New Approaches to Learning & Teaching: Student-Centred Modelling with Visually-Oriented Simulation Packages

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Abstract: The techniques of systems thinking and system dynamics are rooted in the work of Forrester et al, developed over 30 years ago at the Massachusetts Institute of Technology.

Although well-established as a technique for analysing the behaviour of complex systems in a range of academic disciplines, making system dynamics models operational until recently required the practitioner either to program a computer to solve a specific systems modelling problem, or to learn a procedural simulation language. More recently, the development of object-oriented modelling and simulation environments which run under graphics-based operating systems potentially offer more transparent approaches to modelling complexity by removing the high-level language requirement.

Alongside these developments, recent policy changes in UK education in a context of tightened resource constraints, is requiring fundamental changes in the ways in which teaching and, especially, learning are undertaken. A possible solution to providing high-quality learning about complexity in dynamic systems is through adoption of the systems thinking and system dynamics paradigms, using object-oriented modelling and simulation software models which enable students to explore the behaviours of systems in a self-directed manner.

One school of thought argues that developing systems thinking skills is as important a life skill as acquiring functional literacy, numeracy and computeracy, but until very recently, relatively few educators had adopted this approach to learning and developing students' understanding. Work on this approach in pre-University education in the United States has indicated some success in inculcating cognitive skills development and metacognitive development in problem-solving.

This paper outlines preliminary work using these approaches at the NatWest Financial Literacy Centre at the University of Warwick, as part of the development of a national resource of learning materials in elementary economics and finance, with the objective of developing literacy and fluency in comprehension of financial matters and applying this understanding to a broad range of real life experience.

The paper will report current and future directions for research, development of a national resource bank for teaching and learning about finance in secondary schools, together with materials relevant for non-specialist undergraduate study, and for lifelong, continuing education.

Keywords: systems thinking; system dynamics; computer modelling; simulation; pedagogy; finance; financial literacy.

Introduction: Systems thinking, as a conceptual problem-formulation and problem-solving technique is a subset of the broader discipline of systems analysis. An elegant account of the contribution to development of understanding dynamic processes in the

social sciences and systems theory, through analysis of the feedback principle, is given in Richardson, 1991.

This paper argues that in response to recent changes in aspects of UK education, a significant opportunity arises to adopt the systems thinking and system dynamics frameworks for encouraging sound thinking and development of students' problem-solving skills by applying these to analysis of dynamic processes common to a range of academic subjects. Systems thinking offers a potential solution to the conundrum of encouraging students to use coherent sets of transferable skills, through an investigative approach to problem-solving. Such an approach requires a fundamental shift in the perspective of teachers, and revised ways of analysing complex dynamic phenomena, (Forrester, 1992). This is precisely the issue occupying the minds of teachers, parents and other interested parties in respect of the National Curriculum implementation in parts of the UK (Dearing, 1994).

Learner-Directed Learning in systems thinking and system dynamics: Mandinach et al, 1988; Mandinach and Cline, 1994, report trials of this approach with pre-College students in the US between 1986 and 1994 in the Systems Thinking and Curriculum Innovation (STACI and STACI^{N}) Projects. Findings indicated benefits in terms of increased student understanding and motivation with evidence of more effective learning, and modification of teaching styles from teacher-directed to learner-directed learning. Evidence to date suggests that the project has been successful in achieving its overall objectives. The results are sufficiently encouraging to suggest that the approach might usefully be adopted within the framework of the revised secondary school curriculum in parts of the UK, and in developing systems thinking skills with undergraduate students.

Under the revised National Curriculum orders, (Dearing, 1995), requirements for modelling and simulation arise formally within mathematics, science and within information technology. The role of information technology as an encompassing methodology is significantly enhanced, but the requirement to examine modelling and simulation specifically requires teachers to become familiar with areas which have hitherto remained relatively neglected. Modelling expertise is not widely available within the teaching profession. The simplicity of approach and wide curricular applicability of the systems approach provides a possible solution this problem. In particular, many dynamic processes have common features which lend themselves amenable to analysis through a limited number of archetypes (Senge, 1992; Eberlein, 1995; Corben et al, 1994), whose characteristics appear in a number of disguises, while sharing some general attributes.

