Go Back

Moving Forward with System Dynamics in K–12 Education: A Collective Vision for the Next 25 Years

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ABSTRACT

Roughly 20 years ago experimentation began in the use of System Dynamics in K-12 Education. In the last ten years, a number of experimental projects have clearly demonstrated that the use of System Dynamics can have a dramatic impact on the depth of learning by K-12 students. This early developmental stage of K-12 usage has pointed to the next steps. For System Dynamics to have a wide-spread impact on K-12 learning, increased teacher and community exposure to the concepts, large scale development of appropriate curriculum materials, and increased support for bringing the materials into the schools are necessary. To this point, only the some of the "innovators" have been engaged in the effort. A plan for the development, testing, and distribution of these materials has been developed by a group of ten of these "innovators" who met for two days in October. This plan presents an incremental approach taking advantage of leverage points within the existing curricula and educational practices, while calling for increased involvement of the larger System Dynamics community.

Key Words: K-12, pre-college, teacher training, community support, curriculum development

The idea of bringing system dynamics concepts and tools into the K-12 educational environment probably has its origins with some of the work done by Nancy Roberts roughly two decades ago. Her early work provided an initial indication that it would be possible to teach some systems concepts to children in the late-elementary to middle school range. The development of STELLA software by High Performance Systems provided a modeling tool far easier to use than DYNAMO. This opened the possibility of dynamic modeling to teachers who did not have strong programming backgrounds, and also suggested that such work might be possible for older K-12 students as well.

The ensuing years have seen extensive work by a number of small local projects and a few larger groups, most notably the Waters Foundation funded schools and the National Science Foundation funded CC-STADUS and CC-SUSTAIN projects. All of these projects have had a mix of successes and problems, yet all have shown that the use of system dynamics in the classroom is a viable way of helping students to analyze problems in greater depth, developing a fuller understanding of a situation that excludes simplistic answers. From the work they have published, it is clear that the various systems tools (Causal Loops, Behavior over Time Graphs, Stock-Flow diagrams, and functional dynamic models) can be used at a variety of different levels.

In the early stages of experimentation, groups and individuals tended to stake out positions based on their own experiences, their own successes and difficulties. As a result, the community doing this work was somewhat fractured, actually at times working at cross-purposes. With the maturing of our understanding of the use of systems tools, a much more reasonable and realistic understanding of the total picture is now broadly accepted. The value of each tool is now generally accepted by all groups. Focus on one to the exclusion of others ignores the power of each tool in building better understanding of the systems.

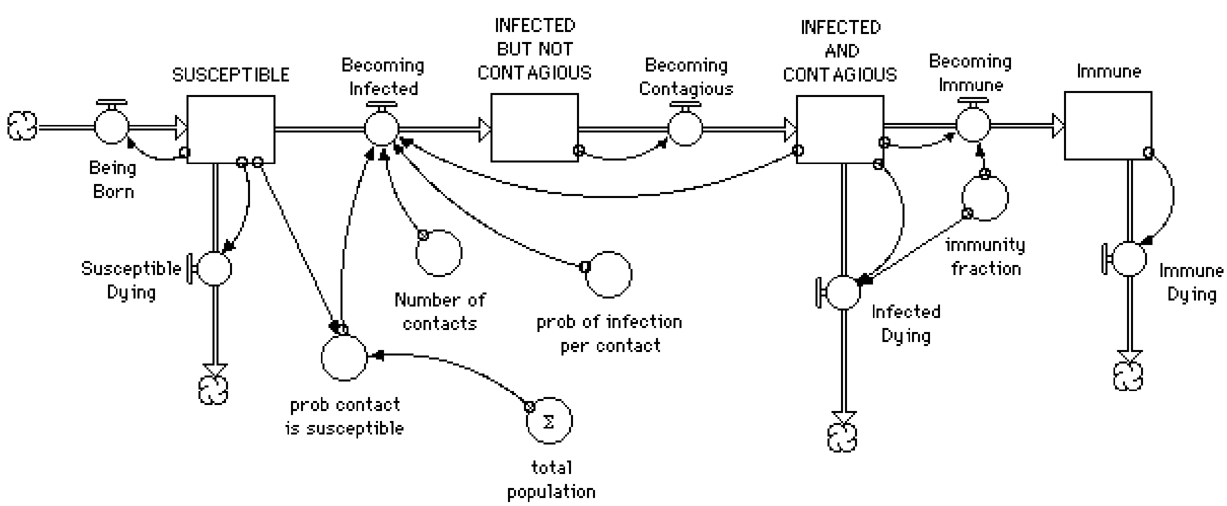
This realization has been facilitated by the sharing of insights within the broader K-12 systems community. The idea that use of all these systems tools can help build student understanding is no longer subject to dispute. We have seen repeated successes. At the elementary level, teachers use literature (e.g., “Rainbow Fish”) to develop an understanding of Behavior Over Time Graphs (BOTG’s). Jan Mons, among others, has shown that students can develop more complex ideas from them, including delays. Some work at this level has also been done with simple stock–flow diagrams and fully functional dynamic models. Others have shown how tools can be used at higher grades. Alan Ticotsky and Rob Quaden use casual loops, BOTGs, and stock flow diagrams in the elementary grades. They even have students in the upper elementary and lower middle school grades building basic models with some guidance. Middle school work at a number of locations, most notably Catalina Foothills, Tubman and Jackson Middle Schools in Portland, Oregon, and in several schools in Vermont and Massachusetts, has broadened to range from simple use of BOTGs to actual development of models by students. High school students see models used in virtually every discipline, and seven schools in the Pacific Northwest now have formal modeling classes.

