

A Review of System Dynamics Pedagogic Techniques

Michael Kennedy

Professor of Educational Development
Head of Department of Accounting and Finance
London South Bank University
Borough Road, LONDON SE1 OAA, UK
E-mail: kennedms@lsbu.ac.uk

Key words: System Dynamics, Pedagogic Techniques, Education SIG of the System Dynamics Society

Abstract

A number of papers have been published describing various pedagogic techniques for the dissemination of the System Dynamics (SD) approach at various Education institutions and academic levels ranging from schools (K-12 in the US) to higher education. This paper builds on previous papers by this author that provided a catalogue and classification of this work in order to highlight potential areas of research in this field of study and to identify system archetypes at different hierarchical levels and discover new ones. This paper builds on the earlier taxonomy by extending the Teaching Practice section. The findings from these investigations are briefly described. The taxonomy is “work in progress” comments and suggestions are welcomed.

1. Introduction

The SDS Education SIG has twin interests in publicising and enhancing both the contribution of SD to Education Management and the evolution of the contribution of SD to the curriculum - in both cases the interest spans the whole span of education from K-12 (schools) to Higher Education. The Author is the Co-Chair of the SIG and has developed this Review of publications of relevant SD work and pedagogical issues to aid future research and to help to spread good practice within the SIG's area of interest. The SIG also wishes to encourage graduate students to consider examining enhanced techniques for improving the contribution of SD to the curriculum in their dissertations and to improve interaction and collaboration with other groups conducting K-12 based activities.

This paper builds on the author's earlier publications in this area (Kennedy 2000a, 2002). Kennedy (2008) separating the SD Pedagogic Techniques reviewed in this paper from the Policy Aspects (described in a sister paper). The objective of this paper is to facilitate and structure debate on the use appropriate Pedagogic Techniques for the dissemination of system dynamics (SD) (Forrester 1961) in Educational establishments.

2. A Review of System Dynamics Pedagogic Techniques

The initial Taxonomy was based on a limited survey of completed SD investigations in higher education management. In subsequent versions the number of sources has been greatly increased and both pedagogical issues and provision for School/ K- 12 have been added

To the six original areas of concern (Corporate Governance, Planning, Resourcing & Budgeting, Teaching Quality, Teaching Practice, Microworlds, Enrolment Demand), two more (External forces/ legislation and Human Resource Management Dilemmas) have been added. Only Teaching Quality, Teaching Practice, Microworlds are felt to be relevant to SD and Pedagogic Techniques. Are more needed?

The five hierarchical levels (National, Regional/ State, University/ Institute, Faculty or Department and School/ K- 12) have been modified to group Faculty and Department together and add provision for School/ K- 12. Are more needed?

Some work spans more than one category. A more extensive summary of the work that was included in earlier taxonomies may be found in Kennedy (2000a and 2002). Descriptions and comments are reproduced from the earlier paper in order to give a better coverage of the area.

		Hierarchical Level				
		National Gov't University Issues	Regional Gov't University Issues	University Wide Management Issues	University Faculty or Department	School, K-12
Specific Area of Concern	Teaching Quality				Kennedy (1998a) Kennedy (1998b) Eftekhar & Strong (2005) <i>McKeachie</i> (1990) <i>Schneider Fuhrmann & Grasha</i> (1994a) <i>Schneider Fuhrmann & Grasha</i> (1994b) <i>Fincher</i> (1994)	
	Teaching Practice			Forrester (1974) Saeed (1997) Frances (2000) Arndt (2007) Friedman et al (2007) Perez Salazar et al (2007) Potash, with Heinbokel (2005)	Runge (1977) Shaffer (1976) Senge (1988) Saeed (1990) Morecroft & Stermann (1992) Stermann (1992) Saeed (1993) <i>Anderson & Sosniak</i> (1994) Saeed (1997)	Foster (1972) Roberts (1976) Roberts (1978) Forrester (1989) Niles (1991) Halbower (1993) Forrester (1995) Forrester (2002) Sweeney and Sterman (2007) Hopper and Stave (2008) Nuhoglu with Nuhoglu (2008) Stuntz with Lyneis (2007) Thompson with Reimann (2007)

					Frances (2000) Nodenof et al (2004)	
	Microworlds			Barlas and Diker (1996a, 1996b) Barlas and Diker (2000) Stermann (1992) Virtual University (2005a) Virtual University (2005b) <i>Blumenstyk (2000)</i> <i>Conte (2003)</i> <i>Dekkers & Donatti (1981)</i> <i>Sawyer (2002)</i>	Stermann (1992) Virtual University (2005a) Virtual University (2005b)	Stermann (1992)

Table 1: Classification of System Dynamics Pedagogic Techniques. Plain items refer to models and items in italics refer to underpinning theory.

