EXPERIENCES TEACHING SYSTEM DYNAMICS AT THE UK MASTERS LEVEL.

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ABSTRACT

This paper describes what is meant by modelling at Sunderland and how System dynamics fits into this ethos. The teaching and the examples covered in this System dynamics module are different the usual course and the paper deals with our experiences in these areas. The reaction of Eastern European (Bulgarian) students to this type of teaching is discussed. Students must complete a project in a work placement to obtain a masters qualification. The reaction of companies to the use of System dynamics (a new experience for most) is discussed and examples of the types of projects that have been completed are given. The paper concludes with a description of a Hypercard project which extends the use of System dynamics to Engineering students.

1. PURPOSE OF THE PAPER

The purpose of this paper is to show how System dynamics has been used on a Masters course by extending its range to include "harder sciences" . This idea has also given birth to a project for developing new software for teaching engineering students.

This paper is felt to be of importance to the System dynamics community as there is still a need in the UK to promulgate the advantages offered by the methodology and the new teaching and learning materials that could be developed.

The paper begins by describing the background to Masters courses in the UK and how System dynamics has played a major role in such a course at the University of Sunderland. It then describes the new software that is being produced. Finally the authors evaluate what has been described and give their thoughts for the future of this type of work.

2. THE USE OF SYSTEM DYNAMICS ON A MASTERS DEGREE

2.1 Background.

The University of Sunderland (the Sunderland Polytechnic) was the first British Polytechnic to offer a Masters Degree in the UK in 1989. The degree was called Mathematical Modelling and Computer Simulation. This was a two year, part time Masters and is still running successfully. Full time taught Masters in the UK are difficult to run as it is extremely difficult for students to get financial support and thus it is impossible for Universities to attract enough students to make such a course viable. However, in 1990, the British government designated certain areas as areas of special skills shortages and Sunderland successfully bid for a full time modelling course. The course was renamed Computer Based Modelling and Simulation and students taking the course received governmental subsidies. This course ran for its maximum span of three years taking thirty students a year. A new course was then devised called "Decision Support Systems for Industry" which is currently running and has hopefully another three year grant.

The aim of all three courses was exactly the same i.e. to produce good modellers rather than good mathematicians and this is the special skill area that the government and Industry have recognised. It is interesting to note the progression of titles in the sense that first the word "mathematics" and then the word "computing" have disappeared. This reflects the unfortunate (in my opinion) movement of students from mathematics and computing as subjects in their own right to wider, more multi disciplinary courses which include mathematics and computing.

2.2 Teaching Modellers versus Mathematicians.

Perhaps the aim of the course given in the preceding paragraph needs more explanation. One must start with a definition of mathematics. This is a difficult task but most mathematicians tend to Hilbert' view that mathematics is a closed self consistent body of knowledge which exists independent of the real world. If one accepts this (as I do) then it is impossible to perform a one-to-one mapping of mathematics onto any real world application. There will always be some fussiness around the edges, some inaccuracies, some indeterminacies. This attempt to map mathematics onto the real world is called mathematical modelling which the authors wish to distinguish from Applied Mathematics.

In Applied Mathematics, one is usually starting from one of the classical equations , deciding on the relevance or applicability of certain terms, using some well established mathematical technique and searching for the correct mathematical solution. Although some of these aspects are part of modelling, mathematical modelling is much wider than this. It embodies a different way of thinking. In my view it is part of a wider subject called problem solving. [1,2,3]

In any problem there are two stages: perception and processing. There are also two ways of thinking: vertical and lateral thinking. It is a common misconception that if one is intelligent enough, one can solve any problem merely by throwing intelligence at it. If you perceive the problem in the wrong way then you may never solve it. Peoples perceptions of the world are a function of their upbringing, culture and background. People perceive in different ways. Mathematicians are taught to think in certain highly structured and logical ways. One could define this as **Vertical Thinking**. What is often needed at this perception stage is **Lateral Thinking**. [4] Once one has a firm perception of the problem (it could still at this stage be a wrong one!) then the solution will probably be best achieved by mathematical type thinking or vertical thinking. Thus both ways of thinking are important to the modeller, but most teaching concentrates on vertical thinking, probably as this is much easier to teach!!!