The idea of teaching and using system dynamics in schools was met with initial skepticism by some. How could concepts taught at the graduate level at MIT and Bergen be brought to a fourth grade classroom? The reality that this can be achieved has been well documented. The future of this work must arguably be the next focus of the SD/education community. System Dynamics will never have the impact on human culture that advocates claim it could have without its tools becoming part of every citizen’s decision making process. Its power cannot be realized without broad exposure.

The work on the use of system dynamics in education is in its infancy. The number of teachers using system dynamics has grown from a handful fifteen years ago to perhaps 1000-2000. This is an impressive increase, but the number of systems users is still less than 0.05% of all teachers in the United States. Most of these teachers are “episodic” users, that is, they use models or other tools once or twice a year to explore specific topics. The “regular” users, those who have incorporated the use of systems more broadly in their teaching, probably number fewer than 200.

Advocates of the use of system dynamics in education have always counseled patience. They tend to use the metaphor of infection, which has been frequently modeled and used in classes, to describe their work. They point out that whether discussing the development of an infection in an individual, or the spread of an infectious disease in a population, the infection is virtually invisible in its early stages. Their numbers are so small that they appear to have no effect. They can be easily missed or ignored. Systems usage in K-12 education behaves similarly, they believe. There are a few system dynamics users now, but they gradually infect others, leading to the exponential growth they love to model. Diseases can be wiped out if the first individuals infected are quarantined in time to arrest the spread. But once the number infected is large enough, the progress of the disease is hard to arrest. So, too, we hope, the spread of systems. The number of users is too large to be wiped out. The spread is inevitable. This scenario has parallels in other educational innovations. The use of computer interfacing in secondary physics is the example most commonly used. Twenty years ago only a handful of physics teachers used computer interfacing to collect lab data. Now, interfacing is used in most high school physics classes. This experience give hope to systems advocates.

Jay Forrester asserts that we make decisions based on our mental models. Supporting our mental models, testing our understanding with dynamic models, allows us to refine our mental models, making better decisions possible. Most commonly, however, we only abandon an existing, comfortable mental model when confronted with a crisis, when our mental model and reality conflict. Such a situation has occurred in the educational use of system dynamics. There is an obvious difference between the early, experimental work that has been done in K-12 systems work and full use in large numbers of classrooms and schools. The groups doing the developmental work have little experience in dissemination or wide-spread application. Their creative work has been impressive, their success at expanding use far more limited. This awareness has been slowly emerging for the last two years. Further, some groups have run out of resources to support their work. The CC-STADUS/CC-SUSTAIN Projects are at the end of their NSF funding cycle. Trinity College closed, placing the Waters Center in transition. These factors provided the impetus for a meeting facilitated by the Creative Learning Exchange in October, 2000. The focus of the meeting was a reassessment of what was necessary to insure the further growth of the use of System Dynamics in K-12 education. The intent was not to merely look at the short-term growth, but, rather, establish a plan for the next 25 years, a plan that recognizes the magnitude of the change in focus and effort required.