3. System Dynamists' Work in Higher Education Management

A number of system dynamicists and others have examined some of the issues associated with the Pedagogic Techniques suitable for the dissemination of SD. I shall briefly describe a selection of completed investigations and key findings.

3.1 Teaching Quality

Quality, Pedagogical and socio- economic aspects of SD in Schools

The earliest teaching of SD was almost exclusively to graduate students but relatively early the potential of teaching SD to schoolchildren was appreciated. Foster (1972) [in one of the many MIT "D" notes] considers the impact of "Education in the City" as an extension of the Urban Dynamics programme. As such this included the socio- economic impact of education (or the lack of it) on a community.

Roberts (1976) describes an early "System Dynamics Curriculum Development Project for Elementary and Secondary Education". As well as examining some practical pedagogical aspects of SD in Schools she critically examines Bloom's Taxonomy of thinking skills (see Anderson & Sosniak, 1994). More recently there has been an increasing interest in Assessing the Effectiveness of Systems Thinking / Dynamics Interventions in the Classroom. Taxonomy that "higher level" skills should not be taught until the previous (lower level) skills have been mastered in full holds good.

Forrester (1989) considers shortcomings in US school education and suggest that System Dynamics could form a more satisfactory basis for High School Education and proposes a programme of action in order to realise this potential.

Quality, Pedagogical and socio- economic aspects of SD in Universities

The information management and modelling research group (IMMaGe) have developed an initial SD model to examine quality management issues at London South Bank University

(Kennedy 1998a, 1998b). Interviews were conducted with academic members of staff to guide the construction of the model. This investigation is considered to be the first part of a long-term project.

Key Findings

- The identification of sectors, *e.g.* Administration, Staff Performance, Department Effectiveness, Funding, Research and Funding, needed to be considered for a future quality management model.
- The identification of metrics (or performance indicators) needed to be collected for further SD investigations.

In an ambitious project somewhat reminiscent of Roberts (1976) earlier work in schools Eftekhar & Strong (2005) examine the process of learning in colleges & universities and outline some aspects of the debate among experts in education as to the most effective approaches to influence or reinforce the learning process. This work is an ambitious undertaking that implements a programme that includes the combination of education metrics and computer simulation. Like Roberts, they include a discussion of Bloom's taxonomy of thinking skills (below)

