Introducing System Dynamics in Schools - the Nordic Experience

by

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Abstract

This paper contains a snapshot of some of the activities in the Nordic countries, regarding the utilization of system dynamics as a basis for educational development. In particular we provide a brief description of the background for introducing system dynamics into public education, point out software developed in Norway for this purpose, present some of the methodological issues addressed, and summerize the classroom experiences reported by two Swedish teachers.

1. The background for introducing system dynamics into public education.

The Nordic countries consists of Denmark (5.1 mill), The Faroe Islands (0.05 mill), Finland (4.9 mill.), Iceland (0.25 mill), Norway (4.2 mill), and Sweden (8.4 mill.), each with their own language (the Danes, Swedes, and Norwegians can normally understand each other) and cultural orientation. Moreover, Finland, Norway, and Sweden share a minority population of Sami extraction.

The educational systems (including the universities) are predominantly public ones, run by the governments, and the education is free at all levels. The national assemblies determine the basic pattern of education by laying down the aims, structure, and contents of educational provision by legislation. An estimated 1.25% of the population are teachers.

All Nordic countries have launched ambitious programmes of action with respect to the introduction of computers in public education. Altogether an estimated $ 100 mill. has been spent on these programmes; on pedagogical development, on courses and design seminars for teachers and software developers, on software development, on harware aquisition support, on classroom testing, on programme evaluation , etc.

In Norway, this programme came about as a result of a governmental initiative in 1983, resulting in a white paper early 1984. Late1984, a central task force was established to evaluate, finance, and coordinate decentralized activities and IMTEC (International Movements Toward Educational Change) (IMTEC 1989) was engaged to perform a running evaluation of the programme. In 1987, an OECD Examiners´ Group reviewed the programme (OECD 1987). In Norway, as well as in other Nordic countries, the technology recommendations did not favour Apple and, at first, not even IBM compatibles. Within each country, computers were built specifically for educational purposes. The technological and the language barriers, created a need for national software development, internationally coordinated by the Nordic Council of Ministers, software which is now available for IBM compatibles. While as the other countries concentrated on developing specific applications, Norway took the lead in the role as developer of a toolkit.

Nordic Summer courses in educational software design were offered by Norway, and this activity was followed up by the other Nordic countries. These courses were offered to teachers who were challenged to develop ideas for educational software within and beyond the framework of existing curricula. The issue was to let the teachers themselves set the stage and to let technologists remain behind the scenes. Computer interfaces were developed using a market square metaphore. The software was developed so as to allow the students to "visit" various "shops" in this square as they pleased, influenced only by the teachers´ default parameter settings. In the metaphore of a theatre, this would allow the students to progress from the role of an audience, through the role of traditional actors, improvicing actors, stage directors, directors, and, finally, play writers. For the purpose of these interface design efforts, the first versions of Mosaikk, then a pure screen design tool box, was developed. The idea was to have teachers with no computer science background design their own interfaces.

At that time (1984), the International System Dynamics Conference was held in Oslo. Professor G. Richardsons (Richardson 1984) eminent presentation on feedback loop dominance and the emergence of games, made is clear to us that system dynamics had a pedagogical potential applicable to public education. Shortly after, Richardson was invited to give a seminar at the University of Bergen and at the Stord Pedagogical College, demonstrating STELLA™ for the first time. This Nordic seminar was the first out of four on the general concept and ideas of system dynamics. It also set the stage for the development of SimTek, an equation-oriented tool for model design and simulation.

The emphasis on pedagogical designs had a tendency to move the attention away from whatever was underlying the applications - in our case the models. It was only by letting the designers experience their own short´comings we had them realize the need for a more in-depth understanding of the system dynamics paradigm. This paved the way for an intensive 8 days Nordic seminar, developed by the Department of Information Science, University of Bergen, where the participants were given a presentation of system dynamics as the foundation for a pedagogical method. The seminar started out with lectures, games, and assignments and ended up in a three days multi-group modeling session. The enthusiasm created by this seminar was echoed by Nordic school officials, and consequently we were shortly after invited to present our system dynamics approach on EURIT 90, The European Conference on Technology and Education (Davidsen 1990).