Typical model of the spread of an infectious disease

A second look at the infection model and the physics experience is instructive in recognizing how the vision must change. The infection models students use have three key components that relate to the systems vision: Probability of Infection per Contact, Number of Contacts, and Fraction Immune. The task facing those spreading the systems dynamics infection is maximizing these first two factors and minimizing the last. How do we infect new teachers? How can we convince them that use of systems tools will improve their instruction and their students' learning? The obvious answer is that we must expose the teachers to use of systems and demonstrate the effectiveness of the tools and techniques. This presents two significant problems. The first involves the exposure. For teachers to commit time and resources to using new materials and ideas, the materials must be readily accessible in a usable form. A three hour workshop, or even a three week institute, is not sufficient if there are few materials available for immediate use in the classroom. Unfortunately, that is currently the case. At no grade level, in no content area, are well developed and tested materials which can easily fit existing curricular topics available. The single exception may be in high school mathematics, where Diana Fisher has published material for algebra, pre-calculus, and calculus. However, these materials are a starting point and have not yet been broadly tested the way most commercial materials have been. We cannot equip teachers with the tools they need, because they don't exist yet. Thus, the probability of "infection" is very low.

Teachers may be broken into four broad groups:

- **Innovators** In any educational change, the innovators generate the first test materials, push the limits of existing practice. These teachers are a fraction of one percent of the teaching population. They are the people who have done the work in K-12 systems thus far. They have a high probability of becoming infected with only a single contact, but their high levels of openness and creativity mean that they are often overcommitted and unable to become heavily involved in the spread of systems.
- **Early Adopters** Early adopters probably make up 2-5% of the teachers. These are risk-takers who will try new ideas, perhaps even adapt them to their own unique situation. However, they must be given something to work with. At this time, the quantity and quality of materials in K-12 System Dynamics is insufficient to provide them with what they need. Their probability of infection from a single contact is high, but the problem of overcommittment is similar to the *Innovators*.
- **Average Teachers** The average teacher will only begin to use new ideas and materials when they have been more broadly accepted. They are not risk-takers, but will change willingly if shown a better, more effective way. They, however, need materials more fully developed than the early adapters. Using the infection metaphor, their probability of infection changes as the size of the infected population (Number using system dynamics) increases. Similarly, the probability of infection per contact will increase as well.
- **Resisters** They will avoid change at all cost. The are the percent immune". Some can be converted, but only very slowly. They may reluctantly join when the "innovations" become the norm. Their probability of infection remains very low until the number infected is very large. Multiple contacts will also probably be necessary.

The question of whether or not the systems techniques and materials (assuming they exist) are effective, that is, improve student understanding, remains key to bringing both the early adopters and the average teacher into the systems "camp". This directs attention to assessment, a topic that the K-12 community has repeatedly considered, with little concrete action. At this point, only the Waters Foundation projects are making any attempt to conduct usable assessment. They are forming "Action Research Groups" to try to obtain hard data about the use and success of systems materials and concepts. All previous assessment has been anecdotal. Yet even the Waters effort may not be convincing to the "unconverted". To present a persuasive case for the efficacy of system dynamics in K-12 education, outside assessors must be brought in and allowed to develop the assessment. The expertise must be "bought", as one participant in the meeting put it. Assessment must be accorded a priority nearly as high as the development of materials

This simple re-visiting of the infection model points out the assumption that usage of system dynamics will simply continue to grow is an over-simplification of the real situation. "Probability of infection per contact" and requirement for susceptibility are different for different groups. The *Early Adopters* are very receptive. A single exposure through a presentation at a local or regional conference may well be enough to motivate them to try systems in their classes. *Average teachers* may need multiple and longer exposures coupled with a level of acceptance in the broader educational community. Just as our students learn to look for the over-simplifications and inaccuracies of models they use in our classes, we need to revisit our own mental models to see how they can lead us to incorrect conclusions.

