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Learning through System Dynamics as Preparation for the 21st Century

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What should system dynamics accomplish in kindergarten through twelfth grade schools? We do not expect most students to spend their lives in front of a computer building system dynamics models. What then should be the outcome of a systems education?

I believe we should give students a more effective way of interpreting the world around them. They should gain a well-founded confidence for managing their lives and the situations they encounter.

The objectives of a system dynamics education might be grouped under five headings:

1. Developing personal skills,
2. Learning about economic behavior,
3. Shaping an outlook and personality to fit the 21st century,
4. Understanding the nature of systems in which we work and live,
5. Achieving the benefits of a systems education.

1. Developing Personal Skills

A system dynamics education should:

1. Sharpen clarity of thought and provide a basis for improved communication,
2 Build courage for holding unconventional opinions,
3 Instill a personal philosophy that is consistent with the complex world in which we live,
4 Reveal the interrelatedness of physical and social systems, and
5 Unify knowledge and allow mobility among human activities.

1.1. Basis for Clear Thought and Communication

The ordinary spoken and written language allows a person to hide behind ambiguous, incomplete, and even illogical statements. Language, within itself, does not impose a discipline for clarity and consistency. By contrast, computer modeling requires clear, rigorous statements.

In ordinary discussion, a general statement like, “How people respond depends on the situation,” might be accepted. But, if this were to become an input for a model, one would be forced to specify which people, what response, dependence on what specific aspect of the situation, and what precise action would be taken under various conditions.

Students must struggle to achieve the precision of expression required to go from ordinary language to explicit statements in a simulation model. Even a process as simple as filling a bathtub with water, or describing the cooling of a cup of coffee, can be surprisingly demanding. Such clarity is not achieved after only a few exercises. Learning precision in thinking requires years of reinforcement.

Translating from descriptive language to model language is only half of the story. One can then make the reverse translation. From a simulation model, reverse translation to descriptive language yields clear statements that embody the precision that came from building and using the model.

I experienced the power of reverse translation from a system dynamics model after publication of my *Urban Dynamics* book dealing with the growth and stagnation of cities (Forrester, 1969). The book achieved such visibility that I would often be invited to conferences on urban problems held anywhere in the world. At such meetings, I had a unique power and influence derived from being able to talk for 20 minutes without contradicting myself. Not contradicting oneself might seem an ordinary competence. But others could not hope for comparable clarity because of incompleteness and inconsistency in their thinking about complex situations. Furthermore, they could not draw the correct dynamic consequences for the future implied by the assumptions they were making. To know the behavior that follows from assumptions about parts of a system can be achieved only through modeling and computer simulation.

In my situation at conferences on cities, I knew the assumptions that went into the *Urban Dynamics* model. I knew the behavior that resulted from those assumptions. Also, I knew how the behavior would change if one adopted different political policies for guiding the evolution of a city. Within the framework of the model, I could be entirely consistent in everything that I said. Of course, one can be internally consistent and still be wrong compared to the real world. So, beyond consistency, it was necessary that the model also overlay and connects with the issues of interest to others.

Students should come out of a systems education convinced that a much better understanding is possible in the present puzzling behavior of personal, social, economic, and business situations. They should realize that any debate about policies for the future can be clarified and made more meaningful if someone will make the underlying assumptions explicit and show which assumptions lead to behavior that best fits the knowledge we have of the real world.

Students in K-12 should have the repeated experience of using modeling to resolve debates, misunderstandings, and differences of opinion. One discovers that the most intense disagreements usually arise, not because of differences about underlying assumptions, but from different and incorrect intuitive solutions for the behavior implied by those assumptions. In building a system dynamics model, one starts from the structure and the decision-making rules in a system. Usually there is little debate about structure and the major considerations in decisions. When a model has been constructed from the accepted structure and policies, the behavior will often be unexpected. As the reasons for that behavior become understood, I have often seen extreme differences of opinion converge into agreement.

Students should see modeling and an understanding of systems as a way to reduce social and political conflict.

