Defining System Dynamics Education

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Abstract

This is the second paper in a series that aims to start a debate on issues involved in university-level system dynamics education. The first paper argues that the field has not experienced the growth that one would expect from its potential and identifies several issues that need to be addressed by the system dynamics community, before the field can proliferate in universities.This second paper tackles some of those problems. More specifically, the paper discusses the academic definition of system dynamics: what is the academic core of system dynamics? what other subjects are of immediate relevance and importance with respect to this core? The paper offers answers to these questions. The second issue that the paper deals with is the problem of terminology. I discuss different types of terminology problems, the most significant being system dynamics, the very name of the field. System dynamics having an established meaning in mathematical and engineering sciences, does not convey the specific meaning that we wish to attach it. I discuss various potential problems caused by this situation. I then offer a short list of alternative, more specific names for the field. I conclude that, once the academic issues are rigorously tackled, the university-level system dynamics education should experience a growth, which would be a major step toward activating an exponential growth process in the field in general.

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Introduction

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The first paper of this series (Barlas 1993) is an overview and introduction paper that identifies the various aspects of the problems involved in system dynamics education. The paper first comments on different types of system dynamics courses, based on personal experience of the author. It then discusses four problem areas: i) lack of formal teaching material, ii) insufficient literature on pedagogy, iii) problems of terminology, and iv) inadequate emphasis on undergraduate education. The first paper concludes that once these problems are dealt with, the university-level system dynamics education can experience a growth, which would be a significant step toward initiating an exponential growth process in the field in general (Barlas 1993).

Furthermore, system dynamics is embedded in an ever changing environment, with new or revised concepts, methodologies and approaches being added constantly (eg. chaos, simulation gaming, soft systems methodology, systems thinking). Relationships between system dynamics and these approaches are being discussed in the literature (Gould-Kreutzer 1993, Richmond 1993, Lane 1993, Towill 1993 and Senge 1990). There are still various issues in these relationships that need to be clarified. Plenary sessions of this very conference are devoted to a comparative debate on alternative "systems" methodologies. I believe that system dynamics and these sister fields can establish extremely beneficial relationships. But I also believe that a pre-condition for this to occur, is to first define the core of system dynamics. Unless this is accomplished, the field's relationships with other fields will increasingly be a source of confusion and vagueness, rather than beneficial cooperation - a situation that already exists to some degree (especially vis-a-vis simulation games and systems thinking; see Gould-Kreutzer 1993).

The purpose of this second paper is to focus on some of the issues raised by the first paper and make some suggestions. Specifically, we deal with two issues: first, the academic definition, the "core" of system dynamics. Second, we discuss the terminology problem, in particular the very name of the field, "system dynamics."

The Need to Define the Core of System Dynamics

In the development and growth of any scientific discipline, formal university education plays an important role. Only the educators (the "reproductive" group), through formal (graduate) university education, can produce educators. Thus, there is a positive feedback loop that must be set in motion for the field to experience substantial growth, and a minimum (threshold) number of educators are needed to activate the loop. This situation is especially true for system dynamics, which is a difficult, intellectually demanding discipline. Experts in such a discipline can not be produced by informal/part-time training; formal university education is necessary. Currently, very few universities offer regular, formal system dynamics courses.

A necessary condition to define formal system dynamics education is to first define the "core" subjects of the field. Philosophically, a mature paradigm is characterized by a well-defined core. The core represents those aspects, assumptions of the paradigm that are never questioned during what Thomas Kuhn calls "normal science" (Kuhn 1962). The core of the paradigm, unlike its peripheral aspects, is very rigid. Peripheral assumptions of a paradigm may be constantly questioned and occasionally thrown away; but when the core assumptions are questioned, this signals a scientific revolution, which in turn may mean the end of the paradigm. It is the constancy of the core assumptions that makes a paradigm a very efficient "puzzle-solver" during periods of normal science (Kuhn 1962). That is why established engineering sciences monitor their core subjects, by periodically publishing standard curricula and list of subjects for their core courses. System dynamics should also start a structured debate on what constitutes the core of system dynamics. Most work on education focuses either on high schools (eg. Davidsen et.al. 1993, Forrester 1993 Brown 1992, Draper and Swanson 1990), or on short-term/informal professional training (Richmond 1993,Ford and Gardiner 1987, the entire special issue of EJOR 1992, especially Graham et al. 1992). With a few exceptions (eg. Anderson and Richardson 1979 and 1980, Clauset 1985), there has been little work devoted to university-level system dynamics education.