The growth of computer interfacing in physics as a metaphor for the growth of system dynamics use presents similar pitfalls. The use of computers in physics allowed students to do something they were already doing in a better, faster, more effective and accurate way. It was an improvement in technique, not a major change in content and delivery. The use of systems, in contrast, is a major step away from traditional methodology and intent. It is not a simple logical extension or improvement in technique. To the contrary, it is a major shift in emphasis. Proponents will maintain that it is merely an improvement in instructional technique and tools, but the task of convincing teachers to use systems dynamics is far more difficult than convincing physics teachers to use computers.

The optimistic and simplistic assumptions about the future growth of K-12 systems use presented the group that met in October with a new, daunting, yet stimulating problem Where did we want system dynamics to go in education? Revising our model of how systems use would grow required a new plan, a new "vision". What must be done now? How could we start the process. Recognizing that further exploration of what can be done will change the vision, how can we insure a structure that will continuously change the plan? The response to these questions, the focus of the remainder of this paper, must be taken as a work in progress. In large measure what is suggested is speculative. A small conference, with fifteen to twenty participants, tentatively including Jay Forrester, George Richardson, Barry Richmond, Lees Stuntz, and some of the most active and influential educators working in system dynamics, is planned for late June to refine the general outline presented here. It will be the first step in a multi-year effort to expand exposure and use of systems tools on a larger scale than previously attempted, to move from the experimentation level to wide–spread use of systems in education. A major component of this effort will be the inclusion of groups that have previously not been involved in the effort, with the final goal the establishment of a stable, long-term organization dedicated to development and dissemination of K-12 system materials.

WHY NOW?

Before attempting to delineate how we propose to expand the use of system dynamics in education, a clearer identification of what the vision is and why this is the appropriate time to pursue it is reasonable. The vision itself has been articulated by many people in many ways. The common thread is easily identified.

- We assume that use of systems concepts and tools is a better way of analyzing problems and arriving at policies to deal with the problems.
- We further assume that everyone can learn and use basic systems concepts, including the ability to run models and evaluate their output.
- The goal of education must be preparing students for their role as intelligent citizens. System dynamics tools and concepts prepare students for this role by developing critical thinking skills.
- Understanding developed through use of systems tools and concepts is transferable, that is, behavior patterns presented in one discipline will be recognized and applied in other fields.

- The understanding developed using systems tools and concepts is inherently "deeper" than the results of traditional instructional methodology.
- To adequately prepare students for their role as intelligent citizens, systems concepts must be an integral part of K-12 education. Lacking this background, our students would be as handicapped for the future as an illiterate is in our current society.

The goal then, is to equip all students with the critical thinking skills that system dynamics develops. They will be able to look at problems in a way that will exclude the possibility of simple answers for complex problems. They will understand patterns of growth and interaction that will allow them to make better informed decisions. As individuals and citizens, they will be equipped to analyze and understand rather than react.

These outcomes require a major change in the way instruction is delivered in our schools. System dynamics, rather than being an episodic "plug–in", would have to be ubiquitous in the curriculum. Students would use it as a learning tool or thinking strategy from early years on, across the curriculum.

This particular moment in time is a especially advantageous one during which to act. There is a significant body of experience and expertise developed in the use of systems in education. Though there is still much to be done, we do have a broad understanding of what works. Some of those involved in this effort are now faced with a decision whether to continue to pursue work in the field or turn/return to other disciplines. The critical mass of experienced practitioners that exists now may actually diminish in the next few years if they are not involved in new efforts. Existing funding sources are unlikely to grow, and those resources cannot realistically be expected to provide the resources necessary for an expansion of work. Thus, while the human resources are available, a new effort to obtain support must be made to allow work to go on to the next level. At the same time, public interest in educational improvement is high and on the rise. This suggests that this is an extraordinarily good time to seek support for an expanded effort to bring system dynamics to K-12 education. Now is the time to begin the journey that will probably take as much as fifty years or more, so revolutionary is the change!

EXTENDING THE VISION

There are three major considerations in extending the use of system dynamics in schools. Increasing visibility of the work and recruiting new users, development of materials, and enlistment of local support groups will all be necessary before the use of systems can truly evolve as the core of the educational system. Of these three, perhaps the most important is the development of materials designed for use in conjunction with existing curriculum topics. Without materials, exposure to the ideas will not result in adoption. Without viable materials, there is little chance of mustering support for change. Therefore, development of materials must be a major consideration in the effort. Successful use of system dynamics on a large scale in any content area will increase visibility and acceptance more quickly that any other effort. If the content area is one broadly taught, but not usually employing technology, the impact will be still greater.