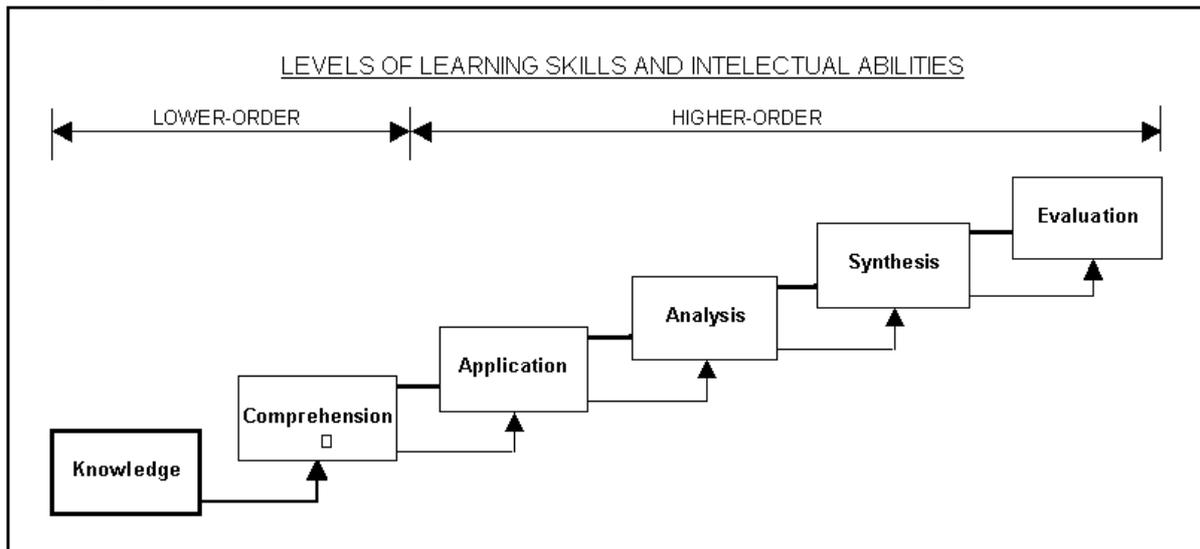


Fig 1: Bloom's Taxonomy of Thinking Skills

They state that their work is based on using a package of a simple control engineering concept, a model of an educational process, a computer simulation in conjunction with a combination of education metrics and that the main purpose is "to develop a model by which one can gain a better insight into the possible dynamic behavior of a learning process".

Eftekhar & Strong (2005) cite some very useful literature on aspects of learning theory and research including:

- Schneider Fuhrmann & Grasha (1994a)
- Schneider Fuhrmann & Grasha (1994b)
- Fincher (1994)
- McKeachie (1990)

3.2 Teaching Practice

Teaching Practice aspects of SD in Schools

As well as examining the wider Pedagogical issues described above, Roberts (1976) describes some practical teaching practice aspects of SD in Schools.

Niles (1991), evaluates the UROP programme of Pre-College Education and Halbower (1993) describes the practical pedagogical aspects of teaching SD in Schools- especially the importance of “The First Three Hours” of tuition.

In common with several of the above Forrester (1995) is concerned with the provision of high quality teaching materials- in his case the “Road Maps” to teaching SD.

Forrester (2002) summarises the progress made over 25 years in K12 SD education provision and looks forward to future enhancements and again proposes a programme of action in order to realise the potential.

Sweeney and Sterman (2007)

In a series of papers John Sterman and co-worker have reported on a number of experiments on the level of ability of school students (and in some cases teachers) in coping with various systems concepts such as feedback, stocks and flows, time delays and nonlinearities, prior to and after formal training in these concepts. They report generally limited intuitive systems thinking abilities. They discuss the nature of students' and teachers' intuitive models of dynamic systems, explore potential barriers to understanding dynamic systems, and discuss implications for effective teaching of systems concepts. From the sequence Sweeney and Sterman (2007) is cited as it appeared in the System Dynamics Review.

Hopper and Stave (2008)

Hopper and Stave (2008) adds rigor to discussions around teaching practice aspects of SD in Schools by proposing methods for assessing systems thinking interventions.

Nuhoglu with Nuhoglu (2008)

Nuhoglu with Nuhoglu (2008) report on a number of experiments conducted with students in middle schools in Istanbul, Turkey. Their experimental design included pre & post tests and a control group.

Stuntz with Lyneis (2007)

In this paper Stuntz with Lyneis (2007) summarise the reflections of teachers and other educators on the on their progress they have made in implementing system dynamics and systems thinking in schools across the United States. They report that although all of the educators have been encouraged and inspired by student engagement and insight using system dynamics in their classrooms, wider adoption has encountered obstacles. They discuss the various strategies adopted to overcome the obstacles. They report that these include: improving the quality and quantity of system dynamics curriculum materials and training opportunities for teachers, integrating the use of systems thinking tools with system dynamics simulation to give students the full benefit of both, seeking ways to work within the K-12 institution to effect change, and working together as a community to learn from successes and mistakes.

Thompson with Reimann (2007)

In this paper Thompson with Reimann (2007) report on a number of experiments conducted with year 9 and 10 students who were given a system dynamics model of the impacts of visitors on a National Park. As in other work described above the students were given a pre- and post-test to determine whether their knowledge of the environment changed. The distinctive feature of this work was that the students were randomly assigned to either the “individual learning condition” (students interrogated the model as individuals) or the “collaborative learning condition” (students interrogated the model with one other student). They report that there was a significant increase in the environmental knowledge score for those students in the collaborative learning condition, but not in the individual learning condition. They discuss the implications of this finding for the use of system dynamics models in educational settings.