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1.2. Building Courage

A strong background in modeling should show students that conventionally accepted opinions about social and economic policies are often actually the causes of our most serious problems. If they realize that popular opinions are not necessarily correct, they should develop courage to think more deeply, look beyond the immediate situation, and stand against majority opinion that is ill founded and short sighted.

Working with models should not only enhance skill in making precise statements, but also bolster the courage to do so. Very often people take refuge in statements that are so general, so incomplete, and so superficial that they cannot be proved wrong. On the other hand, such vague statements cannot be effective.

Making precise statements opens one to being wrong. By a precise statement I mean one that is unambiguous. A precise statement has a unique meaning; it is clear. However, a precise statement is not necessarily accurate or correct. Precise statements are necessary for clear communication. If such statements are wrong, that will be more quickly discovered if communication is clear. In model building, students will many times have the experience of making assertions that model simulations then demonstrate to be incorrect. Students should develop the courage to be precise, even if wrong, in the process of learning and improving understanding.

1.3. Personal Philosophy

Experience in computer simulation should change the way students respond to the world around them.

From simulation models, students should appreciate the complexity of social and economic systems, whether those systems are at the level of families, communities, corporations, nations, or international relationships. They should have seen many times the counterintuitive nature of such systems. They should understand that “obvious” solutions to problems are not always correct, and that apparently correct actions are often the causes of the very problems that are being addressed.

The *Urban Dynamics* book illustrates how well-meaning actions can worsen conditions that the actions are intended to alleviate. The book shows how most popular governmental policies all lay somewhere between neutral and highly detrimental, either from the viewpoint of the city as an institution, or from the viewpoint of unemployed low-income residents. The most powerful influence on a city is shown to be the policy governing building of low-income housing. The United States through the 1960s and 1970s followed a policy that made urban poverty worse. As a city ages, it becomes imbalanced. As industrial structures grow older, they are used in ways that employ fewer people. However, as housing ages, it drifts to lower rents and higher population densities.

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Building low-income housing accelerates the rate of decay. The "obvious" policy of building low-cost housing, in the hope of alleviating poverty, occupies land that could have been used for job-creating business structures while at the same time the housing attracts still more people who need jobs. The apparently humanitarian policy of building more housing actually creates poverty by pulling people into areas of declining economic opportunity.

We can hope that students will develop caution about jumping to premature conclusions and will search for a wider range of alternatives.

Even if individual students do not construct models in later life, they should expect that those who are proposing changes in economic and social policies would construct system dynamics models. Moreover, in the 21st century, citizens should expect that such models will be made available for public inspection. From their K through 12th grade experiences they will know that they can read, understand, and evaluate such models. More and more, computer models will be used as the basis for determining social and economic policies. In order to participate, the public will need to know the nature of such models, to evaluate the assumptions in models, and to feel comfortable in pushing the proponents of policy models to reveal their assumptions and to justify their conclusions.

1.4. Seeing Interrelatedness

Interrelationships in systems are far more interesting and important than separate details. The interrelationships reveal how the feedback loops that produce behavior are organized. Students with a strong background in systems modeling should be sensitized to the importance of how the world is organized. They should want to search for interconnecting structure that gives meaning to the parts.

One sees the significance of modeling in a discussion I had with a student who had graduated from MIT several years before. I asked him what his system dynamics study had done for him. His answer: "It gives me an entirely different way of reading the newspapers." He meant that he sees the relationships between different things that are happening today, he understands the relationships between today's news and what happened last week and last year, and he reads between the lines to know what must have been part of the story but was not reported.

1.5. Unifying Knowledge and Mobility, Return to the "Renaissance Man"

The 21st century will exhibit rapid changes in societies. We see turmoil in many countries. In the past century, change came from new technologies. In the next century I believe change will be driven mostly by population growth, crowding, environmental degradation, pollution, and shortages of

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food, water, and resources. In other words, societies will be continually reshaped and, as a consequence, the roles of individuals will continually change. Today's students should be prepared for major changes.

