[1]Formal System Dynamics Education in Universities

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Abstract

System dynamics, in spite of its solid philosophical foundations and a very promising practical prospect, has not experienced the growth that one would expect from its potential. I argue that a major cause of this relative stagnation has been the lack of formal, regular undergraduate system dynamics courses in universities. System dynamics community must spend more time and effort discussing issues of university-level system dynamics education. This paper is an attempt to start such a process. In the paper, I first present a taxonomy of different types of university-level system dynamics courses. Then, based both on personal experience and published literature, I identify four groups of problems and issues to be addressed by the system dynamics community before the system dynamics education can proliferate. These are: the lack of formal teaching material, insufficient literature on teaching methods, problems of terminology, and insufficient emphasis on undergraduate system dynamics teaching. Personal experience has taught me that system dynamics courses are extremely rewarding for both the instructor and the students. Once the above problems are dealt with, I believe that the university level system dynamics education will proliferate, which should be a major step toward initiating an exponential growth process in the field in general.

Introduction

In the development and growth of any scientific discipline, formal university education plays an important role. An obvious reason why this role is so important is that for the community of an emerging field to expand, a minimum number of educators ("critical mass") are needed. The only process of producing educators is through formal (graduate) university education. Thus, there is a positive feedback loop that must be set in motion for the field to experience substantial growth. System dynamics as a field has not experienced the growth that one would expect from its potential. This observation has been expressed in several publications (eg. Seeger 1992, Devries 1989, Fey 1985), but also in informal conversations and writings (eg. Karsky 1989). Lack of sufficient university education in system dynamics (see Clauset 1985 and Devries 1989 for data) may have been one of the main factors in this stagnation. System dynamics 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. Furthermore, system dynamics is an ever changing field, with new concepts (eg. chaos, interactive gaming) being added every year. A structured discussion of what constitutes a formal system dynamics education is needed, or the field faces the risk of being interpreted in entirely different ways by different people (a situation that is already being experienced to some degree, as I will discuss later). But most work on education focuses either on high schools (eg. Brown 1992, Draper and

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Swanson 1990), or on part-time/informal managerial training (Ford and Gardiner 1987, the entire special issue of EJOR 1992, especially Graham et al. 1992). With a few exceptions (eg. Anderson and Richardson 1980, Clauset 1985), there has been little work devoted to university-level system dynamics education. I suggest that we must spend more time and effort discussing issues of university-level system dynamics education, such as: What materials are appropriate in an introductory system dynamics course? In an advanced system dynamics course? In different levels of graduate teaching? What teaching methods are appropriate in each of these different level courses? In what ways do the answers to the above questions depend on the type of the student audience? Should (can) system dynamics be taught as a stand-alone course exclusively dedicated to system dynamics? Or, does system dynamics teaching have to be embedded in courses in other programs? What steps must be taken in order to increase the overall level of system dynamics teaching in universities? This paper is an attempt to start such a debate.

Types of university-level system dynamics courses

System dynamics course content and teaching style depend on the context in which the course is taught. *Type of audience* is an important factor. There is likely to be differences between teaching system dynamics to mathematically oriented engineering and science students and teaching it to business or psychology students. In many universities, system dynamics is used in courses in various programs (eg. resource management, marketing, defense analysis, city planning) in order to analyze and discuss some selected issues in those programs (see the MIT newsletter 1985). Such courses would be quite different in content and style than a course specifically dedicated to teach system dynamics.

Another distinction has to do with the *level* of the course: introductory vs. advanced; graduate vs. undergraduate. In most universities, system dynamics courses are taught at graduate level, and they most consist of an introductory and an advanced part (Clauset 1985, the MIT newsletter 1985). Very few universities offer system dynamics at undergraduate level.

Another popular way of teaching system dynamics is as a *module* in a course on computer simulation, quantitative modeling or systems analysis (Clauset 1985). Naturally, students in such courses can learn little on a subject as complex as system dynamics. Finally, most universities offer system dynamics-related courses as *electives*. In 1985, Clauset identified 9 required and 29 elective courses. I wonder if there are still as many programs around requiring system dynamics courses. I also suspect that some of those required courses are really courses in other fields that contain system dynamics as modules.

Observations Based on Personal Experience

I have taught system dynamics in various forms for the past eight years. In my first four years at Miami university of Ohio, I taught system dynamics as a module in an undergraduate course on mathamatical modeling and simulation, for systems analysis and engineering (and a few biological sciences) students. Subsequently, that course was tranformed into a course on system dynamics, with heavy emphasis on mathematical analysis. (This mathematical interpretation of "system dynamics" is rather well-known in engineering and sciences, which makes our usage of the term "system dynamics" problematic, as I will discuss in the next section). Finally, last year, I taught an experimental course which was dedicated 100% to system dynamics, as we, the community understand it. The course was open to all departments in the university, but systems analysis students filled the entire quota. This year, I joined the department of Industrial Engineering at Bogazici University in Istanbul, where I am currently teaching a version of that same course, open to seniors and gradute students.