Teaching Practice aspects of SD in Universities

One of the motives for suggesting changes or enhancement to SD teaching practice is the perceived need to improve better methods of teaching SD in order to counter critical responses to System Dynamics Models. An example is Forrester (1974).

As mentioned above, the earliest teaching of SD was almost exclusively to graduate students Runge (1977) makes an early attempt at suggesting methods for Teaching System Dynamics, while Shaffer (1976) suggests an early concept of organizing the system dynamics curriculum.

Later there have been many papers describing (asserted) advances in the methods of teaching SD in particular domains. Senge (1988) describes “New System Dynamics Learning Tools for Management Education and Training”, while Sterman (1992) describes the evolution of “management flight simulators” in general and the beer game in particular. Morecroft and Sterman (1992) describe a collection of “modelling for learning” examples.

Saeed (1990, 1993, 1997)

Saeed in a series of papers has investigated the role of System Dynamics in developing teaching practice in a number of academic disciplines, including social sciences generally (Saeed, 1990), economic development (Saeed, 1993) and for a “New Liberal Education” (Saeed, 1997).

In these papers Saeed points out that (unlike the teaching of engineering and physical sciences and many of the fine arts), experimental learning is rarely incorporated into the teaching of social sciences. He asserts that this is unfortunate “*since experimentation with relationships, whether in a laboratory or a studio, helps not only to corroborate theories and create robust designs, but also to develop the reflective process critical to the creation of innovation in various professions*” and shows how SD is suited to experimentation with relationships (Saeed, 1990). In relation to teaching practice for “New Liberal Education” (Saeed, 1997), he examines how Kolb’s model of experiential learning can be implemented through the use of System Dynamics as a Technology and so this paper is also included in the above category.

Frances (2000)

In this paper Carol Frances introduces the important topic of assessing the impact of new educational technology.

Nodenof et al (2004)

The technology deployed is rapidly advancing. Nodenof et al (2004) state that their approach for the engineering of web based educational applications is grounded in software engineering research and that the applications “require advanced functionality for regulating and tutoring learners' activities (dynamics of learning)”.

They further state that

“our approach aims at proposing models, not only to describe details of such learning situations, but also to characterize the constraints that the Learning Management System exploiting such situations must satisfy in this sense, this approach also contributes to the specification of the Adaptive Web Based Educational System (AWBES) fitted to a particular learning situation.”

Arndt (2007)

Arndt (2007) postulates the proposition that System Dynamics is a suitable method in education for problem-oriented learning and for improving overall system thinking skills. The author proposes the use of an integrated learning environment consisting of System Dynamics models and additional didactical material. In the example described this is concerning an examination of market processes.

Friedman et al (2007)

Like the earlier work of Saeed (described above), Friedman et al (2007) utilises Kolb's learning styles. They state that their research was carried out in order to determine if a relationship existed between the use of specific system thinking tools and Kolb learning styles. They report that the subjects were university students who played the B & B Enterprise game, took the Kolb Learning Styles Inventory and responded to a questionnaire. These questions related to both the frequency and preferences of use of specified system thinking tools and learning styles. They report that the results revealed that for some of the learning style orientations a significant relationship with use and preferences of system thinking tools existed but state that their results indicate that further study is needed to clarify any differences in relationships between groups and between frequency and preferences.

Perez Salazar et al (2007)

Most of the experiments re teaching practice described in this section relate to traditional “face to face” teaching. In this paper Perez Salazar et al (2007) describe and evaluate an e-learning based intervention. They describe the use of the action research method to observe the course evolution and to evaluate new knowledge, skills developed by students and student's improvements on the changing paradigm. They state that teaching using the “right” e-learning environment can result in a good learning experience for students.

Potash, with Heinbokel (2005)

Potash, with Heinbokel (2005) describes a “ladder of engagement” that they have devised. They state that it is

“a structure and sequence of activities supporting a powerful and integrated process by which continuously “better questions” allow us to: (1) probe progressively more deeply into describing the behavior of the system (a rung of KNOWLEDGE); (2) identify the system's features (feedback loops and delays) controlling its behaviors (UNDERSTANDING); and (3) locate and evaluate leverage points in the system where intervention can effectively and efficiently affect its behavior (INFLUENCE) challenges and “enduring” and generic problems”.