This year, an initiative was taken to formalize the long standing collaboration between the University of Bergen and Stord Pedagogical College, in the form of a graduate education in pedagogical information science - one of the first of its kind in Europe. Among its main tasks, this programme will explore the pedagogical potential of system dynamics.

The Centre for Educational Software Development, State College of Karlstad, Sweden, has been conducting the most extensive tests, two of which are preliminarly reported in this paper, using system dynamics as a basis for teaching. Several teachers are associated various centre projects. In one of these projects, a thermodynamic model of a house has been built with an interface designed to help the contractor, the public utility company Vattenfall, inform the public about energy conservation. The Centreis now joined by Professor B. Lindstöm, Department of Education, University of Gothenberg, representing the fourth Nordic cornerstone in a close collaboration on the pedagogical utilization of system dynamics.

2. A software toolkit.

As a result of the aggressive actions taken by the Ministry of Education, Norway has been able to develop an educational software toolkit that has gained widespread international recognition. In a system dynamics perspective, SimTek, Mosaikk, and SimMos are of particular interest:

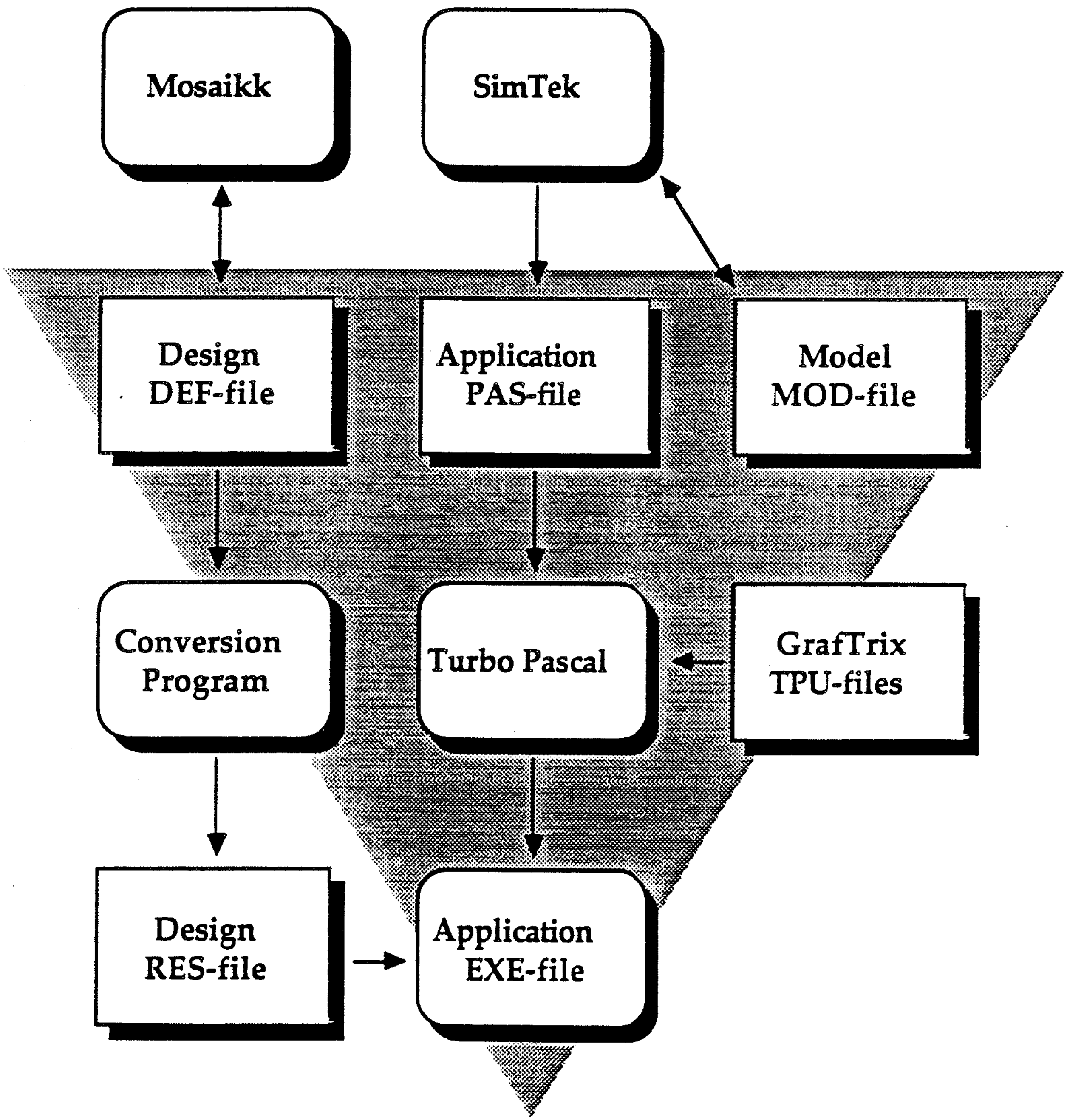

Fig 1: SimMos; Software tools for developing interactive simulation programs

SimTek is a stand alone, equation-oriented model editor and simulator . It can create a TurboPascal source version of a system dynamics model that can be embedded in other Pascal programs. This file may be converted into an object code along with GrafTrix, a library of sophisticated Pascal routines. Mosaikk is an interface design tool, based upon TurboPascal, that allows the user to create a design definition file and convert it into a resource file. This file can be interpreted by a Pascal program, in particular the object code for the Pascal version of the SimTek model, to produce output on the screen in accordance with the design specification. SimMos is that part of the GrafTrix library that interprets the interface design messages and responds appropriately by establishing the communication between the model and its interface. SimMos also contain messages for the communication with data bases, audio- and interactive video-machines, etc.