Very few appropriate materials exist at the current time. Bits and pieces have been put together by a variety of people. The 50+ physics models released by the CC–SUSTAIN grant show one possible progression of model development and use, but lack curriculum support materials and an instructor's manual. The materials recently developed by Jeff Potash and John Heinbokel focusing on the role of smallpox from a biological and historical perspective are perhaps the closest to what will be needed. Those materials, however, assume a comfort level with systems concepts that is extremely rare. They demonstrate the types of materials that may eventually be used when systems concept are broadly used, not the type of transition materials that will lead to more systems use.

It is clear that early in any effort to develop materials, standards must be developed for what good materials should look like. It is necessary that, as a preliminary to developing materials, a group of successful teachers using system dynamics and System Dynamics professionals meet to define what quality materials should look like. The inclusion of System Dynamics professionals is essential. None of the teachers using system dynamics have any significant formal training. Inclusion of professionals will insure that any models, stock/flow maps, or causal loops follow good, standard system dynamics conventions. The guidelines developed will allow people to begin work with a clear idea of what the "product" should look like. This will insure an initial uniformity in materials that, like the universal "cut" and "paste" commands introduced by the Macintosh 17 years ago, will allow users to move confidently from one set of materials to another. This is particularly important because no such monitoring of materials has been carried out in the past. As a result, current materials are widely varying in quality, utility, and adherence to good systems practices. The continued use of some of these materials can actually threaten the growth of systems. Every group, probably every individual who has released curriculum materials in system dynamics, has some materials that, in light of our current understanding, they wish would simply "disappear". A cleansing, a culling of these materials would probably be a good preliminary step in the process of developing materials.

New curriculum packages must include student materials, teacher's guides, models and other tools as appropriate, troubleshooting instructions, and suggestions for extensions. The teacher materials must include illustrations of pitfalls and commonly made mistakes. The materials must be modular, that is, in the case of broad topics, they must be broken down into small, free–standing pieces. Experience has already taught the K–12 system dynamics community that 6-week long units will not easily fit into a curriculum. Two–to–four day activities focused on a topic already taught can and will be used if they are of a high enough quality. A coherent set of these materials that develops many topics covered in the standard curriculum of a content area will allow system dynamics materials to gradually "infiltrate" the curriculum. Episodic use will blend into consistent use.

Before the new materials can be developed, the sequence of system dynamics skills must be agreed upon. Focus must not merely be on the sequence in which various systems skills and tools should be developed. It must be done in the context of developmentally appropriate skills at each age. Experimentation has been done with a variety of tools and skills at each age level. Little attention has been paid to reconciling these efforts with the research done in cognitive development of children and adolescents. The results of this research must be integrated with the system dynamics sequence. This will increase the level of success achieved with any materials developed. Inevitably, this will extend the time line for bringing systems into the core of education, but it will enhance the probability of success as well as increasing the creditability of the effort. The systems community has little experience in this area. The Waters Foundation action research groups are a beginning which must be extended. Efforts must be made to enlist educators and educational researchers with experience in theses areas in defining the sequence.

Since the scale of the work anticipated dwarfs anything done to this point, more people need to be involved in the dialogue about the sequence of skills, with continuous re-evaluation as curriculum materials are released and used. Eight years ago most people assumed significant modeling could only be done by eleventh and twelfth graders. The modeling classes taught in some schools began recruiting freshmen five years ago, who soon proved they could model quite well. More recently, some modeling has been done down to the sixth grade level. Similar downward shifts have taken place for other systems tools. Larger scale implementation of system dynamics will require continuous monitoring of this pattern.

Once these guidelines are developed, ongoing support for curriculum writing must be provided. One possible approach would involve two or three week summer sessions in which curriculum materials were developed by both teachers and system dynamics professionals. These materials would then be distributed for testing the following academic year. The following summer, the use of the materials would be analyzed, with necessary modifications made. This would be followed by a second year of testing, another summer of evaluation and modification, and finally, release. This two-year timeline from initial development to release is far different from current practice, in which materials developed last week are frequently being distributed by the end of the month. However, if the materials are to be taken seriously, they must meet the standards established by traditional publishers. This introduces a cost and delay that has not previously been encountered, but is necessary for materials to have creditability. It is also necessary for adequate assessment, a consideration that will be dealt with in greater detail later.