3.3 Microworlds

Barlas and Diker (1996a, 1996b, 2000)

The main objective of Barlas and Diker's (1996, 2000) research was to construct an interactive dynamic simulation model, on which a range of problems concerning the academic aspects of a university management system can be analysed and certain policies for overcoming these problems can be tested in a "Microworld" format. More specifically, the model focuses on long-term, strategic university problems that are dynamic and persistent in nature, such as growing student-faculty ratios, poor teaching quality, and low research productivity. The model generates numerous performance measures about the three fundamental activities of a university, namely, teaching, research and professional projects. The interactive decision variables of UNIGAME are: New Graduate Students, New Undergraduate Students, Graduate Faculty Hiring Decision, Undergraduate Faculty Hiring Decision, Share on Official Projects income per Faculty Member and Weekly Release Time per Graduate Faculty Member.

The purpose of the simulation model is to investigate the difficulties of keeping the delicate balance that must exist between education, research and service and what measures can be taken to alleviate the potential problem. The validity of the model is tested using 1983-1997 Bogaziçi University data. In the "participatory" (gaming) version of the model (which starts in 1993), certain decisions are made by a "player" interactively during the simulation. The different decision making units of the universities can potentially use the model, especially in strategic planning.

Key Findings

- Simulation experiments with graduate (versus under-graduate study) orientation shows that graduate study can have considerable positive effect on research output, provided that it is coordinated with other related decisions such as instruction-hour requirements, research recognition and rewards etc.
- If, in order to obtain improved teaching quality, we keep class sizes too low, under the condition of high student enrolments this may mean multiple sections (or too many electives). This, in turn would mean increased teaching loads, which may cause serious problems in maintaining the faculty body, because of decreasing faculty supply and increasing number of faculty quit rates.
- The simulation model demonstrated the systemic nature of university management in the sense that a single decision in isolation may yield counter-intuitive results, if not coordinated with a number of other related decisions.

Virtual University

The "Virtual University" (VU) initiative (Virtual University, 2005a) is also included under 3.3 Planning, Resourcing and Budgeting. The VU is one of a new generation of "Serious Games" (below) that combine video game presentation norms with serious content and substantial simulation capacity.

The VU claims very large numbers of users with over 90,000 downloads by over 800 institutions in over 90 Countries no doubt partly because it has received sponsorship that enables it to be free to most users. The composition of these users is:

- 5% administrative staff (chair to president)

- 15% professors
- 24% grad students
- 29% undergrads

VU states that it:

“is designed to foster better understanding of management practices in American colleges and universities. It provides students, teachers, and parents the unique opportunity to step into the decision-making shoes of a university president. Players are responsible for establishing and monitoring all the major components of an institution, including everything from faculty salaries to campus parking.....

VU models the attitudes and behaviors of the academic community in five major areas of higher education management:

- *Spending and income decisions such as operating budget, new hires, incoming donations, and management of the endowment;*
- *Faculty, course, and student scheduling issues;*
- *Admissions standards, university prestige, and student enrolment;*
- *Student housing, classrooms, and all other facilities; and*
- *Performance indicators.*

VU players select an institution type and strive for continuous improvement by setting, monitoring, and modifying a variety of institutional parameters and policies.”

The growing popularity of “Serious Games” may be indicated by the holding on April 15-16 2005 of a two-day workshop at M.I.T entitled “Game Simulations for Educational Leadership & Visualization: Virtual U and Beyond” (Virtual University, 2005b). This event is designed to examine

“the past, present, and future of games about education and educational life”. The organisers state that “to date, there have been over a half-dozen entertainment and non-entertainment efforts dealing with school management and leadership that have been produced or planned”.

They continue

“These games explore such topics as the future of community colleges, how universities are managed, how rumours circulate in schools, and how social cliques form within school environments. We want to examine these games and their application to school management as we reflect back on the evolution of the Virtual University Project over the past four years”.

Sawyer (2002) describes “Serious Games” as follows:

“The mission is simple - to create a better understanding of how commercial game and simulation developers, practices, and technology can be utilized by a wider field of organizations that build and apply models and simulations in the area of public policy.

This includes identifying and detailing specific steps organizations and game developers can take to blend game technology and approaches with proven model and simulation approaches to improve existing and future offerings.