Education must reverse the trends of the last century toward more and more specialization. A specialization interest can start early in life and lead to a professional training in college that will often become obsolete within an individual's working career. Education should provide a foundation that gives a student mobility to shift with changing demands and opportunities.

System dynamics provides a foundation underlying almost all subjects.

When that foundation is understood, an individual will have mobility to move from field to field. An MIT undergraduate in electrical engineering demonstrated such mobility. He studied system dynamics during his junior and senior years. When he continued for a Master of Science degree in electrical engineering, he did his thesis on the way the body handles insulin and glucose in various aspects of diabetes. That may not sound like electrical engineering, but about 10% of such students move to careers in medicine. He immediately developed a working-colleague relationship with doctors in Boston's research clinic for diabetes because, for the first time, they were able to put together their fragments of medical knowledge into a meaningful system (Foster, 1970). But he did not intend to go into medicine. He next worked with me in extending the *Urban Dynamics* model. For a year, he led discussions with a group from Boston's black community to incorporate many aspects of education into the model. Later he went to work with a corporation. He could move from one setting to another because his fundamental understanding of systems allowed him to provide a dynamic organizing framework to any activity.

A person with an understanding of systems sees the common elements in diverse settings rather than focusing on differences. For example, communities may have identical basic structures but behave quite differently because of different policies that are followed at crucial places. Systems with the same structure in very different settings show the same range of behaviors. For example, a simple two-level model for a swinging pendulum can be relabeled and it becomes oscillating employment and inventories at the core of economic business cycles.

Transferability of structure and behavior should create a bridge between science and the humanities. Feedback-loop structures are common to both. An understanding of systems creates a common language. Science, economics, and human behavior rest on the same kinds of dynamic structures.

I see a reversal of the trend toward specialization. As the underlying unity between fields becomes teachable, we can move back toward that concept of the "Renaissance Man," who has broad intellectual interests and is accomplished in areas of both the arts and the sciences.

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2. Understanding Economic Behavior

Pre-college education has been repeatedly criticized for inadequate teaching of economic behavior. The weakness arises because traditional academic economics has been taught as small deviations from equilibrium conditions.

However, to understand economic behavior is to understand the forces that cause major economic change.

The professionals in system dynamics have made many excursions into dynamic economics. Much work is still to be done but the path is clear for teaching in K-12 a wide range of economic issues. Economic behavior can be taught throughout the range from personal to national issues, for example:

1. The way borrowing on credit cards, with payment of interest, reduces ones future standard of living,
2. The driving forces for short-term business cycles,
3. How social attitudes, monetary authority policies, debt, and excess construction of housing and capital plant all interact to produce major depressions at intervals of 50 to 80 years.

3. Outlook and Personality

A systems education should give students confidence that they can shape their own futures. A systems education should help mold personalities that look for causes and solutions. A student should understand that decisions are based on mental models derived from observation and experience and should realize the faults common to such mental models. Working with systems should reveal the strengths and weaknesses of mental models and show how mental models and computer models can reinforce one another.

3.1. Confidence in Creating the Future

Many of the stresses in modern life arise because people feel buffeted by forces they neither understand nor know how to control. Such sense of helplessness can be traced to not understanding the systems of which we are a part. Events that seem capricious when viewed locally are often understandable when seen from a broader systems perspective.

I hope that a system dynamics thread in K-12 education would leave individuals willing and able to appreciate the nature of complexity. They should want to look beyond their immediate setting in search of the fundamental causes of problems. They should develop optimism about understanding those problems of society that earlier generations have found so baffling. Inflation, wars, unfavorable balance of trade, economic stresses, and destruction of the environment have persisted for hundreds of years

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without public understanding of the causes. Such problems are too serious to be left to the self-appointed experts; the public must acquire the insights that permit participation in debates of such importance.

Such better understanding comes in small steps. I am reminded of the story told by a television producer who was taking video pictures in a group of parents, teachers, and students at a school where the systems approach was making excellent progress. The producer turned to a junior high school boy and asked, "What have these systems studies meant to you?" His immediate answer: "I am much better able to deal with my mother."