2.3 Differences between Vertical and Lateral Thinking

Vertical thinking is based on three fallacies:

1. That the established way of looking at the situation is the only possible way because it is right.

2. That by working logically on the situation, you arrive at the best perception of it.

3. That it does not matter where you start, because if your logic or mathematics is good enough, you will eventually reach the correct answer.

Vertical thinking preserves the established order of things. It polarises opinions or thoughts into right or wrong. It proceeds from one certainty to the next. It categorises things into boxes. It also breeds arrogance and smugness.

Lateral thinking recognises the dominant polarising ideas that are in existence and then searches for different ways of looking at things. It relaxes the rigid control of vertical thinking.

More information in this area can be obtained from any of the excellent books of Edward de Bono [1] from where these thoughts were taken. The point the paper is making is that before the mathematics (or vertical thinking) is employed in solving a problem, there is a space for a more questioning, relaxed, informal logic which is rarely taught and often dismissed as trivial. One can very crudely divide these stages into the pre and post equation stage. There are many methods for dealing with the post equation stage but little on the pre equation stage. What is needed is a **formal modelling methodology**, bearing in mind that any such methodology will be of its very nature a much looser softer methodology than normal

2.4 System Dynamics as a Formal Modelling Methodology

System Dynamics has an obvious role in any modelling course as a vehicle for strategic planning, policy making, study of structure etc. What has been investigated at Sunderland, is the development of System Dynamics as a formal modelling methodology. System Dynamics and Causal Loop Modelling rely more on the lateral rather than the vertical thinking side. This is not denying System dynamics the ability to construct accurate quantitative models but stressing the teaching and learning benefits that can be accrued. System dynamics provides the student with a set of tools and the opportunity to construct his own perception of the problem. With software such as STELLA these causal models can be quickly and easily transformed into working simulations or models and qualitative behaviour observed. It is a perfect way of getting involved with a problem without the worries of whether the mathematics is correct or not. In this sense System Dynamics and Causal Modelling satisfy the requirements of a formal modelling methodology.

STELLA's equations can be easily transformed into mathematical ones and then the full power of mathematics can be applied to the problem. But System dynamics has filled that vital gap, that questioning of reality, that investigation of what exactly is causing what to happen, that worry free experimentation , that pre-equation stage in fact the perception stage of the problem solving activity.

For these reasons the Masters courses have been organised so that the **first course is one on System dynamics.** The course begins with an introductory module which sets the general background i.e. the difference between modelling and mathematics, Vertical and Lateral thinking and the modelling process. This is then followed by the course on Causal Modelling and System dynamics.

Superficially, the course follows the normal progression of influence diagrams, causal models and constructing System Dynamics models with STELLA but the emphasis is different. The problems that are discussed involve such entities as velocities, accelerations, forces, impulses and momentum. By forcing the students to think causally about such entities, new insights are revealed. The true meaning of laws such as Newton's Laws are explored. The graphical output of STELLA is analysed in this context. There are many difficulties. Entities such as velocity can be both levels and rates. If acceleration is chosen as a level then what entity is the flow into this level. An interesting aspect is that the models built reflect an integrative approach rather than a differential one. Distance springs naturally as a result of velocity multiplied by time whereas it is difficult to model velocity as distance divided by time. This illustrates vividly the paradox of instantaneous happenings and infinitesimals. This is one example of the many discussions that are brought forward in the discussions generated in this course. Further details are in papers by D. Prior. given at the last System Dynamics meeting in Bangkok.

2.5 Evaluation of the success of the System dynamics Module

Students view

Students select study courses for many reasons. Not all courses are memorable This may be due to the students attitude to learning, the delivery of the course or a number of other reasons.