The delay implied by the two–year development cycle reminds us that the process suggested here will require the patience of a true believer in system dynamics. It is clear that a significant impact in even a single curricular area is at least 5-8 years off. To suggest that the whole process may take twenty-five or more years is, if anything, an optimistic estimate. Rushing, however, can damage the process. Innovation is always risky. When done badly, it can strangle the changes before they have a chance to show their potential. That is not only a compelling argument for caution and patience, but further argument for review of existing system dynamics materials and withdrawal of some from use. Those infected with a disease who recover often retain immunity. Their presence in the population increases the overall immunity of the system. In education, those who try an innovation and are dissatisfied with it not only become immune to it, but end up acting as "vectors" for the immunity, which can spread like an infection itself. We cannot afford that.

At the secondary level, curriculum development should focus initially on single discipline materials. These materials lend themselves to easy inclusion in existing courses. This will speed the initial exposure of teachers and students to system dynamics. The first work should be done in content areas where systems thinking can have the greatest impact. The number of students taking courses in the discipline should be a serious consideration, as should use of the materials in more than one course in the content area. This means that some areas with a lot of developmental work, like physics, could be a lower priority than areas in which relatively few materials have been developed to this point.

The two high school disciplines which have the most promise are social studies and biology. The social studies curriculum has evolved over the last thirty years into an analytic discipline in which policies and their underlying causality has replaced a focus on names, dates, and events. It has a strong preference for the why rather than the what. Dynamic models allow exploration of the "why" and the "what–if?", further extending the depth of understanding through experimentation. Most topics in biology also lend themselves to modeling and systems approaches. Models allow both experimentation and extension of the concepts. From Ecology to cellular metabolism, biology is replete with opportunities for modeling.

Both of these disciplines have a substantial body of models developed for them, but no large body of coherent curriculum materials. These models provide a starting point. Development should simultaneously refine existing materials while identifying other topics which are appropriate for treatment with systems tools. It is important to utilize all systems tools, not merely models in developing these materials. Of course, many more models and systems activities covering other biology and social science content are needed to provide the range of materials, but at least there is a body of work to examine and build on.

At the lower grades, where so much learning is inherently interdisciplinary, materials that are both single–discipline and cross–curricular can be developed in the early stages. Perhaps the most leverage in the primary grades can be obtained through linkages between literature and BOTGs. However, continued work shows that Causal Loop diagrams and even some use of stock–flow diagrams or simple functional models have their place here as well. The upper elementary grades provide similar ranges of options, combined with increased depth of content. In the middle school grades, more use of single discipline models and associated activities will probably require development of materials similar to those for secondary classes, but developmentally appropriate. It is vital that, as those materials are developed, writers keep in mind that middle school students are not merely “short high school kids”. Their experiences, their emerging maturity, and their analysis of problems are very different from older kids, a reality often ignored in the development of teaching materials.

Wonderful, well documented materials promise to bring the power of system dynamics within the reach of every teacher and student. That is, if the teachers learn about them and learn how to use them. This suggests that as materials are developed, a parallel growth in teacher exposure and inservice training for teachers is necessary. The best materials and the most effective training materials will not move the vision forward without a major new effort in “infecting”. Currently, most people become involved in the use of systems in schools through contact with those already utilizing systems, or through a workshop focusing on systems use. Efforts to expose a large number of teachers began with the NSF funded CC–STADUS and CC–SUSTAIN grants. No other group attempted “infection” on this scale. To be effective, efforts must continue and grow in scale. No matter how virulent the “infection”, it can’t spread without contact. To this point, the “number of contacts per infected person” has been small. Before the use of systems can grow, there must be a major change in this part of our infection model.