Such ability to deal better with one's environment starts with even very simple systems. One of our MIT doctoral students in system dynamics went to work for the Department of Energy. Two years later he told me he was amazed and appalled by the amount of influence he could have on governmental thinking with a simple two-level simulation model. Even such an elementary system is often beyond what people in important policy positions are taking into account.

3.2. Authoritarian vs. Innovative Personality

A systems education should mold the personality of students by enhancing innovative tendencies in children and counteracting the forces in society that convert an innovative personality into an authoritarian one. I am here using authoritarian and innovative personalities in the sense described by Everett Hagen in his book, *On the Theory of Social Change* (Hagen, 1962). Hagen contrasts two opposite extremes of personality.

The authoritarian personality fits into a rigid hierarchy. Life is capricious. One does as ordered by those of higher status. There are no reasons for such orders. Capricious orders fit the old army saying borrowed from Tennyson, "Yours not to reason why, yours but to do and die." The reward for yielding to higher authority comes from the individual having authority over someone of lower rank. The pure authoritarian personality expects no reasons for why things happen and has no will to search for reasons.

By contrast, the innovative personality believes there are reasons for why things happen. Even if the reasons are unknown, there is still the assumption that reasons exist. Also, it is worth looking for the reasons because, if one understands, then one can probably change and improve what is happening. The innovative personality looks for causes and works toward beneficial advances.

I believe that babies are born as innovative personalities. They want to explore, to understand, and to see how things work and how to master their environments. But our social processes work to stamp out exploration and questioning. The child is continually confronted with, "Do as you are told," or "Stop asking questions and just mind me," or "Study this because it is good

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for you." Repeated restraint of innovative inclinations gradually forces personalities into the authoritarian mold.

A system dynamics modeling curriculum, by letting students formulate the structure and policies causing behavior under study, will help preserve and rebuild the innovative outlook. Simulation emphasizes reasons for consequences. To be innovative, one must be willing to make mistakes while searching for reasons and improvement. Computer simulation modeling is a repeating process of trial and error. One learns that progress is made through exploration and by learning from mistakes. An authoritarian personality fears mistakes and does not try the unknown. An innovative personality knows that mistakes are stepping stones to better understanding.

3.3. Mental Models and Computer Models

Students should learn that all decisions are made on the basis of models. Most models are in our heads. Mental models are not true and accurate images of our surroundings, but are only sets of assumptions and observations gained from experience.

Mental models control nearly all social and economic activities. Mental models have great strengths, but also serious weaknesses. From a systems education, students should learn how mental models can be useful and when they are unreliable. Furthermore, they should appreciate how computer simulation models can compensate for weaknesses in mental models.

Mental models contain a vast wealth of information that is available nowhere else. Mental models contain information about the structure and policies in systems. By structure I mean the elements in a system and the connections between the elements—who has what information, who is connected to whom, and, what decisions are made and where. By policies I mean the rules that govern decision making—what factors influence decisions, what is a particular decision point trying to accomplish, and what goals are sought. At this detailed level of structure and policies, mental models are rich and reasonably reliable sources of information.

However, mental models have serious shortcomings. Partly, the weaknesses in mental models arise from incompleteness, and internal contradictions. But more serious is our mental inability to draw correct dynamic conclusions from the structural and policy information in our mental models.

System dynamics computer simulation goes a long way toward compensating for deficiencies in mental models. In model building, one must remedy incompleteness and internal contradictions before the system dynamics software will even allow simulation. After a logically complete model has been created, one can be certain that the computer is correctly simulating the system based on the assumptions that were incorporated in the model. It is in simulation, or determining consequences of the structural

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and policy assumptions, that mental models are unreliable, but computer models are completely dependable.

Students should also realize that there is no possible proof of the validity of any model, whether they are mental or computer models. Models are to be judged by their comparative usefulness. Assumptions about structure and policies should be compared with any available information. Computer simulation results should be compared with behavior in the real system being represented. Discrepancies lead to improving both mental and computer models.

