A Bachelor of Science Degree Program in System Dynamics at WPI

James K. Doyle, Matthew W. Grabowski, Amy H. Kao,
Michael J. Radzicki, Kent J. Rissmiller, and Khalid Saeed

Department of Social Science and Policy Studies
Worcester Polytechnic Institute
100 Institute Rd.
Worcester, MA 01609

Email: doyle@wpi.edu

In March of 1998 the faculty of Worcester Polytechnic Institute, the third oldest private college of engineering in the United States, voted to establish the world's first undergraduate major in system dynamics. Housed in WPI's interdisciplinary Department of Social Science and Policy Studies, the B. S. program in system dynamics aims to train students for careers as system dynamics modelers, consultants, and policy analysts in both industry and government and to prepare them for graduate study in system dynamics. The purpose of this paper is to describe the rationale for and design of this new program, to engage the system dynamics community in a dialogue about the role of undergraduate education in the field of system dynamics, and to solicit feedback from the system dynamics community about the program requirements.

The Role of Undergraduate Education in System Dynamics

We believe that the creation of undergraduate major programs is important for the future development of the field of system dynamics. Although system dynamics is currently taught at more than 200 high schools in the United States and at dozens of graduate schools throughout the world, there is currently no place for interested students to study system dynamics at the college level beyond a couple of courses. This interruption in the flow of students from high school to graduate schools and careers in system dynamics is probably at least partly responsible for the current low supply of highly trained modelers and the increasing tendency for companies to hire people to do system dynamics work who have had little formal training. This in turn may reduce the average quality of system dynamics work, lowering the reputation of system dynamics and hindering the growth of the field (see Anderson et al., 1997).

The proposed program is designed to bridge the gap between high school and system dynamics careers by providing the thousands of U. S. high school students currently being introduced to system dynamics an opportunity to continue to pursue that interest at the undergraduate level. It is hoped that this effort will further the growth of the field of system dynamics by increasing the supply of highly trained modelers and encouraging the development of additional degree programs in system dynamics at other universities.

The WPI Philosophy

WPI has adopted an educational philosophy that is remarkably similar to the approach preferred by the field of system dynamics: an emphasis on learner-directed learning, cooperative learning, and learning by doing. Every undergraduate student at WPI is required to complete two extended research projects in which they work in teams to solve complex, open-ended problems in close collaboration with faculty members. These research projects are often completed at one of WPI's many Project Centers throughout the U. S. (e.g., Washington, D. C., San Francisco) and the world (e.g., London, Venice, Bangkok), where students work with sponsoring agencies and businesses to solve real problems. Consistent with this philosophy, the B. S. program in system dynamics is based on an experiential learning model (see Kolb, 1984) in which students will learn the craft of system dynamics modeling by working with faculty in an "apprenticeship-style" learning environment.

University-Wide Degree Requirements

WPI system dynamics graduates will complete three university-wide "project" requirements:

1. <u>The Major Qualifying Project</u> (MQP). The MQP is a three course equivalent research project which is designed to provide the student with a capstone experience in their professional discipline and to develop the creativity, self-confidence, ability to synthesize fundamental concepts, and research and communication skills necessary for success in their chosen field.

2. <u>The Interactive Qualifying Project</u> (IQP). The IQP is a second three course equivalent research project in which students examine some aspect of the interaction between science and technology and society. It is intended to help the student gain an awareness of the interrelationships between technology and people, develop the ability to communicate effectively with disparate groups, and learn to derive solutions to complex social/technological problems.

Both the MQP and IQP can be completed using the concepts and methods of system dynamics. Recent examples of such projects completed by WPI students include:

The Dynamics of the Escalation Phenomenon
Policy Design in Sterling, Massachusetts
The Dynamics of Deregulation in the Massachusetts Electric Power Industry
Sustainable Development in Kingston, Jamaica
A System Dynamics Approach to the Medicare Crisis
The Dynamics of the Emergence and Diffusion of Silicone Gel Breast Implants
A System Dynamics Study of Kiama, NSW, Australia
The Dynamics of the Fishing Crisis
Dairy Farm Dynamics
A System Dynamics Study of Project Management: The Case of a World's Fair
A System Dynamics Study of the Strategic Issues Facing Engineering Schools

In addition, each student will complete a third "project" requirement:

3. The Humanities Sufficiency. The Sufficiency is an integrated sequence of five courses in the Humanities and/or Arts followed by a one-course independent study project. It is designed to provide students more intellectual breadth and a better understanding of themselves, their cultures, and their heritage.