To compare the earlier mathematical version of the course and the more intuitive

ANALYSIS OF CONTINUOUS SYSTEMS (3 credit hours)

TEXTBOOKS:

1- Burghes, D.N. and M.S. Borrie, Modeling with Differential Equations, Ellis Horwood, 1982.

2- Richmond, B., S. Peterson, and P. Vescuso, STELLA User's Guide, High Performance Systems, 1990.

3- Forrester, Jay, Principles of Systems, MIT Press, 1968.

4- Golomb and Shanks, Elements of Ordinary Differential Equations, McGraw-Hill, 1965.

WEEK	TOPIC
1	Course Organization and Overview
	Introduction to Dynamical Models
	Classification of Differential Equations (DE's)
2	Solving First Order Homogeneous DE's
	Applications of 1st order homogeneous DE's
3	Solving Non-homogeneous DE's
4	Applications
5	Simulation with STELLA
6	Second-Order DE's.
	TEST NO.1
7	Applications of Second order DE's
8	Non-linear Second-order DE's
	Concepts of Equilibrium and Stability
9	Linearization
	Applications
10	Systems of DE's
11	Introduction to Numerical Methods
	TEST NO.2
12	Introduction to the SYSTEM DYNAMICS method.
13	Applications of System Dynamics
	Discussion/Course Overview

Figure 1. Topics and Textbooks for a Mathematical System Dynamics Course.

SIMULATION-BASED ANALYSIS OF DYNAMIC SYSTEMS (3 credit hours)

TEXTBOOKS:
1- STELLA II User's Guide.Hanover, New Hampshire: High Performance Systems, 1990.
2- Forrester, Jay, W. Principles of Systems.Cambridge, Massachusetts: MIT Press, 1968.
3- Goodman, Michael, R. Study Notes in System Dynamics. Cambridge, Massachusetts: MIT Press, 1974.
4- Richardson, G.P. and A. Pugh, III. Introduction to System Dynamics Modeling with DYNAMO. Cambridge, Massachusetts: MIT Press, 1981.
5- Roberts, Nancy, D. Andersen, R. Deal, M. Garet and W. Shaffer. Introduction to Computer Simulation: A System Dynamics Approach. Reading, Massachusetts: Addison-Wesley, 1983.

WEEK	TOPIC
1	Course Organization and Overview Systems and Models
2	Structure and Dynamic Behavior; Illustrations. Systems Thinking and Complex Systems
3	Experimenting with Interactive Simulation Models. ("Balance of the Planet," "Market Growth," "Project management").
4	Tools for Systems Modeling: Stock and Flow Variables.
5	Introduction to STELLA and Structure Diagrams. Feedback loops: Positive and Negative Feedback
6	Causal-loop Diagrams; examples. Behavior of positive feedback loop; growth processes.
7	TEST No.1 Behavior of negative feedback loop; examples.
8	Coupling of positive and negative feedback loops S-shaped behavior and "boom and bust" patterns.
9	Linear and non-linear equation formulation. Importance of time delays in systems
10	Case Study: "Managing a firm in a rapidly growing market." Structure of cyclic (oscillatory) systems.
11	Examples of systems with oscillatory behavior. TEST No.2
12	Case study: "Surviving the real estate cycles." Generic Structures and uses of generic sub-systems
13	Case Study: "Rise and fall of People Express." Case discussion and course overview.

Figure 2. Topics and Textbooks for an Undergraduate System Dynamics Course.

(system dynamics) version of it, the contents and textbooks of both versions are shown in Figures 1 and 2. Observe that the mathematical version is organized according to the mathematical structures of the models, with increasing mathematical difficulty. Topics in the second version are, on the other hand, organized according to different types of feedback loop structures and the resulting behavior patterns, with increasing behavioral complexity. The teaching materials, textbooks and methods also differed significantly between the two versions. A major difference was in the pedagogical methods: in the second version, several case-study based simulation games were used and many lectures were held in a computer laboratory. But the most dramatic change for me was in the student behavior in class and student evaluations (which I take at the end of every class that I teach). Students were much more alert and active in the new version of the course. Their evaluation of the course went up from "average" to "good-to-excellent." But more significant were the written comments. In the second version of the course, with one exception, every student took time to make written comments. (Ordinarily, about 50% of students write comments on the forms). Furthermore, 25 out of 28 students made very positive comments, with expressions like "creative learning," "critical thinking" and "innovative teaching." I therefore have great personal conviction that university-level exclusive system dynamics teaching is extremely important and rewarding not only for students, but also for professors. But to prepare and teach such a course is not free of problems. In the following section, I will mention some of those problems.