Several designs may be created and modified for each simulation model, and a design may be applied to various models. The designs are flexible and allow the user to move the screen objects around during simulation so as to compose an interface that emphasizes a specific model property. To control the simulation, a "tape recorder control panel" is available. So far, eight presentation forms have been developed, some of which facilitate a direct interaction between the user and the model during simulation. This software is developed to address some methodological issues that we have considered essential:

3. Some methodological issues.

Briefly stated, our final goal is to provide our students with an effective way of thinking about complex, dynamic systems. Thus we want to change the cognitive style of our students. Far beyond establishing a basis of values, attitudes, and factual knowledge, we believe our schools significantly influence the way each one of our students will be thinking. The influence that our schools have on their cognitive styles, i.e. their ability to;

- perceive reality;
- identify and analyze real problems;
- construct appropriate suggestions for solutions; and
- identify the short and long term dynamic consequences of their suggestions,

has been grossly underestimated, and we suggest that their cognitive potential for solving such problems is being underutilized.

It is the purpose of using system dynamics as a pedagogical instrument to communicate an understanding of the relationship between the structure and the behavior of complex, dynamic systems, so as to facilitate;

- an explanation of observed patterns of behavior through model analysis; and
- the creation of desired patterns of behavior through model synthesis.

This implies that we must teach our students how to consider systems from a structural as well as a behavioral perspective, and that we develop techniques by which we may combine these perspectives. That is, structural forms of representation must be merged into behavioral descriptions, and vice versa, to make the intimate relationship between the two transparent. To do so, we develop ways to exhibit dynamics and ways to exhibit structure that are meaningful when considered separately, and synergetic when combined. Primitive examples are the filling of a level and the use of indicating arrows available in STELLA™ diagrams. Differentiated colouring of feedback loops according to their dominance, are more sophisticated examples.

With the exception of feedback loop diagrams, the stock and flow diagrams, introduced by Professor Forrester (Forrester 1961), are almost unchallenged as a structural form of representation. Patterns of behavior are almost invariably presented in the form of time plots. Some strengths and weaknesses of feedback loop diagramming have been identified (Richardson 1986, Morecroft 1982). In our classroom experiments, we utilize both, often in combination, to benefit from the simplicity of causal loops and the accuracy of the stocks and flows.

