System Dynamics—the Next Fifty Years

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Abstract

Fifty years after its creation, I review the current status of the field of system dynamics and assess prospects for the next fifty. I focus on the challenges the field must face if it is to realize its potential.

The first 50 years of system dynamics have established an introduction to the field. We have shown the importance of achieving a better understanding of complex systems in nature and human affairs. Now, the field is on a plateau ready to launch the next great thrust forward.

We can better understand the present status of system dynamics by comparison to professions that have developed earlier. We are now at about the same state of advancement that engineering was when MIT first opened its doors in 1865, or that medicine was in the late 1800s when the Johns Hopkins School of Medicine was established.

We have as much to learn yet about high-order nonlinear feedback structures around us as those earlier professions have already learned about their fields in the last 150 years. Now is the time to plan how the next 50 years can start to close this huge knowledge gap.

Like those early days in more mature professions, we do not yet have universities devoted to four-year and six-year programs in system dynamics. Like the older professions at their beginning, we do not yet have the equivalent of programs in science and biology in kindergarten through 12th grade education to prepare students for more advanced study at the university level. Nevertheless, there has been major progress in system dynamics during the last 50 years just as there had been in those older professions before they became formalized in advanced educational programs and before they were publicly recognized.

The past 50 years

During the last 50 years, system dynamics has climbed to a plateau below the mountains that lie ahead. The field has spread very widely, but very thinly.

Many academic programs have been started around system dynamics. Most seem to be focused on applications in management, with many other fields getting far less attention. Much less has been done in internal medicine, economics, government policies, and international politics. Most of the academic programs have stagnated at the level of introductory courses taught to students who have no expectation of developing expertise in the powerful professional field of nonlinear feedback systems. We are turning out more and more people who are led to believe that they have been taught system dynamics but who have only a superficial and unworkable preview of the potential of the field.

System dynamics started 50 years ago with academic programs that focused on the outside world with emphasis on major issues outside of academia. However, the pressures inherent in academic institutions are driving our field back into academic journals and away from the public that we should be serving. This scenario leading to reduced relevance has been traveled ahead of us by the field of operations research. Operations research grew out of real problems of the military in World War II. Based on such real-world successes, classes and research programs were launched in universities and a journal was started. Criticism soon arose about how real-world relevance was being lost to the pressure to write for academic journals. As a result, a new society, The Institute of Management Sciences, was formed as the applications branch of the field. However, the same thing happened. The supposedly practical branch reverted to writing for academia and now the two societies are effectively merged. System dynamics is threatened by these academic pressures to retreat from major real-world issues.

The Present

At present, with system dynamics on a rather aimless plateau, the field seems to be catching its breath. The field is pursuing practices of the last many decades, but there is little evidence of a strong reach into new territory.

Because of this stagnation, we see disappointment and frustration. Recently, in the email discussion group of the Society, there have been threads on such subjects as “Lack of Impact on Government Policies” and “The Death of System Dynamics.” These laments do not arise out of limitations of system dynamics or from lack of good effective work in the field. Instead they arise because many people enter the field without the training that would allow them to reach the full potential of system dynamics. Those of you who are doing good system dynamics work know that these messages of despair do not represent the field, but they stand on the record and mislead newcomers to the field. Such messages are going unchallenged by those of you who understand that they are not representative of the field. But these discussion threads probably do represent the doubts and uncertainties of a substantial fraction of members of the Society who have yet to realize the full power of the field.

Impact on Government

Consider the slight impact of system dynamics in government. Already, there are many applications in health care, environmental questions, and the military. However, there is very little penetration into the big issues such as

economic dangers from balance of trade deficits, the future of social security systems, immigration, or the threat of political promises for ever-expanding health care expenditures to the future viability of economies.

Why is there so little impact of system dynamics in the most important social questions? It is because we have not yet taken the steps that would earn us a role in the great issues. The failure of system dynamics to penetrate governments lies directly with the system dynamics profession and not with those in government who are taking little notice of our activities. Those in system dynamics are asking the wrong questions about the sources of low influence.

One hears repeatedly the question of how we in system dynamics might reach "decision makers." With respect to the important questions, there are no decision makers. Those at the top of a hierarchy only appear to have influence. They can act on small questions and small deviations from current practice, but they are subservient to the constituencies that support them. This is true in both government and in corporations. The big issues cannot be dealt with in the realm of small decisions. If you want to nudge a small change in government, you can apply systems thinking logic, or draw a few causal loop diagrams, or hire a lobbyist, or bribe the right people. However, solutions to the most important sources of social discontent require reversing cherished policies that are causing the trouble. There are no decision makers with the power and courage to reverse ingrained policies that would be directly contrary to public expectations. Before one can hope to influence government, one must build the public constituency to support policy reversals.