A two-way street runs between mental models and computer models. Mental models contribute much of the input for computer models. Creating a computer model requires that the mental models be clarified, unified, and extended. From the computer simulations come new insights about behavior that give new meaning to mental models. Mental models will continue to be the basis for most decisions, but those mental models can be made more relevant and more useful by interacting with computer models.

4. Understanding the Nature of Systems

Complex systems behave in ways entirely different from our expectations derived from experience with simple systems. Because intuition is based on simple systems, people are misled when making decisions about complex systems.

We live in a network of complex systems. Yet few people realize the extent to which those systems control human actions. In fact, people seldom realize the extent to which complex systems actively mislead people into making counterproductive decisions. Learning ever since childhood teaches lessons that cause people to misjudge and mismanage complex systems. Students, after a 12- year encounter with systems, should be on guard against the deceptive nature of systems that surround them. Six examples show the dangers in judging real-life systems based on a lifetime of conditioning from simple systems:

4.1. Cause and Effect Not Closely Related in Time or Space

Most understandable experiences teach us that cause and effect are closely related in time and space. However, the idea that the cause of a symptom must lie nearby and must have occurred shortly before the symptom is true only in simple systems. In the more realistic complex systems, causes may be far removed in both timing and location from their observed effects.

From earliest childhood we learn that cause and effect are closely associated. If one touches a hot stove, the hand is burned here and now. When one stumbles over a threshold, the cause is immediately seen as not picking the foot high enough, and the resulting fall is immediate. All simple feedback

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processes that we fully understand reinforce the same lesson of close association of cause and effect. However, those lessons are aggressively misleading in more complex systems.

In systems composed of many interacting feedback loops and long time delays, causes of an observed symptom may come from an entirely different part of the system and lie far back in time.

To make matters even more misleading, such systems present the kind of evidence that one has been conditioned by simple systems to expect. There will be apparent causes that meet the test of being closely associated in time and in location. However, those apparent causes are usually coincident symptoms arising from a distant cause. People are thereby drawn to actions that are not relevant to the problem at hand.

Comments such as I have just made about cause and effect carry little conviction from being stated in a text. Only after a student has repeatedly worked with models that demonstrate such behavior, and has had time to observe the same kinds of behavior in real life, will the idea be internalized and become part of normal thinking.

4.2. Low-Leverage Policies: Ineffective Actions

Complex systems differ from simple systems in another way. In simple systems, the policies to yield better results are obvious and they work. To avoid burning your fingers on a hot stove, you keep away from the stove. But in complex systems, the apparently influential policies often have very little effect.

When I talk to a group of business executives I ask how many have ever had the experience of facing a serious problem, devising policies to correct the situation, and five years later find there has been no improvement. Most will hold up their hands. Perhaps you have experienced the same in education. The quality of education has been severely criticized, many educators have tried remedies, and often there is little change.

In complex systems, there are many interconnecting feedback loops. A new policy, which is intended to solve a problem, causes reactions in other parts of the system that counteract the new policy. In education that reaction may come from administrators, from school boards, from parents who do not want new experimental ideas tried on their children, or from budget pressures.

I believe that a very high percentage, say 98%, of the policies in a system have very little leverage to create change. They do not matter. However, most of the heated debates in communities, companies, and governments are about policies that are not influential. Such debates are a waste of time and energy. Debates about low-leverage policies divert attention from the few policies that could lead to improvement.

Students must have experience working with models of complex systems to appreciate how often proposed policies fail to produce results.

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4.3. High Leverage Policies: Often Wrongly Applied

In simple systems, the direction of action to achieve a goal is obvious. Diligent work and longer hours will increase income. In complex systems, even when a rare high-leverage policy has been chosen, the desirable direction to change that policy is often unclear, or worse, may usually be misjudged and the policy moved in the wrong direction. It is only through comprehensive modeling of complex systems that we can hope to overcome the policy errors that arise from a lifetime of learning the wrong lessons from simple systems.