The Academic Core of System Dynamics

One way to approach this issue is to ask, "what is system dynamics?"But most likely, a single definition will not provide a complete answer to this question.There are various books that provide different definitions,each emphasizing different aspects of the field(for eg. see Wolstenholme 1990, Richardson and Pugh 1981, Forrester 1961).An alternative approach which, I believe will simplify this task, is to ask: "In what ways is a system dynamicist unique?What are those qualities of a system dynamicist that clearly distinghish him/her from professionals trained in other similar disciplines?"Having formal education in industrial engineering, operations research and systemsengineering, and professional association with practitioners from these disciplines, I find out that a system dynamicist is distinguished in two fundamental ways: First, system dynamicists are excellent *causal, feedback modelers*.The emphasis is important; I believe that we are uniquely qualified in building excellent causal models of problems that involve significant *feedback* processes.Thus, system dynamics education must first teach the knowledge that students must acquire to be competent causal modelers of feedback processes.second, system dynamicists are *model-based* analysts of *dynamic policy* issues.Again, the emphasis is that, compared to other professionals, we are uniquely qualified in making use of models to tackle dynamic problems involving long-term policy questions.The core of system dynamics must therefore include the philosophy, tools and methods necessary for this second set of skills.

Using the above core definition of system dynamics as a reference, it is now possible to discuss what specific subjects must be included in a given course.but we also need to define first what *kind* of course we have in mind.As we discussed in the previous paper, there are many different types of courses, depending on the nature of the student audience, the level of the course, whether the course is stand-alone or part of a larger subject, and whether the course is intended as an elective or part of a required sequence.(Barlas 1993).In this paper, I will focus on the type of course which I believe is most crucial for the growth of the field: A sequence of two courses exclusively dedicated to system dynamics. At least the first one (and preferably both) must be undergraduate courses.

Our purpose is to come up with a list of suggested topics for an undergraduate course dedicated to system dynamics.In a similar attempt, Andersen and Richardson (1979) ask the following question:"what do we want everyone to know after having had an introduction to system dynamics?" We try to answer the same question, while keeping in mind the definition of the "core" given in the previous paragraphs. For the first course, we come up with the suggested list of topics shown in Figure 1. All topics are quite self-explanatory, hence we will not discuss them further.

TOPIC SEQUENCE:

- Systems and Models
- Structure and Dynamic Behavior; Illustrations
- Problems of Dynamic Nature; Illustrations
- Systems Thinking
- Causality and Causal-loop Diagrams
- Model Conceptualization; Illustrations
- Tools for Dynamic Systems Modeling: Stocks and Flows.
- Introduction to Stock-Flow Diagrams and SOFTWARE.
- Feedback loops: Positive and Negative Feedback
- Behavior of Positive Feedback; Growth Processes
- Behavior of Negative Feedback; Goal-seeking Processes
- Linear and Non-linear Equation Formulation
- Coupling of Positive and Negative Feedback Loops
- S-shaped behavior and "boom-then-bust" patterns
- Importance of Time Delays
- CASE STUDY in Model Evaluation and Analysis.
- Structure of Oscillatory Systems; Illustrations
- Generic Structures and Generic Sub-systems.
- CASE STUDY in Policy Design
- Term Project Discussions.

Figure 1. Topics Suggested For an Introduction to System Dynamics Course.

Some pedagogical aspects of this course outline need to be mentioned. First, there must be a stream of short assingments through the course to keep the student alert. Second, there must be a term project, but care must be exercised to keep it simple enough.My experiance has shown that students tend to be weak on problem identification and attempt to build models that are too big and too complicated to be fully understood, evaluated and analyzed in one half of a term. Third, the course must be rich in examples illustrations and case studies. There are many aspects of system dynamics methodology (especially in problem idetification, model conceptulization and policy analysis phases) that are almost impossible to convey in the abstract. (See Andersen and Richardson 1979 and 1980 for a rich discussion). Fourth, the level of *mathematical* analysis of system dynamics covvered in the course would depend on the particular student body. But I would nevertheless suggest that mathematical analysis be kept at a minimum in this first course; in one term, there is simply not enough time to teach the mathematical aspects, in addition to all the philisophical, methodological and conceptual subjects that constitute the core of the field. Finall, Here is a tentative list of textbooks and/or references for the course; High Performance Systems (1992) ;Wolstenholme (1990) ; Roberts et.al. (1983) ; Richardson and Pugh (1981) ; Goodman (1974) ; Forrester (1968) and (1961).