System dynamics was my first subject on the MSc course "Computer Modelling and Simulation " at the University of Sunderland and I was not disappointed in my selection of this course. It was a striking and happy experience. "How exciting" was what I said to myself in the first lecture. In discussion with my colleagues I discovered that we all shared the same opinion. Not only was the subject interesting in its own right but the way it was delivered was exceptional.

I would now like to consider the different aspects in which this course contributes to students' conceptual development :

The course helps in *improving students' mental models of complex systems*. They are taught to consider the wholeness and internal connectedness of systems.

Applying system dynamics methodology for "qualitative description, exploration and analysis of complex systems"[1] *helps deeper understanding of the relationship between systems behaviour and its structure and information links.* Throughout the course models of physical and social systems (cooling of tea, production-inventory system, etc) have been developed and simulated over time (using STELLA*) with the purpose of analysing systems behaviour. The effect of alternative systems structures and control strategies on systems behaviour have been examined. This *challenges experimenting with new ideas and overcoming the boundaries of linear thinking and considers a new approach to description and analysis of systems, i.e. systems thinking*.

In my opinion the course would have benefited from case studies of solving real life problems with the help of system dynamics approach (physical and social systems, considering the background and specific interests of the students).

Placement View

Some of the placements using System Dynamics over the last couple of years are listed below:

The Promotion of Simulation for Decision Support Systems in Manufacturing
A Simulation of the Production Planning of the NEK Core manufacturing Area
Simulation Modelling of Resource Scheduling
Simulation of the Hot Metal Cycle of British Steel Teesside Works of Basic Oxygen Steel making Plant

Modelling a Water Distribution System
The Dynamics of Dumper Trucks
A System dynamics Model of a Low Pressure Gas Holder Station
A System dynamics Simulation of Heat Transfer in a Natarium

An investigation into the Use of Hypermedia and Simulation for the production of Management Support Tools

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* STELLA simulation software has proved to be an ideal tool for creating computer laboratory experiments

[1] The citation is from. 'Management Information Systems' by Eric Wolstenholme.

The first four are the normal type of use that one would expect from a System dynamics Project. But even these are not common in the UK and firms have to be persuaded that there will be a payoff for them by using this approach. There is also a problem in that most small UK firms do not own a MAC. The general reaction from the firms was that they were impressed by the ability of STELLA to portray what was happening and most of these firms have since bought their own copies and a MAC which they are now using.

The second group of four are more interesting. This work fits more with our philosophy of System Dynamics as a modelling methodology and it is being used in areas that are quite unusual.

The first was a result of the water privatisation bill in the UK. Water authorities needed to know exactly how much water was being used and to plan the efficient use of various reservoirs. System Dynamics proved ideal for this and the subsequent model is now used by the relevant authority.[5]

The second placement was investigating the behaviour of the suspension system of a dumper truck under very heavy loads. This would normally have been tackled by a second order mass spring damping differential equation. Using System Dynamics revealed new insights to both the student and the company.

The third was even more unusual. In large electrical stations the conductors are surrounded by sealed containers containing an insulating gas. The characteristics of such containers are normally modelled using Finite Element Analysis. Again an understanding of the various components was clearly revealed by a System Dynamics model.

The fourth one covered heat transfer. It is expensive to heat a swimming pool and once heated it is uneconomic to let the heat dissipate. One solution is to cover the pool with an insulating material at night. This study investigated how thick and how effective such a covering would be.

These are four unusual applications of System dynamics. In all cases, the purpose of the exercise was to obtain detailed accurate quantitative results but more to understand the processes involved and reveal what may be counter to intuitive results. The benefit of the modelling was in the doing of it more than the use of it. This extension of the application of System dynamics is, in my experience, new and very exciting.

The last project is typical of a batch using the power of Hypercard linked to the power of STELLA through the link of STELLA STACKS. A model of a general production-distribution system has been developed. The model is supplied with a proper interactive interface which allows the user to investigate the systems behaviour and implement his own policies by varying the values of the parameters.

In summary, every year, more and more students are asking for placements that allow them to use System dynamics. The applications that are found are more and more varied and the number of firms becoming involved is steadily increasing.