Fortunately, a few high-leverage policies can usually be found that can alter the behavior of a system. However, high-leverage policies lay another trap for the unwary. One occasionally finds a person who is working with a high-leverage policy. However, I estimate that more than 90% of the time that a person is pushing the high-leverage policy in the opposite direction relative to what that person wants to accomplish. In complicated systems, intuition provides no reliable guide even to the direction that a high-leverage policy should be changed.

I have several times had the experience of going into a company with a serious difficulty where intended policies were causing the problem. We are talking here of highly visible problems. A situation might be low profitability, or falling market share, or severe instability with the company working overtime one year and having half the people laid off two years later. One carries on extensive interviews to determine the policies (decision-making rules) that people are using in different positions in the company. People justify their policies as intended to solve the major problem. One then puts the expressed policies into a system dynamics simulation model and finds that the model generates the same difficulty that the company is experiencing. In other words, the policies that people know they are following are the cause of their trouble. Local interpretation of symptoms leads to local actions that combine to produce detrimental results. This is a treacherous situation. If people believe their actions will reduce the problem, but do not know those actions are making it worse, then as matters become worse there is growing incentive to take the presumed corrections that are actually causing further decline.

One sees this spiral of system deterioration at all levels in society. Individuals in a family in serious psychiatric difficulty know they are in trouble, each wants to do something to help, yet everything that everyone does makes matters worse. In the *Urban Dynamics* model, we saw that governmental policies for building low-cost housing do not improve cities but cause more decay. In the same way, we might suspect that our national foreign trade policies lead to importing goods made by low-skilled labor while our own low-skilled population loses the jobs that could provide an employment and training ladder to higher skills.

I do not know of any way to determine which are high-leverage policies and in which direction to apply them except to do a system dynamics simulation

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of the situation. Students should have many experiences working with models that reveal the multitude of policies having little effect, that allow them to search for high-leverage policies, and that show them the danger of intuitively judging even the direction of effect of high-leverage policies. Students should come out of a systems education with an appreciation for how mental models alone can lead one astray in multiple-loop systems. They should demand that important issues be modeled, and that the models be made available to the public. They should have confidence that they can read and evaluate such models. Models then become a powerful and explicit means of communication.

4.4. We Cause Our Own Problems

In simple systems, the cause of a failure is clear. One trips over a rock because the foot was not raised high enough; it is obvious that the fault was our own. In complex systems, causes are more obscure; it is not evident that we have caused our own crises, so, there is a strong tendency to blame others. However, the practice of blaming others diverts attention from the real cause of trouble, which usually arises from our own actions. By looking to others as the culprits, we take attention off the more embarrassing, but more productive, need to change our own actions. A management will blame the competition, or bankers, or its employees for low profits or falling market share, even though other companies in the same business, that deal with the same customers and bankers, are successful. The difference must lie in the policies of the failing company. The United States has a problem of illegal drugs; so drug-supplying countries are blamed, rather than asking why our country is the largest market for drugs. There would be no suppliers if there were no users. In simple systems, the source of a problem is evident and lies in our own actions. In complex systems, causes are hidden and blame can be attributed to scapegoats through which correction is not possible.

The often-quoted line from the comic strips, “We have met the enemy, and he is us,” has more than a grain of truth. Usually, problems exhibited by a social system are caused by the people in that system. However, people naturally tend to blame others. When Detroit was losing market share to Japanese automobiles, executives of American companies blamed Japan for dumping at low prices, when the real cause was Detroit’s own declining quality. Parents blame schools for low competence of students, when perhaps the deficiency arises more from preschool home life and failure in parental guidance. A company is more inclined to blame falling sales on unfair competition or fickle consumers than on its own poor products and service.

In preparation for the 21st century, a systems education should condition students to look for the source of their troubles first in their own actions before blaming others.