A second course in system dynamics (either graduate or undergraduate) is really a must, if our goal is to produce a growth in the field, via a growth in system dynamics education. Such a course would have several objectives. First, it would discuss in more depth, some of the topics already covered in the first course, such as model validity, sensitiviy and policy design. Second, it would introduce new concepts and tools, such as stochasiticity in systems, discrete models, chaotic behavior, and in general a host of mathematical analysis techniques. Third, it would introduce a number of related fiels that have important ties with system dynamics. And finally, being a second course, it would give the a students an oppertunity to work on a major term project. Suggested topics for such a course in system dynamics is shown in Figure 2.

TOPIC SEQUENCE:

- Systems and Models and Differential Equations
- Systems Simulation as a Numerical Method
- Mathematics of Linear System Dynamics
- Equilibrium and Stability Analysis
- Phase-plane Techniques
- Non-linear Systems and Linearisation
- Model Sensitivity
- Model Validation
- Policy Design
- CASE STUDY
- Optimisation
- Stochasticity in Systems
- Discrete versus Continious Models
- Chaotic Behaviour
- Role of Interactive Simulation Games
- Survey of Related Fields
- CASE STUDY
- Term Project Discussions

Figure2. Topics Suggested for a Second Course in System Dynamics

Note that this being a second course in system dynamics, it should provide a much greater degree of freedom to the instructor. Therefore, the suggested topics are rather tentative in nature, compared to the ones suggested for the first course. The instructor depending on his/her expertise and the student audience, may wish to emphasis certain topics, and spend little time on others. For instance, an instructor may prefer spending more time on the simulation-related analysis and design issues, and less time on mathematical techniques. In addition to the list of textbooks given for the first course, the second course would naturally revolve around a variety of reading material, as suggested by the instructor.

Problems of Terminology

My previous paper indicates that system dynamics field has some terminology problems. Some concepts central to the field do not have a unique technical name. For instance, the same technical concept is called "stock" by some authors, "level" by others and "state" by yet others. There is "flow" and then there is "rate" that define the same concept. Model diagrams are sometimes called "flow diagrams," sometimes "stock-flow diagrams" and sometimes "structure" diagrams. Rich vocabulary is good for a natural language, but not necessarily for a technical field, especially if it is in the development phase. It creates unnecessary communication difficulties and gives the impression that the field is somewhat ill-defined and immature. Students in introductory system dynamics classes are confused by this multiplicity of terms, especially since they have to read extensively from a variety of sources. As part of our attempt to strengthen system dynamics as a formal academic field, we must make sure that there is only one term for each major technical concept. For instance, I propose that we consistently use the term "stock" (instead of "level" or "state"), "flow" (instead of "rate") and "stock-flow diagrams" (instead of "structure" or "flow" diagrams).

Another terminology problem is our usage of certain terms in ways that differ from their standard usage in other established disciplines. For example, Seeger (1992) explians that the terms "open" and "closed" have technical meanings in established fields of social sciences that differ substantially from our usage of these terms. (See Richardson (1991), for a thorough historical and philosophical discussion of this and other similar terminology issues). Similarly, "influence diagram" in decision theroy is quite different than the one used in system dynamics, I suggest that, we use the term "closed-loop system" (instead of "closed system) and "causal-loop " diagram (instead of "influence" diagram).

Problems with the Very Name of the Field, "System Dynamics"

The most dramatic example of terminology problem lies in the very name of our field, "system dynamics." In my previous article, I state that: "this term has an established meaning in mathematical and engineering sciences. In short, in applied mathematics it means 'mathematical analysis of dynamics of systems' and in electrical, mechanical and systems engineering it means 'analysis and design of dynamical engineering systems.' (Barlas 1993. Also see Towill 1993). There are many articles and books in applied mathematics and engineering that have the keyword "system dynamics" (or a minor variation of it, such as "dynamics of systems" or "dynamic systems") in the title. (See tables 1 and 2). Again, in my previous article, I observe that: "System dynamics is an old mathematical and engineering term with a rather general coverage. The choice of such a general and established term to name an emerging new field with a very specific philosophy and methodology was, in my view, a mistake. It was like calling a newly emerging sub-branch of statistics 'statistical analysis". Such a general term undermines the rigor of the field and renders its boundaries fuzzy. The term 'system dynamics' in the title of a presentation, course, book etc. does not convey the specific meaning we attach to it." (Barlas 1993).