One of our tasks is to design new ways to represent structure as well as behavior, to try them out, separately as well as in combination, and to develop a set of recommandations for their use. For instance, we recommend the use of a state space plot of a variable versus its derivative, combined with a time plot of the same variable, to examine the relationship between the structure and behavior of a non-linear (ecological) system, exhibiting shifts in feedback loop dominance and the disappearance and reappearance of equilibria (Davidsen 1989). It is important that these representational forms should be applicable rather by example than by programming so as to provide the teachers themselves with ways of experimenting in the classroom without being dependent upon a programmer.

Another issue arises when focusing on interface designs: The traditional ways of describing complex dynamic systems are of fundamental importance. We realize however that, for many educational purposes, they are too abstract. As representations of generic structures and patterns of behavior, they are excellent. In a pedagogical process, however, much more concrete systems descriptions must constitute our points of departure. From examples, portrayed very concretely, we must converge towards the generics by a process of gradual abstraction. Conversely, thus having discovered basic similarities between a broad spectre of systems, we should diverge in the opposite direction; to generalize and to utilize the pedagogical principle of transferability of knowledge between systems. Consequently, we need a software toolkit that can take us stepwise through this process - back and forth.

The need for a concrete point of departure is exemplified by the use of games and role games developed in Sweden. E.g. social diffusion processes, such as the spread of a rumor or a disease, are being simulated in various versions in the classroom, typically one student affecting another each time around. Through an intense study of the results, it is possible to identify the regularities characterizing the rate of diffusion, i.e. its propotionality to both the number of affectors and the number of affected. In Denmark hands on systems experience is offered by letting the students turn nobs on electical circuit boards equipped with exchangable covers partraying various systems structures. In Norway, water basins and pipelines have been applied to exemplify levels and rates, and colours are used to represent intensities (e.g. of energy, i.e. temperature).

Knowledge aquisition is cumulative, and most effective when organized in a hierarchy. Having familiarized oneself with a structure and its associated behavior, it should be possible to encapsulate this understanding in an object, accessible from the outside only by ways offered by the real structure. Among others, John Morecroft has indicated the need for encapsulation by encircling decision processes in his diagrams (e.g. Morecroft 1986). Generic structures, such as positive and negative feedback loops, coflows, etc. constitute typical units of encapsulation. From a pedagogical point of view, we are forced to apply a dual perspective: On the one hand, we must equip the teacher with units of understanding appropriate at various educational levels. On the other hand, because our students and our teachers are so different, and because teaching is a result of an interactive process between them, we must allow for them to define their own units of encapsulation.

By providing teachers with a set of standard generic structures, tuned to the students' level of systems understanding, we can build subject oriented curricula in parallell that utilize that same generic patterns and structures, so as to facilitate an inter- and a multi-diciplinary approach to teaching. Our first task will be to identify such patterns and structures, and to try them out in various sequences, and at various levels so as to identify an efficient sequence of introduction across educational levels. We have noticed that the debate in the Nordic countries is about to change from how to utilize modern technology within the framework of a traditional curriculum to how to develop a better curriculum that utilizes modern technology.

In creating an understanding of the relationship between the structure and behavior of dynamic systems, the issue of differentials and integrals is being addressed in a project by H. Wikström (co-author) in preparation for his Ph.D. thesis. He takes Professor J. Forresters word; "Nowhere does Nature differentiate; in real systems, dynamic change arises only from accumulation, that is integration" (Forrester 1980), as his point of departure. Contrary to common educational practice, he argues that it is pedagogically more efficient to establish an understanding of accumulation and decumulation processes, upon which the teaching of integration can be based - only later to introduce the inverse process of differentiation. The study of intergration processes creates a platform for the understanding of computer simulation as well. Therefore Wikström, as a side effect, develops techniques for the smooth transition from game- , blackboard-, and calculator-simulations, easily captured by the student, to the mysteries of computer simulation. Some of his experiments are summerized below.

4. The classroom experiences of Hugo Wikström

4. 1 Introduction

Hugo Wikström has been studying two groups of students;

- one group of 8 (50% female) positively selected primary school students (15 years of age) over 26 hours (3 x 6 hours + 4 x 2 hours); and
- one group of 30 (27% female) high school science students (17 years of age) 105 hours (35 x 3 hours).