Do we see system dynamics activity of the kind that can change public opinion? It seems to me there has been very little in recent years. We need books addressed to the public that are understandable, relevant, important, and dramatic. We must focus debate in newspapers, blogs, League of Women Voters meetings, and parent-teacher associations. Have there been any such since *Urban Dynamics*, *World Dynamics*, and *The Limits to Growth*? A man in Iowa decided to run for Congress as a result of reading *Limits to Growth* and he organized a husband-and-wife team in each precinct as the focus for discussing long-term political issues. He was elected. We are now doing almost nothing to generate that kind of reaction. *Limits to Growth* led to Congressional hearings, and intense public debate in almost every public medium. The debate was so intense that many in system dynamics wanted to escape to less controversial territory. The momentum launched by those books was not pursued sufficiently, although now, after 35

years, the environmental pressures highlighted in the earlier books have grown so strong that they cannot be ignored.

What stands in the way of a new series of powerful books to address the important issues that dominate the newspaper headlines? There seem to be several reasons:

1. There is lack of courage in the field to open oneself to severe debate and criticism. However, we will never change intended and widely-supported detrimental policies without intense debate.

2. The field has a very small number of people capable of such publications. Where are those with an incentive to do so? The failure can be traced back to academia. The universities are turning out so-called system dynamicists with a superficial understanding of the field. Junior faculty without tenure avoid major public debates because of risk to their promotions. Senior faculty with tenure have settled comfortably into writing for the professional journals rather than for the public on matters of social concern.

3. There is an assumption that expensive sponsorship must precede an effort to address important issues. However, if the objective is sufficiently clear, a rather powerful small model can be created, and the insights sharply focused. Often, the consequences of such a book will be so dramatic and controversial that few financial sponsors are willing to be drawn into the fray. However, the task can lie within the resources of an individual. Where are the people who can carry system dynamics to the public?

4. We see many people trying to "dumb down" system dynamics into "systems thinking" and "causal loop diagrams" which lack the power that is inherent in system dynamics. This may be because too many in the field lack the deep system dynamics competence necessary to convey and demonstrate the undiluted power of the field. Making system dynamics simple is a losing game. System dynamics is not simple. The problems of complex feedback systems are not simple. Reversing popular but harmful policies necessary to improve society is not simple. The simplified dilution of the field will fail and will discredit system dynamics so that even excellent work is suspect.

Focusing on High Leverage Policies

Many in the field of system dynamics see the great problems in the world and lament the fact that a long-term, dynamic, systemic perspective is not more widely used. Despite doubling times for system dynamics activity of ten years or less, some complain that the field is growing too slowly and offer a variety of suggestions to quickly draw people into the field. Many of these complaints appear to be written by those who have not yet had an opportunity to immerse themselves in the full scope and power of system dynamics. Such expressions of despair shows that much of the field has fallen victim to some of the characteristics of complex systems that we should be teaching.