Having made the above observation, I later carried out a library search to test this personal "impression". The results of this limited and "non-scientific" title search are showm in tables 1 and 2. Results of table 1 were obtained by carrying out a computerized search in Science Citation Index and Social Scienes Citation Index, for years 1988-1993 . The figures represent the number of times the exact term "system dynamics" appeares in titles of the articles. Thus, in Science Citation Index, we found 8 articles that had the term "system dynamics" in their titles, that we would classify as "core system dynamics work" . We found 42 articles with the term "system dynamics" in their titles, that belong to some other established field . Thus in our limited data set,only 16% of all articles found in Science Citation Index with the keyword "system dynamics" in their titles actually belong to our field . The next row of table 1 displays the results obtained from Social Sciences Citation Index . Here, we observe that the numbers are reversed ;41 out of 51(80%) of all such articles were identified as "systems dynamics work" as we understand it . Finally, when we pool the two data sets, a total of 49 out of 101 articles (49%) were identified as core system dynamics work . My personal impression is that this percentage is rather low, that there are too many articles with the keyword "system dynamics" in the title, that do not belong to our field . A much more objective (and very time consuming!) way to judge this would be to conduct similar searches using keywords that characterize other comparable fields, and see if there are significant differences between our results and the ones obtained from other fields.

Table 1, Results of 1988-1993 Article Title Search

	Appearances of the keyword "systems dynamics"		
	In articles that we would classify as "system dynamics"	In articles that belong to other fields	Ratio
Science Citation Index	8	42	8/50=16%
Social Sciences Citation Index	41	10	41/51=80%
Total	49	52	49/101=49%

Table 2, Results of Book Title Search

	Appearances of the keyword "systems dynamics"		
	In books that we would classify as "system dynamics"	In books that belong to other fields	Ratio
Keyword is "system dynamics"	8	8	8/16=50%
Keyword is "system dynamics" or "dynamics systems"	8	31	8/39=20%

Finally , Table 2 displays results from *book titles* search . In the first row , we see a total of 16 books with the exact keyword " system dynamics " in the title . Of these 16 books , 8 belong to our field , and the other 8 belong to "other" (traditional hard engineering)fields . The ratio is 50% . During the search , I noticed that there were too many book titles with terms " similar " to system dynamics (such as "dynamics of systems or "dynamic systems"). Just to illustrate the point , the second row of Table 2 displays the results obtained when we allow the keyword "dynamic systems" in addition to "system dynamics." We see that in this case, the ratio of system dynamics books (in our sense) to the total of books found drops to 20% (8 out of 39).

A more extensive and scientific library search is needed to reach a definitive conclusion as to whether the field has a "name problem." (Another interesting dimension of this is that, many system dynamicists prefer not to use the term system dynamics in the titles of books, presentations, courses, even conference proceedings). Nevertheless, our limited data set at least tentatively indicates that there is a problem. These empirical findings are in general agreement with my concern that there is a widespread, established use of "system dynamics" and that the term does not convey the specific meaning we wish to attach to it. Audiences already familiar with this general usage of the term fail to appreciate that the author is referring to a very specific philosophy and methodology and ask questions like "what type of system dynamics do you exactly mean?" "System dynamics" name has contributed to the incorrect perception that the field is just an application of control engineering to socio-economic systems. And those who were able to see the field's distinguishing features, have preferred to refer to our work as "DYNAMO models" or "Forrester models" or more recently as STELLA. It is a shame that a field as profound and important as system dynamics must be reduced to software names. It seems to me that this has been happening because the field does not have a unique and specific name. Here is how Richardson (1991, p.9) explains his usage of the term "feedback" in his book: " there is probably a normative component to my use of a single term to cover these myriad ideas: I see a value to using a single label, so that what is in common to these ideas becomes the focus." This is a very productive approach, and applicable to a collection of terms as well as a single term, provided that the term we choose has certain unique and distinct features. The term "system dynamics" really refers to the very general area of inquiry to which our field belongs, and it could be kept and used as such. But in addition, we need a more specific and unique name which depicts what distinguishes us from other modeling fields. This need is going be felt more acutely in the future, because, as mentioned earlier in the article, we are witnessing a proliferation of systemic methodologies. Defining the core of the field and giving it a unique name would help clarify the hierarchy and interrelationships among these fields.

In trying to select a specific name for the field, I suggest that we refer to the "core" defined earlier in the article, and ask the question: "what terms most uniquely characterize the core of the field?" Here is a simple list of "keywords" that are all vital for the field: Feedback; dynamics; systens (systemic); closed-loop; structural; causal maoeling;policy-orientation and simulation. The question is to select a collection of terms that reflects the distingushing features of the field. Here are some suggestions:

-Dynamic Feedback Systems(Methodology, Modeling, Approach, Simulation)
-Systemic Dynamic Feedback(...)
-Causal Systemic Feedback(...)
-Closed-loop Dynamic Systems(...)
-Causal Dynamic Systems(...)