4. 2 Purpose.

The purpose of his study has been to investigate whether students at the age of 15 and 17, respectively;

- can understand what a dynamic system is, when presented in the form of a model;
- can follow and contribute effectively to the conceptualization and gradual formalization of a model;
- can understand the structure of a model and draw appropiate conclusions with respect to its patterns of behavior;
- can transfer their knowledge to models of similar systems;
- can develop an understanding of the integration process that effectively serves as a basis for the calculus of integration and differentiation;
- can develop an understanding for the principles of simulation, through the study of integration processes; and
- can, after having been exposed to several models, be able to design their own models.

4. 3 Evaluation of point of departure.

Through 7 questions, we tested the students ability to reason about dynamic systems. The questions were selected from various social and ecological sciences and adapted to the level of conceptualization familiar to the students.

Partly, the questions presented textually a behavioural pattern and challenged the students to identify the underlying structure. Partly, structures were presented and the students were asked to predict the systems behavior.

4.4 Teaching

Generally speaking, the introductory teaching in the high school was similar to the one in the primary school although more brief. The follow-up teaching in high school was much more extensive; concerned a broader spectre of models from various sciences and contained an in-depth study of mathematical phenomena with which the students were unfamiliar - in particular integration.

An interest rate growth model was presented in the form of a positive feedback loop diagram and applied in order to;

- introduce the concept of positive feedback, and
- initiate a discussion on the insufficiency of positive feedback as an complete explanation to many real life phenomena.

Initially the students were asked to calculate the interest rate by means of a caculator. The calculations were based upon the iterative use of a level and a rate equation.

The results of their own calculations were represented in a table were the bank balance was listed along with the corresponding interests earned. The students were then challenged to write the general form of the level and the rate equation into SimTek and to initialize a simulation. The results were listed in a table similar to the one the students had already made. This was done to familiarize the students with the process of simulation and to create an understanding of what the computer actually does when performing a simulation. Having understood this process, they were soon comfortable about leaving the simulation to the computer.

Using other simulation languages, like STELLA or Professional Dynamo, one may use graphs instead of tables. We have not examined which of the two is of greater pedagogical value. We expect the tables to, more effectively, create an understanding of the underlying simulation process, while as graphical forms of representation have obvious advantages for other pedagogical reasons.

In our discussion and the calculations of earned interests, dt was assigned the value 1 year. Tentatively, the students were asked what would happen if dt was reduced, i.e. the interest rates where compounded more frequently. Simulations indicated the very suprising and agitating fact that the consequent increase in the bank balance and earned interests gradually increased less significantly, and that the behavior of the system seemed to approach a limit as a result of the linear reduction in dt. This is one way to introduce the formal process of integrating a continuous system. The students´ response to this process, and to the effects of reducing dt, indicates how we may successfully approach the teaching of integration, starting out informally and ending up with a formal description of the integration process.

Quite a lot of time was spent discussing the need for balancing the growth, created by positive feedback loops in general. The need for saturation mechanisms was recognized. In the case of interest rates, a tax rate on the bank balance was used to create a negative feedback loop. The resulting system was portrayed in the form of an extended feedback loop diagram.

In our case, a progressive tax rate was applied, after a discussion on how the tax rate change in reality according to bank balance. The tax rate was first introduced in the form of a curve, which was then transformed into a table interpretable by SimTek. For pedagogical purposes, a constant tax could have been used initially, and the students could have been asked to study the effect of varying this tax rate. This would support their understanding of how the tax rate could be applied to regulate the net income. With this in mind, a suggestion using progressive tax rate could arise from the classroom discussion.

This bank balance model was exposed to a series of experiments, such as: What happens if;

- the money was kept at home and no interests were obtained, - but tax was still paid?
- a constant withdrawal rate were introduced in the model?
- you winn one million $, what policy should you follow to fully utilize this capital gain?