Questions and Issues to be Addressed

Among the various types of system dynamics courses described above, I will focus on the type that can be described as: "undergraduate stand-alone course dedicated exclusively to system dynamics." I believe that it is this type that is least common, yet most important for the growth of the field. The following is a list of questions and problems to be encountered in teaching such courses:

1- Lack of formal teaching material. The field has several books that can be used as textbooks in an introductory course (see Figure 2). But there are no books that come with supplementary teaching material such as examples, assignments, tests and projects. I personally had to contact the MIT group that generously gave me a package of supplementary teaching material. It would me much more efficient if we had some textbooks that are packaged with such material (see also Forrester 1992). Also, some of the more popular textbooks are too much software-dependent. An ideal university textbook must be more conceptual and generic in its symbolism, rather than equating concepts with a particular computer language.

2- Insufficient literature on teaching methods. The best and most complete article on the pedagogy of system dynamics is by Anderson and Richardson, published 13 years ago (Anderson and Richardson 1980). We need much more work/discussion in this area in order to develop a well-defined pedagogy of system dynamics. We need a formal list of suggested topics for an introductory course, and one for an advanced course. It would also be very useful to have a taxonomy of teaching methods: traditional lectures; laboratory teaching; case-studies; interactive simulation games... In what parts of a given course and to what extent are the different methods appropriate?

3- Problems of terminology. System dynamics field has some terminology problems in general.There are many concepts central to the field for which we 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. There are more examples. 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, the course not having a single textbook. In our attempt to make system dynamics a formally recognized field of study and an undergraduate course, we must make sure that there is only one established technical term for each major technical concept.

Another dimension of the terminology problem is our usage of certain terms in ways that differ from their standard usage in other established disciplines. For example, Seeger explains that the terms "open" and "closed" have technical meanings in established fields of social sciences that differ substantially from our usage of these terms (Seeger 1992). A similar problem exists in the term "causal explanation." In statistical modeling and experimental design, this term means decomposing the statistical association between a dependent variable and a set of independent variables so as to decide what weight each independent variable has in predicting the value of the dependent variable. This meaning is of course very different than what we mean by causal explanation in system dynamics. Similarly, "influence diagram" in decision theory is quite different than the one used in system dynamics. I am not sure what the solution to this type of term conflict is. I personally think that in most cases, our usage of the conflicting term is philosophically sounder than the usage adopted by the competing discipline. But we certainly can not force other fields to change their terminology. Another solution could be to give the ownership of the conflicting term to whichever field first invented it.

Finally, the most dramatic example of terminology problem lies in the very name of our field, "system dynamics." As I mentioned before, this term has an established meaning in mathematical and engineering sciences. In short, in applied mathematics it means "mathematical analysis of dynamical systems" and in electrical, mechanical and systems engineering it means "analysis and design of dynamical engineering systems." There are many books and articles in applied mathematics and engineering that have the key word "system dynamics" in the title. Thus, 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. Audiences already familiar with the general, established usage of the term either fail to appreciate that the author is referring to a very specific philosophy and methodology, or ask questions like "what type of system dynamics do you exactly mean?" (As a matter of fact, many system dynamicists prefer not to use the term system dynamics in the titles of books, presentations, courses, even conference proceedings). As a result of this, through the years other fields 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. The term "system dynamics" really refers to the very general area of inquiry to which our field belongs, and it should 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. (For example "causal systems modeling," "causal feedback modeling," "systemic feedback modeling," "causal systems simulation," "causal feedback dynamics" etc.). There are many more aspects of this issue that are beyond the scope of this article. I suggest that such a debate be started in the system dynamics community.

4- Insufficient emphasis on undergraduate system dynamics education. I have argued in this paper that university-level system dynamics teaching is important for the growth of the field. Furthermore, it is crucial to have the students acquainted with system dynamics at the undergraduate level, because only then will they be able to appreciate the potential of and be motivated for pursuing a graduate education in system dynamics. Unfortunately, among all the different types of system dynamics courses mentioned above, the least common type is an undergraduate course dedicated to system dynamics (see Clauset 1985 and the MIT Newsletter 1985). Since this type of system dynamics teaching has perhaps the greatest potential influence in the growth of the field, I suggest that the system dynamics community be engaged in a special effort to increase the undergraduate system dynamics education.

Conclusion

System dynamics, in spite of its solid philosophical foundations and a very promising practical prospect, has not experienced the growth that one would expect from its potential. I argue that a major cause of this relative stagnation has been the lack of formal, regular undergraduate system dynamics courses in universities. I have identified four groups of problems and issues to be addressed by the system dynamics community before the system dynamics education can proliferate. Personal experience has taught me that system dynamics courses are extremely rewarding for both the instructor and the students. Once the problems are dealt with, I believe that the university level system dynamics education will experience a growth, which should be a major step toward initiating an exponential growth process in the field in general.

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