System Dynamics: What to teach?

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Abstract

The topic of this paper is to discuss system dynamics as a subject in universities and colleges. The reason for my interest in this topic is that I have been giving classes in system dynamics since 1991 at Sogn og Fjordane University College. My students have mainly been undergraduates in economics and finance. This is also reflected in the cases I have chosen to elaborate - from a technical as well as a pedagogical point of view. My lectures form the basis of a textbook I have written (also available on the Internet) that represents my understanding of what a course in system dynamics should contain. The cases are from the spheres of finance, cost-benefit analysis, macroeconomics, demography, consequence analysis as part of decision analyses and system dynamics as a tool in strategy development.

When I search the Internet for courses that are offered at universities around the world and read the literature lists, I get the impression that there is a shortage of textbooks for introductory courses. This conference might be an excellent opportunity to discuss the problems this shortage creates and to point out guidelines for standardised courses in system dynamics. Hopefully my proposed textbook can be a small contribution towards that aim.

1 Area of application

A prerequisite for building a model is that the builder has an understanding of what she is modelling. Domain knowledge is essential, and in a beginner's course it is an obvious advantage to introduce cases from domains that students are familiar with. In the following I shall discuss some of the topics my classes have worked thoroughly with. The complete list of contents of my proposed textbook is given in section **4 Contents**.
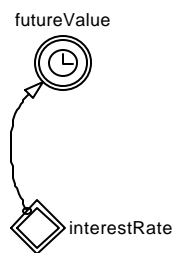
1.1 Finance

System dynamics is an excellent methodology for learning most of the topics that are dealt with in textbooks on finance. For instance, the formulae of capital growth can be easily modelled, and even better, they can be made more general. Let us look at an example that illustrates this point: the future value of an annuity as calculated by the formula is based on a constant interest rate. This is not a very realistic situation. We all know that interest rates fluctuate, and we bear this in mind when we save money or especially if we borrow

money. In the latter case we are concerned with questions like: what will be the consequences to my economic situation if the interest rate increases? System dynamics can easily deal with such a question and makes it possible to incorporate scenarios in economic analyses. These qualities prove to be extremely useful when analysing the profitability of an investment. The examples dealt with are

- future value
- annuities
- present value of future cash flows
- amortisation
- cost-benefit analysis
- value of bonds.

Some of the aspects of finance can be viewed in two different ways that will affect the ways models are built, and I illustrate them in the following way. Calculating the forward value of one dollar can be regarded as raising (1+r) to the power of t, where r is the interest rate and t is the number of years. A different way of thinking is to animate what is done by the bank clerk at the end of every year: take the end balance of the previous year and multiply it with (1+r). The latter procedure corresponds to a difference equation. The models I work with reflect that I prefer the *difference equation* to *raising to the power of t.* The reason is that they open up for different options when doing simulations. I shall illustrate my point with two extremely simple models.

futureValue

interestRate

Raised to a power model

futureValue

prevFutureValue
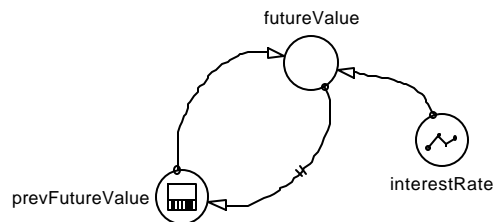
interestRate

Difference equation model

The *raised to a power model,* with small extensions, enables you to produce all the future values and net present values that are tabulated in a textbook on finance. The interest rate is given as a vector where each of the components is time independent. And in simulations you only get results that are based on constant interest rates over the relevant period. The difference equation model handles the interest rate as a time series. That is hardly ever done in any textbook on finance! The elements of the time series can for instance show the impact of an interest rate that in the first year is 4 %, and for the following years takes on the values 5 %, 5.5%, 7% etc. or whatever one may choose. My view is that the use of time series instead of vectors opens up for more realistic simulations in finance.