Any casual observer who has seen someone interact with a computer or video game can easily understand how games can quickly captivate their audience. With their exciting visual and audio power, computer and video games take the competitive and fun nature of games to an entirely new level. Combining simulation, strategy, and the ability to play alone (if partners are not available) electronic gaming builds on basic instincts for competition, interaction, and imagination that are instinctive in so many people. By combining these elements with instructive materials, or wrapping important content in a gaming package, the hope is to utilize the strength of gaming to elevate learning and especially strategic learning among players.”

Blumenstyk (2000) examines the issues re such simulations; Conte (2003) examines the impact of such simulations on public awareness and hence public policy while Dekkers & Donatti (1981) consider the research agenda re the use of simulation as an instructional strategy.

4. Future Evolution of this Taxonomy

As indicated above this review is an attempt to produce a focussed taxonomy by continuing the separation of these SD Pedagogic Techniques from the Policy Aspects initially created in Kennedy (2008). Currently it has retained the same structure but the author suspects that this will not prove ideal for the Taxonomy of Pedagogic Techniques. In addition the author is keen to add more publications – particularly in the K-12 area. Your ideas and contributions to any of the above are therefore most welcome!

Acknowledgements

The assistance of Sangeeta Sardiwal, Martin Rafferty, Golda Komanapalli, Naresh Mall, Garry Bell, Grzegorz Reczek, Chris Clare and Ddembe Williams in preparing this paper or earlier papers in this sequence is gratefully acknowledged. The encouragement and helpful comments of Yaman Barlas, Carol Frances, Peter Galbraith and Geoff Coyle among many others is also gratefully acknowledged.

References

Anderson L. W. and Sosniak L. A. (eds) (1994) Bloom's Taxonomy: A Forty-year Retrospective, Ninety-third Yearbook of the National Society for the Study of Education (NSSE), Distributed by The University of Chicago Press, Chicago, IL

Arndt, H., (2007) Using System Dynamics-based Learning Environments to Enhance System Thinking, Conference Proceedings, The 2007 International Conference of the System Dynamics Society and 50th Anniversary Celebration, July 29 – August 2, 2007, Boston, Massachusetts, USA

Barlas, Y. and Diker, G. (1996a) Decision Support for Strategic University Management: A Dynamic Interactive Game, *Proceedings of the 14th International System Dynamics Conference*, Boston, USA.

Barlas Y. & Diker, G. (1996b) *An interactive dynamic Simulation Model of a University Management System. Proceedings of the 1996 ACM Symposium on Applied Computing.*

Available from <http://portal.acm.org/citation.cfm?id=331119.331162> [Accessed 9th March, 2005]

Barlas, Y. and V. Diker G. (2000) A Dynamic Simulation Game for Strategic University Management. *Simulation and Gaming*. Vol. 31, no.3, Sept.

Blumenstyk, B. (2000) A computer game lets you manage the university. *Chronicle of Higher Education*, 46(28), A51. Retrieved September 8, 2002 from the World Wide Web: <http://www.chronicle.com>.

Conte C. (2003) *Honey, I Shrunk the Deficit!* *Governing Magazine/December 2003*

Dekkers, J. & Donatti, S. (1981). The integration of research studies on the use of simulation as an instructional strategy. *Journal of Educational Research*, 74, 424-427.

Eftekhari, N & Strong, D.R. (2005) *Dynamic Modelling of a Learning Process*. The International Journal of Engineering Education Available from <http://www.ijee.dit.ie/articles/999995/article.htm> [Accessed 9th March, 2005]

Fincher C. (1994) Learning Theory and Research, In Feldman K. A. and Paulsen M. B. (eds) *Teaching and Learning in the College Classroom*, ASHE Reader Series, Ginn Press, MA

Forrester, J.W. (1961). *Industrial Dynamics*, Productivity Press, Cambridge, MA, USA.