Adoption of systems thinking in education: Although the systems approach is straightforward, and widely applicable across disciplines, its impact on education has been relatively modest. As a partial explanation, until relatively recently, it was necessary for the analyst either to write process-specific computer programs, or to adopt one of a limited number of simulation languages, such as DYNAMO (Pugh-Roberts Associates 1986), or other high-level language modelling environments such as DYSMAP2 (Dangerfield and Vapenikova 1987).

Additionally, the need to represent the processes in mathematical notation and adopt numerical analysis techniques for solution have conspired against the wider adoption of systems methods.

Richmond, 1991, has provided explanations for the relative neglect of the systems approach to analysing complex processes, including the requirement of an inter-disciplinary approach and the need for a fundamental change of intellectual perspective in systems thinking.

A further disincentive to embracing systems thinking is that, for most participants, making the change is difficult. Corben, 1994, reports on the use of systems approaches with practising managers. Powerful, user-friendly computer modelling environments provide less daunting access to systems representation, enable presentation of both qualitative and quantitative results, and provide deep insights into process behaviour through the use of such packages[1] as cognitive tools. Whereas the new generation of software tools has made the processes of model construction and use much easier, model conceptualization remains problematical for most people.

By adopting such approaches the user is largely relieved of the requirement to specify the high-level mathematical relationships and greater attention given to understanding the underlying processes and modelling context. Consequently, it has proved possible to expose students with modest mathematical expertise to complex dynamic subjects in a range of disciplines including pharmacokinetics (Washington, et al. 1990), applications in economics, ecology and social systems (Radzicki, 1994; Hannon and Ruth 1994), operational research (Wolstenholme, 1990), and other subjects.

The application of systems approaches in effecting sound learning through modelling may be classified in four categories (Mandinach, 1994). Each may be used in the manner deemed most appropriate according to the professional judgment of the teacher.

System dynamics provides a common communication tool connecting many academic disciplines, by causing students to think critically about the true nature and structure of problems through the process of developing and analysing system structure. Importantly, within the system dynamics paradigm, students make the mental link between the structure of a system and the behaviour which the system exhibits. This approach to learning about processes emphasises the need for the learner rather than teacher to take prime responsibility for the actual learning, and is a favoured model for encouraging effective learning at tertiary level. Mayes, 1992 indicates the metacognitive skills development associated with self-directed and cooperative learning, thereby giving rise to effective learning (Vygotsky 1978). These views are strongly supported by Brown, 1990.

The US Educational Testing Service has promoted classroom implementation of learner-centred learning (Mandinach and Cline, 1990, 1994), and reported that by making the student an active part of the learning process, a greater interest in learning was encouraged with hands-on activities reinforcing and giving context to factual learning.

Work in Progress: The above approaches to modelling form part of a wider research programme dealing with questions of financial awareness, to understanding economic and financial processes, and how these impact on the general population. Significant effort has been expended in supporting functional literacy and numeracy, but little appears to have been available in the past to address questions of the importance of financial literacy. Typically, knowledge of financial processes such as financial planning, personal budgeting and related issues has been acquired by trial-and-error. At a number of critical periods in peoples' lives it is necessary to undertake financial decision-making, and to evaluate the implications of these decisions. A number of problems arise. Firstly, the mathematics required to understand many financial processes and to evaluate specialist financial services is beyond the capacity of a significant proportion of the population. Secondly, sources of disinterested advice on finance have not been widely available in the past. Thirdly, little formal attention has typically been paid to these matters in mainstream education, although research suggests that they are deemed important (Noctor, Stoney et al. 1992).The NatWest Financial Literacy Centre at the University of Warwick has been constituted to undertake a programme to develop materials for addressing these issues among a number of potential groups within society and contribute toward achieving greater coherence in financial decision-making.

Use of systems thinking and system dynamics modelling paradigms, with learning approaches focused on student-directed activities, can assist in providing learning gains in pre-College education. US evidence indicates deeper cognitive development and student learning through these approaches. Adoption of the systems methods may address development of core competencies and life-skills for students in UK secondary and higher

education. Some benefits may accrue to using common systems archetypes to facilitate development of models having common structures and in analysing their dynamic behaviour. Current research examines whether adopting these methods leads to increased financial literacy, and general economic understanding. Simple finance models for use in pre-University education are included as an Appendix.

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