The two last questions led to a fairly advanced model behavior, characterized by a competition between a linear erosion of the capital and the positive exponential growth that the interest rate constitutes.

Thereafter, a rabbit population model was introduced by the teacher. To carry over the experience, already gained by the students, a causal loop diagram was used for them to point out the analogy between the two models (the rabbit population and the bank balance model).

To simplify matters, hunting (corresponding to withdrawals) was deleted from the model. And to stimulate the classroom discussion, the number of rabbits did not (so far) influence the death rate. The death rate was debated extensively, and this was a natural reason for the students themselves to suggest the introduction of predators. Again by analogy, a fox population model was introduced. This inspired the students to explain how the two populations were interacting. The result was portrayed in a corresponding flow diagram which constituted the basis for the transformation of the bank balance equations to the dual-population models.

At this point, due to lack of time, the teacher was forced to provide appropriate parameter values for the students. This, however triggered a discussion on how the students could identify reasonable values themselves, by asking biology teachers, searching in the library, calling scientists and officials etc.

Having experienced severe oscillations, the students were challenged to identify attenuating factors; such as lack of food, space etc. and they agreed upon using the aggregate term "stress" for these factors influencing the rabbit death rate.

Several experiments were performed, such as reducing one of the populations, stepwise changing the fecundity, and introducing more rabbit food. These changes were introduced, using a compiled version of the model with potentiometers representing its parameters.

Before each of the experiments with the bank balance model and the predator-prey model, the students were asked to predict the behavior of the model. There was a significant difference between the students relatively poor ability to predict some of the more complex patterns of behavior and their ability to explain these patterns on the basis of the graphical representation of the underlying model.

At this point, the students were asked to build yet another model, which was not based upon the previous ones, but required the utilization of SimTek with which the students were now familiar. The purpose of this model was to utilize the students engagement in pollution problems to study accumulation snd decumulation processes, i.e. integration, and delays associated with integration processes.

As a point of departure, a polluting industry was chosen and the question was asked; what happens to the residual pollutant on its way through an ecological system. Various rates of pollution were applied to a one level (lake) model, modeled by the students from a stock- and flow diagram. The resulting accumulation was studied and explained both in terms of graphical integration and computer simulations.

Thereafter, absorbing species were introduced in the form of a food chain, and the accumulation of the poisoning pollutant in the various species were studied. This exercise emphasizes the concept of a delay and focus on the cumulative effects of various inputs and delay times.

At this point, the time was out for the primary school students, while as the high school students went on examining a range of models, spanning from epidemiology, through Newtonian mechanics, to electricity and thermodynamics. Throughout the exposure to these examples, the teacher focused on the identification of the relationship between the rates and the levels, investigating the potential value of this approach as an introduction to the mathematics of integration and differentiation.

Using the simple accumulation of pollution as a point of departure, and referring to experiments conducted in the physics class, a model of the relationship between distance, speed, and accelleration was developed by the students. A series of assignments were given, followed by corresponding simulations, to develop an intuitive understanding of the relationship between rates and the resulting levels, fundamental to the understanding of intergration and differentiation.

These students had had an introductory course in differentiation of polynomials, and by inverting this process, the "primitive function", applied as a term for the integral, has been introduced. Therefore, they had no real understanding of differentiation and integration as mathematical processes. I.e. they did know that the differential of a curve represented its steepness at a certain point, but not how it determined the trajectory of the curve. This was revealed when the students, after a short while of working with simple rates, recognized the relationship between rates and levels as the relationship between a function and its "primitive", or a function and its differential, respectively, and admitted that this was a stunning experience. Their discovery was then corroborated by a series of simulations whereby the students calculated the area under various rates only, over and over again, to identify the value of its "primitive".

Among the rates tested, some moved stepwise, along a continuous curve. By gradually shrinking the step (time-) interval, we obtain an approach towards the curve, resembling the process of integration and its illustrating correspondance to the principles of a discrete simulation of a continuous function. In approximating the continuous functions, the students themselves became aware of the fundamental relationship between simulation accuracy and resource requirements.

4. 5 Evaluation of result.