While the CC–SUSTAIN project has regularly presented sessions at local, regional, and national science and mathematics conferences, little similar work has been done by other groups. No group has aggressively pursued what is potentially the most fertile soil, the Social Science community. Major efforts must be made in this area. Success stories must be identified and spread. Presence at all types of K–12 conferences must be a priority. Local media coverage must be pursued by emphasizing the development of higher–ordered learning skills, increasingly a priority and educational “buzz word”. Teachers are not trained in sales, but must enlist those who can sell systems. This will probably require assistance from local system dynamics professionals who have multiple contacts with businesses and others who can increase the visibility of system dynamics in education. In “Field of Dreams”, we hear “If you build it, they will come.” Well, they can’t come if they don’t know about it! Exposure of the general public as well as other teachers to educational use of system dynamics is probably the greatest area of weakness in the existing K–12 movement. It is the one area where assistance from the broader system dynamics practitioner and “purchaser” (businesses that demonstrate a belief in the usefulness of system dynamics through their use of consultants) communities are the only real hope.

One consideration which should ease the recruitment of teachers will be increased and improved assessment. Clear evidence that the use of system dynamics will improve student learning will be a powerful attractant. That will require something that has never been done before in the K–12 SD community – a seamless connection between development, use, and formal assessment. In part that has never been done because the budget has never been there for it. Additionally, there are no individuals within the current K–12 systems community with significant expertise in assessment. If a large scale effort is to be made to develop system dynamics as an integral part of the educational experience, the time, effort, energy, and financial resources must be devoted to a comprehensive assessment program which will convincingly validate what the enthusiasts already believe. Without the creditability assessment can provide, systems will never progress beyond the status of a fringe player in education, regardless of how much exposure it gets.

Assuming that system dynamics becomes more visible and the demand for training increases, a minimum of three levels of training will be needed. Two of these three levels already exist, although not necessarily in the form they will ultimately take. The basic level of training should be focused on broad use of systems concepts and tools. Based on the experience of the various groups involved in training, a full week for this program will probably be required. Initially the training would be intended for the group identified as the early adopters. The teachers would get a basic exposure to all of the basic tools of system dynamics, including building and running basic (one or two stock) models. The focus would not be on model building, but rather on causal relationships, feedback, delays, and interpretation of BOTGs. The current program most similar to this training would be the one–week sessions developed by Heinbokel and Potash. Participants would leave with a basic background in the language and concepts of systems and a basic ability to use models. As the use of systems grows, this type of training will be modified to fit what has been described as the average teacher. The exact emphasis may shift as systems use changes. Almost certainly the training will not be "one size fits all". The range of training modalities should fit the range of teachers and environments they work in. Some training may be grade-level specific, some may cut across grade levels, as has been the case with much of Heinbokel's and Potash's work. Discipline specific training as well as interdisciplinary training will probably be developed. The magnitude of the task and the diversity of needs will result in many different approach To be successful as introductory training, however, they must emphasize development and use of all the systems tools.

The intermediate level of training will focus on more detailed and sophisticated use of tools, usually emphasizing a single tool. The current summer institute run by CC–SUSTAIN most closely approximates this training. However, its focus on modeling and model building will not necessarily be the focus of all training at this level. For system dynamics to grow, there must be a much larger body of teachers able to develop models, applications of other tools, and curriculum. Such teachers will need this level of training. Current experience suggests a minimum of 8–10 days for this training. This greater time commitment will provide a self selection process for those interested in more serious pursuit of systems work. Most teachers will never need nor take this level of training.

Once again, there are likely to be alternative paths. Some training may focus on curriculum development that can be done without focusing on a single tool. The core concepts of system dynamics constantly remind us that simple causality, simple progressions, simple solutions rarely have anything to do with real–world problems. Changing education, one of the most conservative and tradition-bound institutions, will require many different paths.

The experiences reported by all groups currently working with teachers make it clear that a vital element of all the training must be ongoing support and nurturing. The learning curve need not be steep, but it is certainly long. As more experience is gained in large–scale use of systems, as more assessment is done, the understanding of the learning and teaching process will improve, but a systems approach is a significant enough change to require a lengthy transition. This transition will require continuous support in the form of workshops, discussion groups, and continuous training and experimentation. This means that significant financial support must be committed to the process of bringing new users to a high level of comfort with the new tools. Such ongoing training is the norm in business and industry, where "refresher" courses are part of the normal training cycle. By contrast, educators seem to think one single half–day training does the job forever.