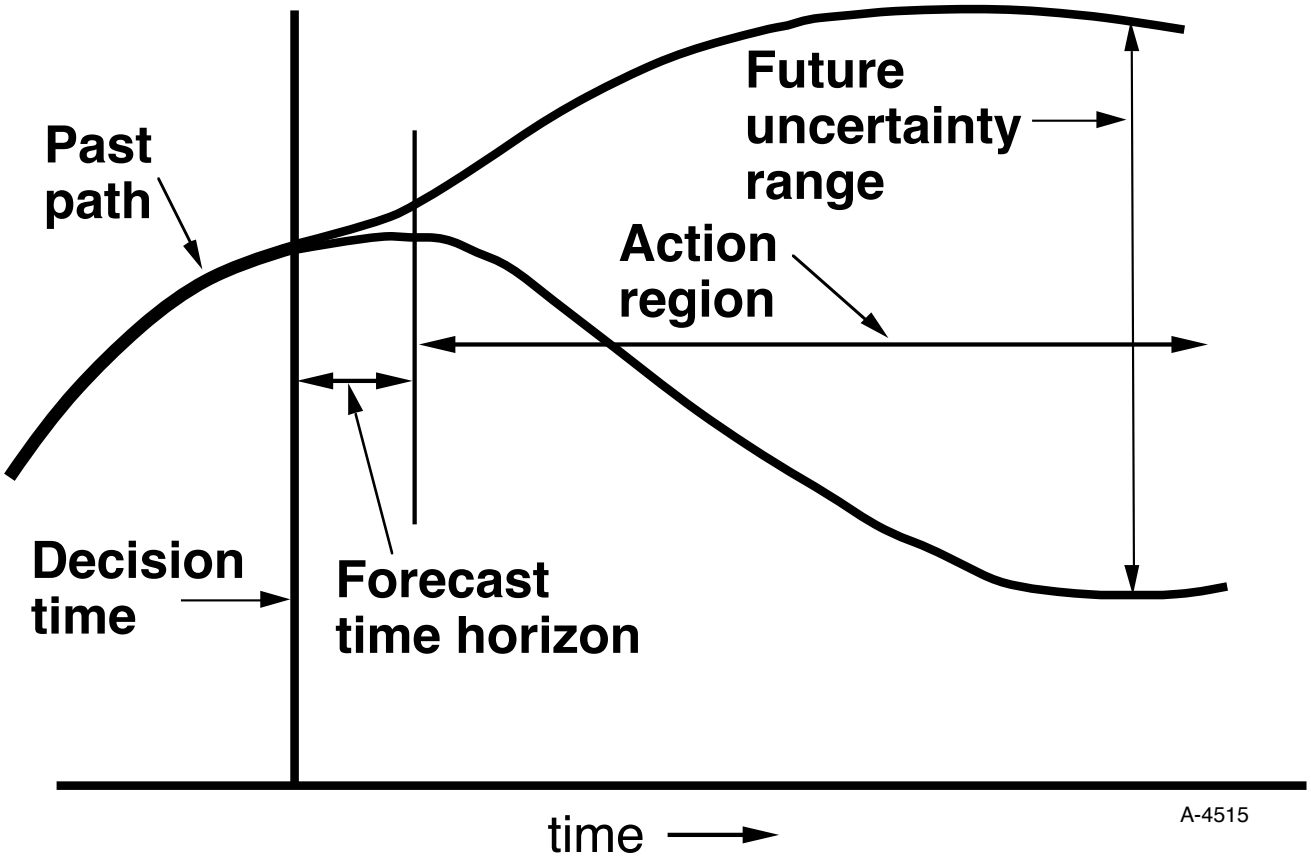
Complex dynamic feedback systems draw people's attention to low leverage policies. I have been struck by the way people in system dynamics are grasping at low leverage policies in search of solutions to their frustrations. For example, in response to how to communicate with managers and the public, the obvious but low-leverage response is to simplify explanations until they become indistinguishable from ordinary conversational debate. Those who take the road of systems thinking and causal loop diagrams are not practicing system dynamics. They remain dependent on the human mind for solving the dynamic behaviors. It has been repeatedly demonstrated that the human mind is not suited for solving high-order dynamic feedback systems. Such simplifications of system dynamics will almost always lack clarity, lack insight, fail to show how the problems at hand are being caused, and incorrectly evaluate and compare alternative future policies. We should not be surprised that audiences show indifference. Only by going the full road to extensive computer simulations is one prepared for the depth of understanding required in real-world situations.

Our colleagues who take the road of watering down system dynamics fail in one of the major goals in their own personal development. One should enter a complex dynamic situation and aspire to be the only person present who can talk about the issues for 20 minutes without contradicting oneself. Through an appropriate simulation model, one should know the structure causing the problem, should know how the problem is created, should have discovered a high-leverage policy that will alter behavior, should understand the reasons why the low-leverage policies will fail, should be able to explain how strongly defended policies within the system are actually the cause of troubles, and should be able to argue for better alternative policies. Everything that one says should fit into a totally consistent story, which is possible when built on insightful computer simulations. Of course, being consistent does not mean that one is right in the context of the real world,

but, if every part of the story matches the fragments of information known to the audience one can present a powerful analysis.

Along with unwise simplification, we also see system dynamics being drawn into attempting what the client wants even when that is unwise or impossible. Of particular note are two kinds of effort—using system dynamics for forecasting, and placing emphasis on a model's ability to exactly fit historical data.

With regard to forecasting specific future conditions, we face the same barrier that has long plagued econometrics. Econometrics has seldom done better in forecasting than would be achieved by naïve extrapolation of past trends. The reasons for that failure also afflict system dynamics. The reasons why forecasting future conditions fail are fundamental in the nature of systems. The following diagram may be somewhat exaggerated, but illustrates my point.