Through 6 questions we tested the students ability to reason about dynamic systems after having been exposed to 22 hours (primary school) and 35 hours (high school) lectures, exercises, and assignments. Again, the questions were selected from various social, ecological, and physical sciences. These questions were somewhat more demanding, but of a similar character as the ones used initially to measure the students´ points of departure.

4. 6 Conclusion.

An analysis of the replies to the 6 experimental questions, compared to the corresponding 7 control questions, clearly reveals a change in the students´ way of thinking about problems, relating to dynamic systems. In particular, we observe that every statement was now supported by an argument, which, in many cases was far more sophisticated than what the teacher would ever expect from even a superior student. Causal chains were being pursued, and delays in negative feedback loops and the resulting oscillations were being described as if they were a part of every-day discussions.

Moreover, the engagement and enthusiasm diplayed among these students had not been experienced by the teacher throughout his 17 years of practice. Even if the students were working for 6 hours every time (theory and practice intermittently), far from typically, they showed no signs of exhaustion or irritation. They looked foreward to the lectures, and they did not want to leave the classroom by the end of the sessions.

To illustrate the interest generated in the course, this year 15 out of 45 high school students volunteerly chose the computer science course. Next year, 23 out of 25 will attend, having been informed by their fellow students about the content of the course. It is to be noted that they would otherwise not have to attend any lectures during these hours and that the lectures have been offered after normal hours and in addition to 38 hour lectures per week.

More importantly, several students explicitly states, in introductions to their assignments, that the way they perceive their surroundings and conceptualize is quite different after exposure to a system dynamics education. Says Ann (15), typically;
"Now, when I encounter problems, similar to those we addressed in the classroom, I start wondering about how to create a model that portrays the underlying phenomenon, how to provide realistic parameter values, and how to design interesting experiments - and about what my findings would be. I never thought this way before".

5. The classroom experiences of Margaretha Bjurklo

5.1 Introduction

Margaretha Bjurklo has experimented with a class of 26 (62% female) high school economy students (18 - years of age) over a period of a full Spring term (10 weeks, 3 hours per week, in addition to classroom assignments) . Half of these lectures were spent on the introduction to macro-economics and half of the time was spent testing the students abilities to reason about a computer based macro-economic game, which has not specifically been designed with respect to systems dynamics teaching.

5.2 The purpose

As a statement of purpose, Bjurklo initially formulated the following specific goals for her system dynamics based education: "To give the students an appreciation and respect for the complexity of social and natural systems. To develop a critical attitude among the students towards the use of models in problem solving. To establish an understanding of the dynamics of systems, based upon their underlying structure. To analyze short term and long term dynamic consequences of decisions. To improve the students´ abilities to solve problems (design policies) related to complex, dynamic systems. To make our students apply a wholistic, inter- and multi-diciplinary systems perspective when facing real life problems. To train our students´ abilities to make abstractions and transitions from concrete, intuitively understandable models to formal simulation models. "

In summary, our systems dynamics teaching should inspire our students to participate reflectively in group and classroom discussions on the conceptualization, analysis, and policy design with respect to complex, dynamic systems.

5.3 The teaching.

The students were divided into two groups by a stratified selection so that the groups were equal with respect the distribution of their gradings. One person was teaching both groups. Both groups were using the same text book. The main differences between the teaching of the two groups, were the following:

One group was offered a macro-economic education, based upon a traditional curriculum. This group was divided further into six subgroups, each challenged by one major assignment specifically addressing current macro-economic issues. The result of their work was to be presented to the main group. They were asked to address the following questions;

- How had the current economic situation come about?
- Which solutions to current problems were being suggested and how where they argued?
- What would be the consequences of the suggested policies?

The purpose of these assignments were to make students in the two main groups address the same kind of issues: They were both asked to analyze economic systems intuitively.

The test group was offered an education, based upon system dynamics principles. As an introduction, the students were given a set of economic concepts and asked to identify how these were interrelated. The results were discussed in the classroom, and the teacher finally summerized the relevant interrelations without using any system dynamics concepts or forms of presentation, e.g. causal loop diagrams.