The final level of training anticipated involves more sophisticated instruction in dynamic modeling and other system dynamics tools. Right now no programs beyond the sophistication of the CC–STADUS style training are readily accessible to teachers. Such options must be made available to provide those who wish to develop a more sophisticated understanding of system dynamics the necessary resources. While these teachers will remain a very small minority, if system dynamics really does become widely used the demand for such training would dwarf the capacity of all the system dynamics graduate programs presently available in the world. More importantly, these teachers would not benefit from the types of programs currently in place. The connection with the classroom would have to be maintained at all times. This would require the development of instructors for this training who can exist in both worlds, that of standard system dynamics applications and the K–12 classroom. Whether these people come from the ranks of current and future system dynamics professional, or from the ranks of teachers, they and the courses they will teach do not currently exist and must be developed.

To facilitate all levels of training, alternative methods of delivery must be explored. Both the Waters Center at Trinity for System Dynamics and the CC–SUSTAIN project have looked into the possibilities of distance learning activities. This may ultimately evolve into a major methodology for providing both basic and intermediate training. In the interim, areas with an established K-12 system dynamics presence will probably function as the training centers. It will be vital to involve professional system dynamics practitioners in the operation of these training sites and the development of training materials to ensure compatibility with the existing conventions of system dynamics usage.

The vision articulated here suggests a major change in the way students are educated. It may trigger major changes in the structures of schools. It certainly will result in major changes in what is taught and how it is taught. Such changes cannot reasonably be achieved by the educational community acting in isolation, much less a small subset of that community. It can only take place through the establishment of connections and communication among all the stakeholders, all the individuals and groups who will be affected by and benefit from the changes. The Society for Organizational Learning has already been approached for assistance in applying its expertise to the effort. Connections between schools, universities, businesses and communities must be established. In particular, businesses which use system dynamics must be involved as advocates for application of system dynamics concepts in schools. Their own self–interest would argue that more system dynamics in schools would provide the world with a more effective work–force. This type of mutual support and communication would have been unthinkable a decade or two ago. With greater public concern about education and the increased visibility educational reform has gained, what happens in schools increasingly involves more “players”. To make system dynamics the centerpiece of educational change will require more effort, more resources, more influence, and more involvement of those outside the traditional educational infrastructure than any previous reform efforts. It also holds more promise for the future. The effort must be made.

It is clear that the effort will vary from environment to environment. Smaller school systems clearly have an advantages and disadvantages in bringing system dynamics into schools. Small districts can be more nimble and change more quickly, but are also more directly accountable to the community. While the bureaucratic inertia may be less, the community inertia can replace it in resisting change. People care what happens to their kids, know what is happening, and talk about it. Close attention is paid to the budget by local taxpayers. In order to effect change in these communities, all stakeholders must be brought along and assured that the change is a good thing. Resistance cannot be sidestepped. It must be met head on. District or building administrators are key in this environment. If they have the trust of the community and staff, they can drive change forward at a rapid pace. Scheduling, funding, professional development, released time, and other variables that can support or inhibit change are under their control. Similarly, community leaders as advocates can play a major role in reform. The number of individuals involved, however, is small, the task less daunting than in large districts. The possibility of community involvement leading to a reinforcing loop driving system dynamics forward in schools can become a reality in smaller communities if efforts are coordinated and the idea is “sold” to the community by a concerted effort.

Larger communities cannot hope to effect the same changes as quickly as smaller ones. Urban districts are less sensitive to the actions of individual administrators and community members. Nonetheless, the process that works in smaller community schools can be brought to the larger systems. Just as other reforms come to parts of large school systems through changes in part of them, ranging from individual buildings to clusters of schools, system dynamics can be spread by a few key teachers, administrators, or community members a building at a time. This represents another example of the infection model. In working with urban districts, we must find pockets of support and cooperation, then support and connect them. If this can be done, the same reinforcing loop more easily established in small communities can evolve. If the small districts move more quickly, they can be the guide, the example which will make the work in the larger districts easier.

Whatever the district size, the community profile, the task is the same. To make system dynamics a key part of every student’s educational experience, teachers, administrators, and system dynamics professionals must make an unprecedented effort to develop public awareness and support for the use of systems. This commitment must not only involve time, but financial resources and influence. If we truly believe in the potential, we must make the effort.

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