Forecasting vs. Action

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A system variable has a past path leading up to the current decision time. In the short term, the system has continuity and momentum that will keep it from deviating far from an extrapolation of the past. However, random events will cause an expanding future uncertainty range. An effective forecast for conditions at a future time can be made only as far as the forecast time horizon, during which past continuity still prevails. Beyond that horizon, uncertainty is increasingly dominant. However, the forecast is of little value in that short forecast time horizon because a responding decision will be defeated by the very continuity that made the forecast possible. The resulting decision will have its effect only out in the action region when it has had time to pressure the system away from its past trajectory. In other words, one can forecast future conditions in the region where action is not effective, and one can have influence in the region where forecasting is not reliable. You will recall a more complete discussion of this in Appendix K of *Industrial Dynamics*.

The emphasis on forecasting future events diverts attention from the kind of forecast that system dynamics can reliably make, that is, the forecasting of the kind of continuing effect that an enduring policy change might cause in the behavior of the system. We should not be advising people on the decision they should now make, but rather on how to change policies that will guide future decisions. A properly designed system dynamics model is effective in forecasting how different decision-making policies lead to different kinds of system behavior.

I believe that fitting curves to past system data can be misleading. Having a model give results that fit past data curves may impress a client. However, given a model with enough parameters to manipulate, one can cause any model to trace a set of past data curves. Doing so does not give greater assurance that the model contains the structure that is causing behavior in the real system. Furthermore, the particular curves of past history are only a special case. The historical curves show how the system responded to one particular combination of random events impinging on the system. If the real system could be rerun, but with a different random environment, the data curves would be different even though the system under study and its essential dynamic character are the same. Exactly matching a historical time series is a weak indicator of model usefulness. One must be alert to the possibility that adjusting model parameters to force a fit to history may push those parameters outside of plausible values as judged by other available information. Historical data is valuable in showing the characteristic behavior of the real system and a modeler should aspire to have a model that shows the same kind of behavior. For example, business cycle studies reveal a large amount of information about the average lead and lag relationships among variables. A

business-cycle model should show similar average relative timing. We should not want the model to exactly recreate a sample of history but rather that it exhibit the kinds of behavior being experienced in the real system. Again, yielding to what the client wants may be the easy road, but it will undermine the powerful contributions that system dynamics can make.

I see a tendency for those associated with system dynamics to fall into another trap that complex systems set for the unwary. That is the better-before-worse scenario. A policy that seems better in the short run is almost always worse in the long run. For example, one can borrow on credit cards for a brief improvement in standard of living, but with a lower standard of living when faced with interest and principal repayment. On a longer time scale, for several hundred years, better agriculture and improved public health led to better lives, but we are now in the day of reckoning when the good policies of the past have reversed into supporting a growing population that exceeds environmental capacity, causing conflicts over land and resources. In the same way, system dynamics is threatened by practices that cater to short-term pressures but undermine the longer-term strength of the field.

Quality of work in system dynamics

System dynamics is still far from reaching the quality of work to which we should be aspiring. We need to begin debating how to raise quality and scope in applications, published papers, and especially in academic programs.

Rather than believing we have rising standards in system dynamics papers, we should consider the possibility that work in the field is declining in average quality. How often do you see a paper that shows all of the following characteristics?

1. The paper starts with a clear description of the system shortcoming to be improved.
2. It displays a compact model that shows how the difficulty is being caused.
3. It is based on a model that is completely endogenous with no external time series to drive it.
4. It argues for the model being generic and descriptive of other members of a class of systems to which the system at hand belongs.

5. It shows how the model behavior fits other members of the class as policies followed by those other members are tested.

6. It arrives at recommended policies that the author is willing to defend.

7. It discusses how the recommended policies differ from past practice.

8. It examines why the proposed policies will be resisted.

9. It recognizes how to overcome antagonism and resistance to the proposed policies.

None of these require new advances in system dynamics but only a demand for higher standards of work. It is wrong to blame the many authors who fall short of these standards. Most have had no opportunity to internalize those standards. They have not had an educational opportunity to learn what these standards mean or how to achieve them. Here the shortcoming and challenge fall back to our educational institutions.