The alternative terms in parentheses are not part of a fixed part of the suggested name for the field; they would be appropriately chosen, depending on the context of use. (Such as Dynamic Feedback Systems modeling; Dynamic feedback Systems approach, etc.). My list is not exhaustive. It is possible to come up with many other representative names. Another approach would be to chose an acronym, which would have the advantage of being a single term. What is important is that we start this debate in the community as soon as possible.

Conclusion

System dynamics, over thirty five years after its conception, has not experienced the growth that one would expect from its potential. System dynamics is not merely a tedious application of feedback control engineering to socio-economic problems. Through the years, it has grown to become an original, creative field of inquiry, with solid philosophical and methodological foundations. Today, in contrast with the reductionist and logical-empiricist philosophies of the first half of this century, "systemic" philosophy and methodologies are on the rise. Time is right for the field to turn its potential into action and growth. In this article, I discuss two problems that I believe have contributed to the field's stagnation. The first one has been the lack of emphasis on formal, regular, university-level system dynamics education. To strengthen system dynamics in academia, we need to sharply define the core subject matters of the field. I offer a tentative core definition and a list of core topics that will hopefully start a debate. The second problem is one of "terminology." There are ambiguities and duplications in our terminology. More significantly, both my personal experience and my (informal) library search indicate that the very name of the field is problematic. "System dynamics" has an established meaning in mathematical and engineering sciences. It does not convey the specific meaning that we wish to attach to it. Worse, it is likely to give an erroneous perception of the field. I offer a short list of alternative, more specific names for the field. I hope that this series of papers will start a debate on academic aspects of system dynamics. Once these academic issues are rigorously tackled, I believe that university-level system dynamics education will experience a growth, which would be a major step toward activating an exponential growth process in the field in general.

References

Andersen, D.F. and G.P. Richardson. 1980. Toward a Pedagogy of System Dynamics.In System Dynamics, Legasto, A.A., J.W. Forrester and J.M. Lyneis, eds. New York: North-Holland.

Andersen, D.F. and G.P. Richardson. 1979. A Core Curriculum in System Dynamics. State University of NY Occasional Paper Series GSPA 1-79,
Albany, NY. Brown, G.S. 1992. Improving Education in Public Schools: Innovative Teachers to the Rescue.System Dynamics Review. 8 (1): 83-89.
Ford, A. and P. Gardiner. 1987. Bringing the Results of the Bonneville Project to the Classroom. University of Southern California. Los Angeles. Ca.

Forrester, J. W. 1993. System Dynamics as an Organizing Framework for Pre-college Education. System Dynamics Review. 9(2):183-194.

Forrester, J. W. 1968. Principles of Systems. Cambridge MA:Productivity Press.

Forrester, J. W. 1961. Industrial Dynamics Cambridge MA:Productivity Press.

Graham, A.K. J.D.W. Morecroft, P.M. Senge and J.D. Sterman. 1992. Model-Supported Case Studies for Management Education. Special Issue of EJOR on Learning 59 (1): 151-166.

Goodman, Michael R. 1974. Study Notes in System Dynamics. Cambridge, Ma: Productivity Press.

Gould-Kreutzer. 1993. Foreword: System Dynamics in Education.System Dynamics Review. 9(2): 101-112

High Performance Systems. 1992. STELLA II: An Introduction to Systems Thinking. Hanover, NH.

Karsky, M.1989. What is to be Done. Informal Written Communication. Paris, France.

Kuhn, Thomas. 1962. The Structure of Scientific Revolutions. Chicago: The University of Chicago Press.

Lane, D.C. 1993. With a Little Help From Our Friends: How Third Generation System Dynamics and the Problem Structuring Techniques of Soft OR Can Learn From Each Other. In Proceedings of the 1993 System Dynamics Conference Cancun, Mexico.

Richardson, George P. 1991. Feedback Thought in Social Sciences. Pennsylvania: University of Pennsylvania Press.

Richardson, George P. and Alexander L. Pugh III. 1981.Introduction to System Dynamics Modeling with DYNAMO Cambridge, MA: Productivity Press.

Richmond, R. 1993. Systems Thinking: Critical Thinking Skills for the 1990s and Beyond. System Dynamics Review. 9(2): 113-133.

Roberts, Nancy, D. F. Andersen, M. Garret, R. Deal. and W. Shaffer. 1983. Introduction to Computer Simulation: The System Dynamics Approach.Reading, MA: Addison-Wesley.