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4.5. Drift to Low Performance, Collapse of Goals

In simple systems, goals are reinforced and maintained. The goal of staying in the proper highway lane is sustained by the threat of an accident. In less obvious systems, goals can gradually erode. One's goal of maintaining a sound financial condition can yield to pressure to borrow for a vacation or to purchase a fancier automobile. The goal can gradually decline from a safe financial condition, to wanting to fall no farther into debt, to striving to meet debt payments, to hoping to avoid foreclosure on one's house.

One component of any feedback loop is the goal toward which the feedback process is striving. In simple models, goals are usually given as constants; for example, the goal of a pendulum is to seek the vertical as it swings from one side to the other. The goal of an inventory manager may be to maintain a given level of inventory. The goal that determines the amount of sleep we get is to maintain a certain degree of restfulness. But in a more complete representation of systems, the goals themselves are properly shown as variables. We may be striving toward a certain goal, but, failing to reach the goal, we may readjust our goal to something that seems more achievable.

There is a strong tendency for goals of all kinds—personal, community, corporate, or national—to drift downward. Pressures tend to cause performance to fall short of goals. But failing to meet goals is uncomfortable. The response is often to let the goals adjust downward toward the actual performance. As goals fall, the incentives for high achievement decline. Performance continues to fall short of the new lower goals and the downward spiral continues.

Falling goals will in time lead to crisis, but by then recovery may be impossible. One sees erosion of goals in attitudes toward the national deficit. Thirty years ago, the present size of the national deficit would have been unthinkable. But as the deficit rose, people came to accept each new rise and adjusted to the higher deficit. Eventually such goal erosion can lead to disaster. Successful people, successful corporations, and successful countries have leadership or deeply held beliefs that stop such goal erosion.

Students should be exposed to the dynamics of goal collapse in models and have an opportunity to relate the process to their own lives. Goal collapse, that is, becoming accustomed to and accepting falling standards, may be the greatest threat to the future of individuals and countries.

4.6. Long-Term vs. Short-Term Tradeoffs

In a simple system, a goal can be accomplished and a task finished. When the water glass is full we turn off the water, the objective has been met, and there are probably no indirect unpleasant consequences. However, in complex systems there is nearly always a tradeoff. If the short-term goal is maximized, the result is a longer-term undesirable consequence. A child takes a toy from a playmate, the goal of having another toy is achieved, but a fight is likely to ensue.

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A fundamental conflict exists between short-term and long-term goals. Students should observe this conflict between the present and the future in system dynamics models and then relate the lessons to their own lives. Actions that yield immediate rewards almost always exact punishment in the long run, and vice versa. Quick gratification is the enemy of future wellbeing. It is hard to find exceptions where actions with an immediate reward do not extract a price in the more distant future.

A person who steals may benefit immediately, but usually suffers later. A person who works all night to finish an important task pays by being inefficient for the next several days. Taking mind-altering drugs may give an immediate sense of well being at the expense of future ill health or poverty. Borrowing on credit cards allows an immediate increase in standard of living but the consequence in the longer term is a lower standard of living while paying back the loan and interest. Under pressure from voters, the U.S. Congress is borrowing money to provide ever-increasing goodies to constituents, with the probable future consequence that government becomes insolvent and may not be able to provide basic public services. Over a much longer time horizon, improved public health and modern agriculture raised the standard of living and reduced death rates, resulting now in the threat of an unsustainable population explosion.

Conversely, accepting a short-term disadvantage can often yield rewards in the longer-term. For example, saving now, rather than spending all one's income, can increase the future standard of living. A company that foregoes higher dividends and increased executive salaries can invest in research on new products and increase future income.

The conflict between short-term and long-term goals bears directly on what should be considered ethical and humanitarian. Humanitarian impulses are usually based on short-term considerations but often lead to worsening the situation in the more distant future. Food aid to starving populations seems humanitarian in the short run, but may well encourage population growth and greater starvation of even more people in the future.

Students should study the fundamental conflicts between short-term and long-term goals in the context of system dynamics models and have the opportunity to relate the lessons to their families, communities, and nation.