1.2 Macroeconomics

One of the most exciting fields for the use of system dynamics is that of macroeconomics. The theoretical foundations are described in *The General Theory of Employment, Interest and Money* (1936). This classic book by John Maynard Keynes is generally regarded as probably the most influential social science treatise of the 20th Century. Keynes changed the foundations of macroeconomics and the way the world looked at economy and the role of economy in the society. The systems we are going to study are described by equations in accordance with Keynes's theories. We start the model building by studying a very simple society where the national product in one period is equal to the sum of the aggregated consumption and aggregated investment in the previous period ($R_t = C_{t-1} + I_{-1}$). This simple difference equation is the basis of a tentative model. Small refinements of it lead to the illumination of the concept of equilibrium, and how a step to a higher level of for example investment, transfers the system to a new equilibrium state. Further modifications help to illustrate what a *multiplicator* effect on an investment is. The most advanced model is the ISML model. This is a representation of Keynes' theories that was introduced in 1937 by John Hicks. The corresponding Powersim model makes it easy to simulate what impacts various measures will have on society. One case in point: a government wants to increase its spending and compensate for this by increasing taxes. The answer to the question what effects this will have, is given by Haavelsmo's theorem: employment will increase and export decrease. It is very rewarding for students to be able to build models that produces the correct answers to this and other kinds of if-then questions.

1.3 Demography

Demography is a study of the quantitative aspects of human populations. The focus is on their changing size and composition, and the causes and consequences of such changes. This kind of knowledge is very important for the public as well as the private sector. When planning kindergartens, schools, health services, nursing institutions etc, demographic knowledge is important. Public planners have to know not only the size of the population but also its composition which means the proportion of children, young and elderly people in the population. For business people knowledge of the size and composition of populations is essential when making decisions about location, and what products and services to offer.

The start of the simulations is models of animal populations. And these are developed into realistic models of the development of the population of Norway. Use of vectors makes it simple to handle variables such as fertility and mortality for all age groups. Hopefully these cases show that system dynamics is a useful tool for demographic studies.

1.4 Decision models and strategy development

Decision making consists of two different processes, namely *analysis of consequences* and *analysis of preferences*. The combination of these two processes constitutes the *decision paradigm*. The decisions we make are based on what we believe the future will be like, and possible futures are described by scenarios. When a scenario can be expressed as a set of parameters, system dynamics is an excellent tool for consequence analysis.

A strategy can be looked upon as a collection of ideas of how to meet challenges in the future. We usually comprehend strategy as something connected with businesses or organisations, but it definitely also pertains to our personal life. We all make plans for the future, for the next coming hours as well as for life. Most people have a number of plans

that can be classified as strategies. And the plans have been made taking into account a lot of questions of the type "what happens f…" In this way plans are actually made by taking into account different visions of the future.   In short, *strategy* as well as *scenarios* are phenomena   that we deal with in mental models that concern our everyday life. However, they are not labelled the rather prestigious words of strategy and scenario. The realisation of how common   strategy thinking is, is an excellent starting point for systematic development . System dynamics   models can be used in settings as those described by Agyris and Schön (1978 and 1990) . And likewise the models fit superbly into the micro world thinking as described by Morecroft (1994). There is a short step from our intuitive perception of strategy development to playing with models.

2 Educational challenges

The purpose of teaching system dynamics is to train students in model thinking, model building and simulations. An additional and more ambitious goal is to create an understanding of the role that system dynamics methodology can play in the development of mental models, and how system dynamics can be used in scenario analysis and the evolutions of strategies.

Essential to any training project is the subjects chosen for training purposes. In this section I will discuss some pedagogical aspects of teaching system dynamics.

2.1 From spreadsheet to flowchart

System dynamics was developed as a methodology for analysing how time-dependent systems develop as time passes on.   It can be regarded as a supplement to spreadsheet programmes that are efficient when studying time- independent (static) systems.   A significant difference between the two types of programmes is that system dynamics programmes have a graphic user interface and are focused on problem structures rather than numbers and formulae as spreadsheets are. Model building requires a profound understanding of how things work, in other words, about structures and relations. Even building a tiny model demands abstractive faculty. As teachers we have to bear in mind this demand, even more so because many students have a low   abstractive faculty. To perceive a level as an idea that is separated from particular instances is an example of the process of abstraction. So drawing flow diagrams implies thinking in structures rather than numbers. In a way a system dynamics programme may be perceived as an abstraction of a spreadsheet.