3. EXTENSION TO NEW SOFTWARE

The success of such models led the Sunderland team, led by Don Prior, to investigate if such methods could be useful in the general teaching of engineers. We decided to produce a series of modules. [6,7]

In order to access the potential effectiveness of the learning material it was needed to decide precisely who the material is aimed at. It was decided to aim it at the **mathematically unadapted** (and physically unadapted) learner who is taking, or wishes to take, a degree course in an engineering discipline. Such a learner can be assumed to have acquired only a basic ability to manipulate mathematical expressions and be able to interpret basic graphs. It will be assumed that the learner is physically unadapted in the sense that even a nodding acquaintance with, say, Newton's Second Law cannot be immediately used. The underlying physical concepts used in the modelling process will be introduced to the learner within the appropriate micro world before the modelling process is started. No mathematical modelling skills will be assumed. To a limited extent these skills may be regarded as independent of the skills of the competent mathematician who would normally enrol for a course in an engineering discipline. In short, the unadapted learner can be described as having acquired a limited mathematical background but be totally lacking in the skills necessary to apply mathematical skills to the development and interpretation of mathematical models of simple physical systems.

The intention of the project was to answer three questions:

1. Was it possible to apply the ideas of System Dynamics to engineering situations?

2. Would this approach be suitable for mathematically unadapted students?

3. Could this be achieved though heuristic learning using the full power of the Macintosh?

The first two objectives were seen to be possible. The team knew that the methodology was suitable but how to arrange it in a heuristic learning situation At this stage it is important to define what we understand by heuristic learning.

The student is presented by a set of screens which could be investigations, experiments or simple discoveries. Using the mouse he is left to discover or find all the relevant information,. This can then be assembled to form a model. There will be a preferred pathway through the software but the software itself is presented in a loose, flexible, non-structured format where the user can proceed in any direction whatever. Extensive help is provided but it is for the user to ask for this or any information he may need

In the initial stages of the project, it was foreseen that the major difficulty would be a pedagogical one i.e. how best to present the concepts. Although the subject area i.e. Causal Modelling and System Dynamics was well understood and had been successfully taught for several years to all levels of students, the novelty of this project was both its application to "hard" dynamic systems and its delivery via a computer aided or distance learning mode. It was envisaged therefore that there would be several attempts to discover " the best method" and certainly that a minimum of one year would be needed to determine the philosophy of the approach experimenting with various delivery modes.

The final approach on two processes that are essential to modelling. i.e.

representing what is physically happening (what you see)
representing the causal links (what you think causes behaviour.)

These two processes occur contemporaneously in every model and in the new approach were introduced through ORACLE. ORACLE is an all seeing all thinking guru who for the purpose of this software has two attributes : his EYES and his MIND. The user is asked to use the EYES of ORACLE to look at the problem and build a model representing what he sees. This will be physical STOCKS or LEVELS and physical FLOWS. This model is therefore termed the PHYSICAL MODEL.

There are mechanisms that enable the effects of the physical model to take place. This is normally by the existence of INFORMATION LINKS. The user is now asked to use the MIND of ORACLE to build the more difficult CONCEPTUAL MODEL which consists of these information links. By combining the PHYSICAL and the CONCEPTUAL models together, the final model is produced. Experiments and investigations are provided in both the EYES and MIND stacks and extensive HELP is available all through. The five areas of investigation remain the same.

Predator-prey (Herbivore Island)
Mass Spring Damping (The Baby Bouncer)
Projectiles (The Bouncing Ball)
Electrical Circuits (Resistor and Condenser)
Newton's Law of Cooling (The Cup of Tea)

4. CONCLUSIONS

System Dynamics is used as an important part of the modelling MSc at the University of Sunderland Our experience tells us it should be an integral part of such courses. System dynamics should no longer be considered solely in the examination of "soft" systems as it has been successfully extended since 1990 to cover "hard" subjects at the University of Sunderland.

The success of the course and its popularity among students and employers has lead to many new initiatives and the development of new software with Hypercard and STELLA Stacks.

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