Forrester, J.W. (1974) Educational Implications of responses to System Dynamics Models D-2021. In Forrester, J.W. (ed) (2004) *MIT System Dynamics Group Literature Collection DVD*, System Dynamics Society, Albany, NY, USA

Forrester, J.W. (1989) System Basis for High School Education D-4018-1. In Forrester, J.W. (ed) (2004) *MIT System Dynamics Group Literature Collection DVD*, System Dynamics Society, Albany, NY, USA

Forrester, J.W. (ed) (1995) Road Maps D-4450-2. In Forrester, J.W. (ed) (2004) *MIT System Dynamics Group Literature Collection DVD*, System Dynamics Society, Albany, NY, USA

Forrester, J.W. (2002) A new Frontier in K12 Education D-4882. In Forrester, J.W. (ed) (2004) *MIT System Dynamics Group Literature Collection DVD*, System Dynamics Society, Albany, NY, USA

Foster, R.O. (1972) Education in the City D-2144. In Forrester, J.W. (ed) (2004) *MIT System Dynamics Group Literature Collection DVD*, System Dynamics Society, Albany, NY, USA

Frances, C. (2000). Using System Dynamics as a Tool for Decision Making in Higher Education Management- U.S. Experience, in Kennedy, M. (ed). (2000). Selected papers presented at an international seminar on 'Using System Dynamics as a Tool for Decision Making in Higher Education Management' held in June 1999 at the Royal Society, London and London South Bank University, under the auspices of the Society for Research into Higher Education, *London South Bank University Technical Report SBU-CISM-12-00*, London UK.

Friedman, S. with Cavaleri S. and Raphael M., (2007) Individual Learning Style and Systems Tool Preferences, Conference Proceedings, The 2007 International Conference of the System Dynamics Society and 50th Anniversary Celebration, July 29 – August 2, 2007, Boston, Massachusetts, USA

Halbower M. C. [Revised Whelan J]. (1993) The First Three Hours D-4230-3. In Forrester, J.W. (ed) (2004) *MIT System Dynamics Group Literature Collection DVD*, System Dynamics Society, Albany, NY, USA

Hopper, M. and Stave K., (2008) Assessing the Effectiveness of Systems Thinking Interventions in the Classroom, Conference Proceedings, The 2008 International Conference of the System Dynamics Society, July 20 – 24, 2008, Athens, Greece

Kennedy, M. (1998a). A Pilot System Dynamics Model to Capture and Monitor Quality Issues in Higher Education Institutions Experiences Gained, *Proceedings of the 16th System Dynamics Conference*, Quebec City, Canada.

Kennedy, M. (1998b). Some Issues in System Dynamics Model Building to Support Quality Monitoring in Higher Education, *Proceedings of the 16th System Dynamics Conference*, Quebec City, Canada.

Kennedy, M. (2000a). Towards a Taxonomy of System Dynamics Models of Higher Education, *Proceedings of the 18th International Conference of the System Dynamics Society (2000) 6-10 August 2000 Bergen, Norway*

Kennedy, M. (2002) An extended Taxonomy of System Dynamics Models of Higher Education, *Proceedings of the 20th System Dynamics Conference*, Palermo, Italy.

Kennedy, M. (2008) A Taxonomy of System Dynamics Pedagogic Techniques, Conference Proceedings, The 2008 International Conference of the System Dynamics Society, July 20 – 24, 2008, Athens, Greece

McKeachie W. J. (1990) Research on College Teaching: The Historical Background, *Journal of Educational Psychology*, Vol.82, No.2, 1990

Morecroft, J.D. and Sterman, J.D. (eds) (1992) Modelling for Learning, *European Journal of Operations Research*, Vol 59 (May, 1992)

Morecroft, J.D. and Sterman, J.D. (eds) (1992) Modelling for Learning, *European Journal of Operations Research*, Vol 59 (May, 1992)

Niles, R. (1991) Pre-College Education Project UROP Evaluation D-4229. In Forrester, J.W. (ed) (2004) *MIT System Dynamics Group Literature Collection DVD*, System Dynamics Society, Albany, NY, USA

Nodenof T., Latorcade P, Marquesuzaa C & Sallaberry C. (2004) *Model based Engineering of Learning for Adaptive Web Based Educational Systems*. Proceedings of the 13th international World Wide Web conference Available from

<http://portal.acm.org.lispac.lsbu.ac.uk/citation.cfm?id=1013385&coll=Portal&dl=GUIDE&CFID=39697420&CFTOKEN=40723049> [Accessed 9th March, 2005]

Nuhoglu, M. with Nuhoglu H., (2008) The Effects Of System Dynamics Approach In Science Education In Middle School , Conference Proceedings, The 2008 International Conference of the System Dynamics Society, July 20 – 24, 2008, Athens, Greece