2.2 Time

The problems associated with the concept of time are easily underestimated. Time is definitely not as concrete as some system dynamics programmes make it look like (for instance Powersim).   The essence of a model is that time flows. Recalculations are monitored by time. But in some instances it is desirable to let another quantity have control of the calculations. For instance when simulating difference equations an index of some sort will be in that position. When working with macroeconomic models, the time unit is a period. What this period is   uncertain - at any rate to me. The time concept should definitely be broader than that of the calendar. In the model Hanoi Tower (Henden, 2003, 54) the lapse of time is   measured by the number of disks (which iThink allows you to use).

2.3 Causality

A fundamental problem has to do with identifying causal relations and to understand the concept of *causality*. This word has three principal meanings (Bunge, 1963, 3-21). In science we often observe constant and unique connections. An example is the velocity which is determined by the time. But the word *determination* does not convey the activity and productivity inherent in causation. So this is not a causal law. Another problem is associated with distinguishing between correlation and causation. An objective of a course should be to pass on some of this insight. A more pragmatic view is: "the verbs *cause*, *affect*, and *influence* are used (here) to mean approximately the same thing" (Roberts et al., 1982, 2). In my opinion, there are obvious reasons for using the term *influence diagram* rather than the more ambitious *causal diagram*.

2.4 Communicative gains

An important part of group work is the exchange of ideas between students. When solving problems of mathematics, discussions often are a one-way communication from one student to another, and the content of what is being communicated is technical help. System dynamics apparently has inherent properties as far as communications are concerned, and discussions over flow charts are ample. Unlike mathematical formalism System dynamics rarely inhibits students from communicating their views.

2.5 Modelling and observational learning

The theory of observational learning acknowledged modelling the most powerful means of transmitting values, attitudes, and patterns of thought and behaviour (Bandura 1986, 48). From observing and learning we make models that contain conceptions and rules for generating our structures of behaviour. Modelling must necessarily be a process, and the value of this paradigm, as I see it, depends on how well this process can be understood. A model is not a sort of response mimicry or imitation. Learning means making a model by processing the information about the structures of events that we observe. The information is transformed into symbolic representations that serve as guides for action. The way we analyse phenomena no doubt affects the ways we understand them and the level of cognition we attain. The mechanism of observational learning is, I think, such that the analytical approach of system dynamics has a structure that induces the modelling process characteristic of observational learning. Observational learning is shown most clearly when models exhibit *novel patterns* (Bandura 1986, 49). In the process of analysing and solving problems it is possible to observe solutions that students were unlikely to come up with prior to learning system dynamics even if they possess the prerequisite knowledge. This corresponds with the definition of *novel pattern*. And such novel patterns are frequently observed.

3 Conclusions

Even for a teacher the mechanism by which the subjects we teach are selected is rather obscure. Looking at mathematics it is hard to comprehend why so much emphasis is put on solving equations rather than devoting more time to number theories. The rate of change is also extremely low; once a subject has become part of a curriculum it often remains so for a very long time. What we teach is apparently bound by tradition because the foundations of most disciplines have been laid centuries ago; in the case of mathematics even more than a thousand years back in history. This stability, especially in terms of the analytical sciences, might be an obstacle to making changes when there is paramount reason for doing so. This

might affect our aptitude to change pedagogy or methodology of teaching as well as the subjects we teach.

What we teach is in accordance with conventions that have been formed over a long period of time. Typical constraints of curricula are what is taught at similar colleges. Another obstacle to change is the fact that diverting from the traditional approach could put you out of pace with what advanced courses are based upon. Given circumstances where less consideration could be taken to the surrounding world, most likely more teachers would divert from traditional curricula.   My conclusion is that system dynamics enhances the understanding and enables the students to go well beyond the oversimplifications of traditional textbooks, and that the use of the methodology in various disciplines should be advocated.

4 Contents

The contents of my proposed textbook are as follows:

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