5. Achieving the Benefits of a Systems Education

A systems modeling curriculum will not automatically yield the lifetime insights and personal guidance that I have been discussing. A student might easily go through the motions of working with models without gaining the understanding that is potentially available.

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5.1. Experience and Participation

Students will not internalize their understanding of systems merely from being told. Nor will discussion and debate be effective. Coming to an understanding of systems must be a participative activity. Learning about systems in not a spectator sport; such learning comes from active involvement. One does not learn to ride a bicycle or play basketball from lectures alone; one must practice. A person learns from experience. Computer modeling allows an accelerated vicarious experience.

5.2. The Deeper Lessons

A student can work with computer simulation models without realizing the deeper lessons that should be absorbed. Students can miss most learning for the 21st century that I have discussed unless the right guidance is provided. Students must create their own models and learn from trial and error. They must be led toward models that can teach the lessons that I have been discussing. Even with models that contain the lessons, students can miss the most important implications, so they should be encouraged to see the deeper consequences of what they are doing. They should relate what they are learning to systems they already know in families, community, and school.

5.3. Systems Thinking vs. System Dynamics

K-12 conferences on systems are often advertised as “Systems Thinking and Dynamic Modeling.” Consider those two activities in the context of learning for the 21st century. I understand and define the two terms, systems thinking, and dynamic modeling, to mean quite different activities.

Systems thinking appears to be thinking about systems, talking about the characteristics of systems, acknowledging that systems are important, discussing some of the insights from system archetypes, and relating the experiences people have with systems. Systems thinking is lecturing about systems, as I am doing in this paper. Systems thinking can be a door opener and a source of incentive to go deeper into the study of systems. But I believe that systems thinking has almost no chance of instilling the lessons that I have described.

Systems thinking will change very few of the mental models that students will use in their future decision making. Systems thinking is not more than five percent of a systems education.

On the other hand, system dynamics modeling is learning by doing. It is learning through being surprised by the mistakes one makes. System dynamics modeling is a participative activity in which one learns by trial and error and practice. I believe that immersion in such active learning can change mental models.

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5.4. Revision of Road Maps

Many of you are already familiar with the Road Maps series that was written by undergraduate students at MIT with my guidance. Road Maps are documents intended as a self-study guide to learning about systems. Chapters are now available through the Creative Learning Exchange.[1]

However, in creating lessons for students, it became clear that, even though students worked with computer simulations, intended insights about systems could be missed. While working with systems, the implications must be stressed. Road Maps should be extended to be more explicit about fundamental principals of systems and to call attention to the general characteristics of systems that should be observed.

5.5. On Teaching Systems

I believe that confining student learning to systems thinking and to discussion about systems will convey very little understanding of the nature and behavior of the systems within which we live.

To appreciate the nature of systems, students must have extensive personal experience in working with systems. This means creating system dynamics models on a computer, simulating their behavior, exploring how the models respond to changes in structure and policies, and comparing model behavior to the real systems being represented. Such active modeling should extend at least throughout the several years of middle school and high school. As early as possible, schools should move away from canned models that have been previously prepared for student use. Instead, students should create models, examine their shortcomings, and learn from discovering improvements.

Students should gain experience in modeling systems in which they have a personal interest. Such systems can be drawn from family and community situations. Items from the newspapers should be converted to formal models to reveal student understanding of current events, to detect omissions and contradictions in the news items, and to provide practice in moving in both directions between mental and computer models. History and literature likewise provide material that can be made more explicit and understandable through modeling.

Throughout student work with models, more should be learned than just the details of the models themselves. Beneath such models are the underlying principles of systems (Forrester, 1968). Beyond such models are the kinds of learning discussed in this talk. Students probably will not see such general and transferable insights merely from exposure to models. The larger and more enduring lessons must be pointed out. Such active use of the insights will thereby become part of their thinking and the way they look at the world around them.

[1]Creative Learning Exchange, Lees Stuntz, Executive director, 27 Central Street, Acton, MA, 01720, tel: 978-635-9797, fax: 978-635-3737, URL: clexchange.org.

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6. For Further Reading

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