Perez Salazar, G with Scheel C. and Martinez Medina M., (2007) Achievements teaching Systems Thinking and Systems Dynamics to Graduate students through e-learning, Conference Proceedings, The 2007 International Conference of the System Dynamics Society and 50th Anniversary Celebration, July 29 – August 2, 2007, Boston, Massachusetts, USA

Potash, P. with Heinbokel J., (2005) Unleashing the Revolutionary Implications of a System Dynamics 'Education', The 23rd International Conference of the System Dynamics Society, July 17-21, 2005 Boston

Roberts, N.H. (1976) System Dynamics Curriculum Development Project for Elementary and Secondary Education D-2435-1. In Forrester, J.W. (ed) (2004) *MIT System Dynamics Group Literature Collection DVD*, System Dynamics Society, Albany, NY, USA

Roberts, N.H. (ed). (1978) System Simulation of Student Performance in the Elementary Classroom. In Roberts, E.B. (ed) (1978) *Management Applications of System Dynamics*, Productivity Press, Cambridge, MA, USA.

Runge D. (1977) A Note on Teaching System Dynamics D-2653. In Forrester, J.W. (ed) (2004) *MIT System Dynamics Group Literature Collection DVD*, System Dynamics Society, Albany, NY, USA

Saeed, K. (1990). Bringing Practicum to Learning: A System Dynamics Modelling Approach, *Higher Education Policy*, Vol. 3, No. 2

Saeed, K. (1993). Bringing experimental learning to the social sciences: a simulation laboratory on economic development, *System Dynamics Review*, Vol. 9, No. 2 pp 153-164.

Saeed, K. (1997). System Dynamics as a Technology for New Liberal Education, *Worcester Polytechnic Institute, Report No. 3*, Worcester, Mass. USA.

Sawyer B. (2002) Serious Games: *Improving Public Policy through Game-Based Learning and Simulation*. Foresight and Governance Project, Woodrow Wilson International Center for Scholars, Publication 2002-1 <http://wwics.si.edu/subsites/game/index.htm> [Accessed 21st March, 2005]

Schneider Fuhrmann B. & Grasha A. F. (1994a) The Past, Present, and Future in College Teaching: Where Does Your Teaching Fit? In Feldman K. A. and Paulsen M. B. (eds) *Teaching and Learning in the College Classroom*, ASHE Reader Series, Ginn Press, MA

Schneider Fuhrmann B. & Grasha A. F. (1994b) Toward a Definition of Effective Teaching, In Feldman K. A. and Paulsen M. B. (eds) *Teaching and Learning in the College Classroom*, ASHE Reader Series, Ginn Press, MA

Senge, P.M. (1988) *New System Dynamics Learning Tools for Management Education and Training D-3999*. In Forrester, J.W. (ed) (2004) *MIT System Dynamics Group Literature Collection DVD*, System Dynamics Society, Albany, NY, USA

Shaffer, W.A. (1976) *An Initial Concept for Organizing System Dynamics Curriculum D-2438*. In Forrester, J.W. (ed) (2004) *MIT System Dynamics Group Literature Collection DVD*, System Dynamics Society, Albany, NY, USA

Sterman, J.D. (1992) *Teaching Takes Off OR/MS Today*, (October, 1992)

Stuntz, L. with Lyneis D., (2007) *System Dynamics in K-12 Education: Lessons Learned*, Conference Proceedings, The 2007 International Conference of the System Dynamics Society and 50th Anniversary Celebration, July 29 – August 2, 2007, Boston, Massachusetts, USA

Sweeney, L. Booth and Sterman J., (2007) *Thinking about systems: student and teacher conceptions of natural and social systems*, *System Dynamics Review*, Volume 23 Issue 4, Pages 391 – 413, Accepted July 2007

Thompson, K. with Reimann P., (2007) *Do school students learn more about the environment from a system dynamics model by themselves or with a partner?*, Conference Proceedings, The 2007 International Conference of the System Dynamics Society and 50th Anniversary Celebration, July 29 – August 2, 2007, Boston, Massachusetts, USA

Virtual University (2005a). *Virtual University*. <http://virtual-u.org>. [Accessed 21st March, 2005]

Virtual University (2005b). *Game Simulations for Educational Leadership & Visualization: Virtual U and Beyond* <http://virtual-u.org/conference-invite.asp> [Accessed 21st March, 2005]