveness is established.

APPENDIX D

THE COSTING MODEL

Our working matrix became a spreadsheet model used to estimate the cumulative costs of implementing the curriculum development plan, the training plan, and other elements of the program over twenty-five years. For example, the following diagram outlines the costs of supporting a Level II school. Schools will move through three levels of development. A Level I school has at least one teacher who is using system dynamics in a classroom in a limited way. A Level II school has multiple teachers who participate in training and are using multiple system dynamics lessons throughout the year; this school may have a systems mentor – a teacher who helps other teachers learn and apply system dynamics who is in turn supported by a mentor or system dynamicist. A Level III school meets the criteria of the ideal school described in our vision. (Currently, most schools in the USA are not using system dynamics at all, many schools are at Level I, a handful of schools are at Level II, and no schools are at Level III.)



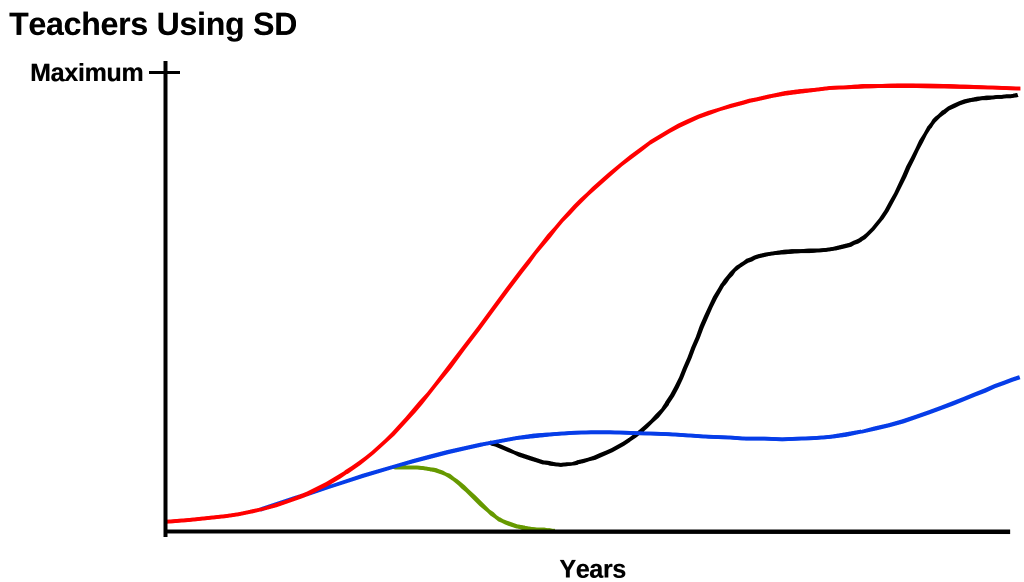
This diagram represents costs for Level II schools. The rest of the spreadsheet model tracks total cumulative costs. Total cumulative costs include annual costs to support a growing number of schools at all three levels plus annual costs of curriculum development, ongoing assessment, a development office, and project management. It is assumed that schools will need substantial outside support at first to introduce change, but that the need for that support will eventually diminish as change becomes more established and schools assume their own costs.

Details of the spreadsheet model are still being refined. Needless to say, the costs for a project of this scope will be substantial.