Thereafter, a simple economic model, generating capital growth was presented in the form of a causal loop diagram. Models, relevant to other diciplines (ecology, epidemiology etc.) were introduced as well to indicate alternative forms of growth. In this introduction role-games were utilized for pedagogical purposes in order to create a "hands-on" experience of dynamic trajectories. This lead to the discussion of various generic forms of dynamic behavior. Referring to several real life systems, the relevance and scope of a systems dynamics approach and the use of simulation were demonstrated.

The students were now ready for the introduction of the basic concepts of system dynamics. This set of concepts was specifically applied to macro-economics, and causal loop diagramming was used during the presentation.

In summary, the students were provided with identical sets of economic concepts; the same economic terms were used to refer to economic variables and relationships. Both groups had access to the traditional forms of reasoning about economic systems as presented in modern economic textbooks (Eklund, K., 1988). The test group was additionally offered the opportunity to reason about an economic system in terms of system dynamics.

5.4 The experiment

The students were subsequently exposed to a computer based macro-economic gaming environment and challenged to stabilize an economy characterized by business cycles, with respect to;
- inflation;
- employment;
- foreign trade; and
- governmental budget.

The students were assigned the following parameters as leverages;
- tax rate;
- governmental transfer of funds for private puposes;
- various forms of governmental spending; and

- changes in the exchange rate (devaluation/revaluation).

After a short introduction to the mechanics of the game, the students formed groups of two persons each. The result was that members belonging to a group were relatively homogeneous with respect to basic talents. Members belonging to each such group were selected from the same main group, and the two main groups were kept separate to avoid cross group classroom communication. Each of the small groups were assigned the same set of fundamental "what if..." questions, designed to reveal their intuition with respect to the model underlying this particular game. Their answers were recorded and kept for subsequent comparisons.

Thereafter, the students were exposed to the game, starting off in two kinds of disequilibrium caused by increased demand or decreased supply, respectively. Initially they tried out various leverages separately in order to test they previously recorded systems intuition. They had to explain, in writing, why the results of the simulations differed from their expectation. The recorded expectations and the discussion of the simulation results constituted the basis for the subsequent analysis of the effects using system dynamics in economic education.

5.5 Conclusions

The frequency of correct expectations were 10% higher among students belonging to the test group than among those belonging to the control group.

In trying to identify the reasons for descrepancies between expectations and simulation results, the students in the test group applied system dynamic concept (e.g. feedback, delay) to a moderate extent, while as one could not identify corresponding terms among the answers from the control group.

The students in the test group were more conscientious about the dynamic behavior of the system, frequently traced causal relationships in their explanations, and searched more intensively for potential policy paramet- ers. Among the control students one could not identify any attempts to identify causal loops or to reason about the relationship between the structure and behavior of the model.

The best students, characterized by their basic talents, were generally more able to utilize the systems dynamics approach.

The moderate use of system dynamics concepts among the students in the test group may be considered a consequence of a major loss of momentum between the teaching and testing due to several holidays, exams, and so on during the late Spring.

One year after this first experience in utilizing system dynamics as a pedagogical tool in economics, one of the students recently recently met her teacher and claimed that the approach changed her way of thinking about complex systems and that the urge to pursuit causal loops was still lingering in her mind.

5.6 Current and future work

In order to utilize system dynamics didactically, we would suggest that the students are being exposed to the system dynamics more broadly as well as over a longer period of time. To obtain a broader exposure, more teacher will have to be involved so that system dynamics may be used across a series of diciplines. Until a broad enough basis of teachers has been established, those currently involved use system dynamics in the same class over a longer time range.

Currently a full class of highschool students, grade 11, constitute a test group. They are being exposed to various forms of patterns of behavior, structural presentations (diagrams), simulations, and games in social sciences and mathematics. This is done as a preparation for an extensive utilization of system dynamics in their economics education in the years to come. The effect of this long-term effort will be compared to the results reported in this paper through the same kind of tests. Furthermore, we expect to carry out several other tests designed to identify pedagogical challenges in the teaching of complex dynamic systems and ways to effectively meet these challenges.

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