The next 50 years

As we contemplate the next 50 years in the development of system dynamics, we should think about its status as a profession for designing complex systems. Comparison to more established professions should help in setting the proper perspective. System dynamics is a more difficult profession than engineering or medicine. System dynamics takes one far out into the realm of nonlinear, multi-loop, feedback systems that lie beyond what has been explored in other professions. We should not expect system dynamics to be easy to master. Designing an airplane is hard. Designing a bridge is hard. Doing a heart transplant is hard. System dynamics is even harder. Those other professions have not succeeded by simplifying complexity, but by facing up to it. The older professions do not expect to instill adequate skill with a few introductory subjects in a university department that is devoted to some other theme.

One prepares for a medical profession by starting with biology in K-12 education, then a pre-med course in college, followed by medical school and then an internship. We must begin to think of the same depth of study in system dynamics.

We accept the existence of schools of engineering and schools of medicine. When will we have schools of system dynamics and courses throughout an entire university devoted to the design and management of complex feedback systems?

Up to the present, we have been putting too much emphasis on spreading system dynamics widely, but at a superficial introductory level. Such introductory courses are excellent as cultural subjects that give people a different way of viewing the world around them. However, when such courses are presented as equipping one to be a professional system dynamicist, they are misleading and do not serve the needs of the students or the profession.

I turned my attention to system dynamics as a foundation for a new kind of kindergarten through 12th grade education after several years of futilely trying to establish an understanding in corporations. In a corporation, one can devote several years to moving the thinking of top executives to an understanding of dynamic behavior and the need for radical policy change. At about the time they are ready to act, they retire or die, and one must start over with a new group that must be conditioned from the beginning. It became clear that to affect governments, corporations, and other organizations one must take the much longer road of instilling systems ideas into a wider public in pre-college education.

We find that it is easier to teach the ideas of systems the earlier one starts. In elementary school, students have much less to unlearn than they do later after years of being conditioned by linear and uni-directional cause-to-effect education. Also, at a younger age, students are more willing to cope with bigger and more important issues than they are after being trained to solve only problems to which they have already been given the necessary tools. In real life, problems come upon us whether or not we have been trained to solve them. Why should not education be structured like real life with important problems being undertaken followed by a search for ways to respond?

Teachers at the grass roots level are pioneering how to bring a systems understanding into pre-college education. A conference on systems in K-12 education can attract 200 teachers and administrators. However, as we see elsewhere, all efforts are so far at the introductory level. So far, there are no schools of education that prepare teachers to go down the systems road. In time, the goal is to have a cumulative program from kindergarten through 12th grade that builds a systems background.

Now, think of some future time when students come to colleges already having 12 years of exposure to systems. They will be advanced far beyond what is now taught in the universities. What then are the universities to do in building on that foundation? I do not see universities preparing for that day. Nor do I see the

universities even planning four- or six-year systems programs for students who have not had an earlier exposure to systems.

When might we expect to have universities of social system design? What public background must be established to make a system dynamics profession possible? Who might be the people to lead creation of a powerful systems education?

It seems to me that the present universities are not strong contenders for creating a systems education of the future. Universities are some of the most conservative institutions in our society. For decades the liberal arts universities resisted the incursion of science and engineering. We can expect the same for systems and social system design. The existing universities will respond only to public demand or to competition from new institutions that are more responsive to what is needed for understanding an ever more complex world.

Before going further with such generalities, let me sketch one possible future educational approach. I will use management as the vehicle for discussion because many of you are interested in management applications. However, my comments apply to systems applications in many other fields. At the present time, management schools still lie in the category of trade schools. Consider the analogy of an airplane. Who are the two most important people in the successful flight of an airplane? I suggest they are the designer of the plane and the pilot. The designer creates a plane that can be flown successfully by ordinary pilots. Aircraft designers are trained in a university engineering department. Pilots are trained in trade schools. Is today's manager more like the airplane designer, or the pilot? Managers are more like pilots but are trained in trade schools that have established themselves in universities. Where is there a university department devoted to training corporate designers? We do not have such yet. So, what might such a department of corporate design look like?

First, a future school of corporate design must break the boundaries between disciplines such as finance, marketing, production, and personnel. Any significant management situation crosses many such boundaries. The problems and opportunities arising from disciplinary interactions cannot be successfully left to a final academic term in a capstone or integrative subject. Also, the academic structure must change. A one-year or two-year MBA is suitable as a trade school, but it is not sufficient for venturing into corporate design. We should be thinking of management education being more like that in engineering, with an undergraduate program followed by a graduate program.