APPENDIX E

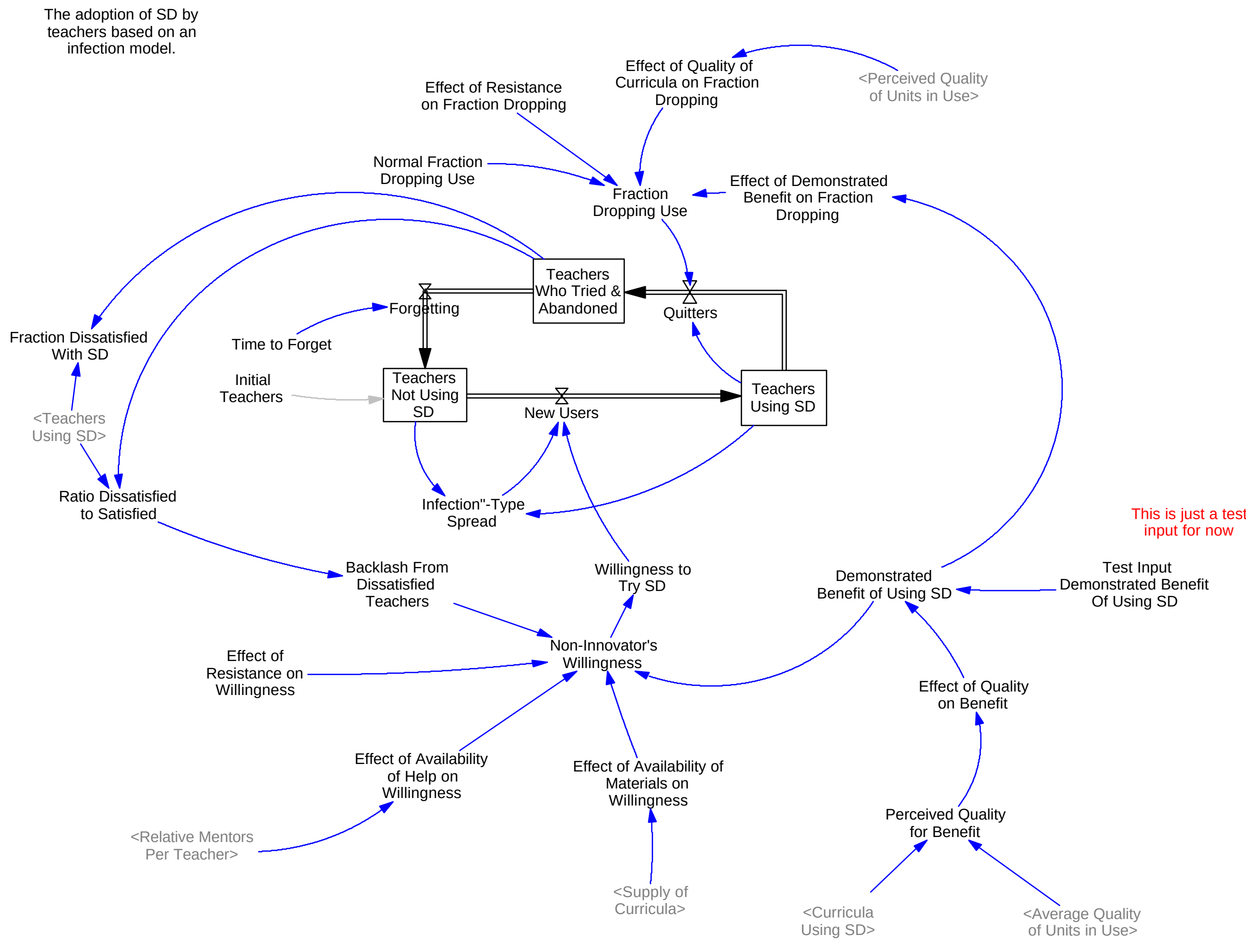
THE SYSTEM DYNAMICS SIMULATION MODEL

The future of system dynamics in K-12 education could follow many different paths, as shown on the behavior over time graph below, depending on policy decisions made along the way. Ideally, teachers using system dynamics would observe its benefits for their students and spread the word to their colleagues, who would in turn use it successfully and "infect" others, until the systems approach becomes widely accepted standard practice in schools. Many elements of the complex education system would need to work together to achieve that ideal s-shaped scenario.



A system dynamics model based on discussions at Essex explores how system dynamics is adopted in schools. At the local level, what resources are needed, and when, for curriculum development, training programs and mentor salaries? How fast can the adoption successfully grow? How do we overcome entrenched resistance within schools and in the broader community? The generic model addresses similar issues at the national level: How do we allocate limited development dollars – curriculum development, training, or mentor support? For greatest long-term impact, do we focus efforts on a few schools or spread the funds over many? This simulation model will help us surface and quantify assumptions on these important complex issues, identify leverage points and test various policies. It will help us make decisions on how to proceed.

The core of the model is the "infection model." Individual innovative teachers try system dynamics, experience success with their students and convert other teachers – that is, if all goes well. The model explores the feedback effects of factors that influence the process of adoption, including those that cause teachers to give up. These include the quality and availability of materials, the availability of mentoring help, and the effects of natural resistance to change. The model addresses the need to cross the "chasm" between enrolling the innovative early adopters and engaging the vast majority of teachers who will need stronger evidence of proven benefits before changing the way they teach. The following diagram models the adoption process.



Other sectors of the model deal with curriculum development and adoption, the expansion of system dynamics within the total curriculum, mentoring, and quality issues. For example, quality is important to sustainability because poor quality materials can lead a teacher not only to stop using system dynamics but also to convey negative opinions to colleagues.

This system dynamics model is still being refined. We will use it as a tool to explore policy alternatives. Meanwhile, we will also use the process of refining it as a way to expand and deepen our own skill and understanding of system dynamics. Finally, we will distill the model's basic feedback lessons into a simpler format so that we can use them to educate a wider audience.

Back to the Top