Such a management education will evolve over time, but we might start with the following image. Suppose that we had some 20 generic structures that would cover more than 90 per cent of the situations that a manager ever encounters. One example would be a production/distribution system such as dates back to the earliest days of system dynamics. Each such generic structure would require a separate textbook; each would be studied at least to the extent of a full semester subject. The student would come to understand the many modes of behavior that the structure might exhibit; there would be an examination of different management policies and how to decide which might apply to a particular real-life situation; and there would be laboratory experience of going into real corporations and learning to identify the structure and how to improve its behavior. If you think this is more than would be justified by one generic structure, I call your attention to the fact that the production/distribution system is now the basis of a separate society devoted to supply chains that sponsors training programs in that subject alone. These 20 generic structures alone might require three years of full-time study. Along with related studies in the fundamental nature of systems, we can see an undergraduate program plus a graduate degree in the future.

Before any of this can happen, there must be plausible plans of action and then people who are willing and able to move us toward the future. A first step would be to create a plausible 50-year detailed plan for the future of system dynamics. Such is possible. There has been one small step in this direction. Six years ago, some eight K-12 teachers and several system dynamics experts met for a full week to map out the next 25 years for system dynamics as a foundation for pre-college education. There are very few organizations that dare to make 25-year plans but it is possible if you are willing to try. Such a plan is a plausible road to the future. It is not necessarily the road that will be followed but it shows a path down which people can start and details the kind of work that will be needed along the way.

A detailed plan also keeps one from falling into misleading optimism about how much can be accomplished in a short look into the future. Our study of the 25-year future of system dynamics in K-12 showed that in 25 years, at an expenditure of some two billion dollars, we could hope to bring system dynamics into about a third of the schools in the United States. That may seem pessimistic to you; it is likely to be too optimistic in terms of cost and time required.

The promoters

The future that I have suggested depends on there emerging a leadership group in the field that I have not yet been able to identify. We need a group of full time, enthusiastic, charismatic, visionary, energetic promoters. I use "promoter" in the best sense of the word. Such a person can project a clear picture of a future that will rally money and people to a cause. Such a person can think in terms of hundreds of millions of dollars. Private money rather than support from government or older foundations is most likely.

I have had some experience in the powerful effect of detailed long-term planning and know that it can be done. In 1948, we wrote a report and forecast of the future of digital computers in military applications. At that time, no general-purpose, high-speed, reliable digital computer had yet operated. The 29-page document ended in a large grid with 15 years horizontally and 10 areas of military application vertically. The square at each intersection was filled in with the expected status of computer use and the cost in that year for research and engineering and production. The lower right corner totaled some six billion dollars. We took the report into a conference with the U.S. Navy where they thought the agenda was whether or not we should get another 100 thousand dollars and we said they would be spending six billion. There was a substantial communications gap in that meeting. That report became a cornerstone for planning that led to creation of the MIT Lincoln Laboratory for air defense. The Lincoln Laboratory designed the computerized information system for air defense that was installed across North America in the late 1950s. It was completed some one or two years ahead of the schedule that had been anticipated in 1948.

Public understanding and support

The time has probably not yet arrived for the kind of promoters that I have described. The stage is not yet adequately set with the public. The public, including so-called opinion leaders, does not yet understand that there are deep flaws in the way policies are established. Governing policies are driven by short-term pressures to the detriment of long-term good. Most debate is expended on policies of little leverage for change. High leverage policies are usually pushed in the wrong direction. But none of this is understood or even suspected by the public.

We need books from authors who are willing to be politically incorrect, who have the courage to attack sacred cows, and know how to show the public that the emperors have no clothes. Global warming is now a hot topic but the debates are

about how to reduce symptoms rather than eliminate causes. Environmental pressures come from rising population and increasing industrial production per capita but these causes seem to be taboo subjects. System dynamicists must go behind the symptoms of trouble and identify the basic causes. At first, such arguments will be met with disbelief, scorn, and ridicule. To prevail, the battle must be sustained until public understanding begins to change.

Therefore, I leave you with the challenge to plan for marching upward from the present aimless plateau and start climbing the mountains ahead. We should be able to move sufficient understanding of the behavior of complex systems into the public sector. It is not necessary to reach or convert a large fraction of the public but only a subset of newspaper writers, elected officials, and thoughtful opinion leaders. When that has been accomplished, we will be ready for creating the universities that can train a true profession of system dynamicists.

The first step is a 50-year detailed year-by-year plan that is realistic, that identifies the work to be done, that clarifies the steps to be taken, that outlines the wide-ranging education programs to be created, that recognizes the resistances to be encountered, that articulates goals to be achieved, and that launches the next fifty years.