System Dynamics Major Requirements

System Dynamics

System Dynamics students will complete a five-course sequence in system dynamics modeling. The first course is designed to provide a general overview of the system dynamics approach to both SD majors and nonmajors. The next three courses are intended to introduce SD majors to the basic “nuts and bolts” of system dynamics modeling as well as important advanced modeling techniques and group model building. The fifth course is an advanced seminar in which students will produce an original system dynamics model of a self-selected problem. The course descriptions are as follows:

SS1510. Introduction to Economic and Social Systems

The goals of this course are to acquaint students with the fundamental structures underlying economic and social systems, and to motivate them to begin analyzing economic and social problems dynamically and holistically. These goals are pursued via the integration of basic economic and social concepts into interactive simulation models and computerized learning environments.

The curriculum materials have been formulated with a simulation technique that has its origins in control theory and electrical engineering. As a consequence, engineering students will find them complementary to their engineering work. Moreover, the course materials have been designed to stimulate the recognition of "generic structures" or combinations of stocks, flows, feedback loops, and system limits that produce the same dynamical behavior in a diverse array of economic, technological, and social systems.

A partial list of the economic and social problems that will be addressed in the course includes: the origin of economic cycles, the deficit and debt problem, natural resource depletion, the economics of poaching, the economics of illegal drug markets, the stagnation and decay of urban economies, global warming, the pros and cons of economic growth, arms races, the escalation of commitment to failing courses of action, and the cycle in the supply and demand for engineers.

SS1520. Dynamic Modeling of Economic and Social Systems

The purpose of this course is to teach students the basic techniques of producing dynamic simulation models of economic and social systems. Models of this type can be used to examine the possible impacts of policy changes and technological innovations on socioeconomic systems.

The curriculum in this course is divided into three distinct parts. First, a detailed examination of the steps of the system dynamics modeling process: problem identification (including data collection), feedback structure conceptualization, model formulation, model testing and analysis, model documentation and presentation, and policy implementation. Second, a survey of the "nuts and bolts" of continuous simulation modeling: information and material delays, time constants, the use of noise and numerical integration techniques, control theory heuristics, and software details (both simulation and model presentation and documentation software). Third, a step-by-step, in-class production of a model, involving the construction, testing, and assembly of sub-sectors.

SS2530. Advanced Topics in System Dynamics Modeling

This course will focus on advanced issues and topics in the computer modeling of complex social and economic systems. A variety of options for dealing with complexity through developing models of large-scale systems and partitioning complex problems will be discussed. Topics will include an extended discussion of model analysis, the use of summary statistics and sensitivity measures, the model validation process, and policy design. System dynamics applications to theory building and social policy are also reviewed. Complex nonlinear dynamics and the chaotic behavior of systems will be discussed.

SS2540. Group Model Building

This course will review the system dynamics practice of group model building, in which a system dynamics model is created through close interaction with a team of policy makers or managers. Topics will include mental models theory, alternate techniques for eliciting, mapping, and sharing mental models for use in model building, procedures for group facilitation, individual and team learning, group communication and decision making processes, and factors that promote or impede group performance. Special attention will be paid to the rigorous assessment of learning and group performance.

SS3550. System Dynamics Seminar

This special topics course is designed primarily for System Dynamics Majors and students presently engaged in planning system dynamics projects. Students will be required to complete an original system dynamics modeling project and will be encouraged to choose a project that can serve as the "first cut" at an MQP or IQP idea. The course will be conducted as a research seminar, with many sessions being reserved for student presentations. Classic system dynamics models will be replicated and discussed. Students will read, evaluate, and report on research papers representing the latest developments in system dynamics.

Other Social Science and Management Courses

Students will also complete 7 additional courses in social science and management in subjects that are either traditional SD modeling application areas (economics, management, public policy) or that provide a background in topics relevant to the system dynamics approach (e.g., mental models, decision making and problem solving). Students will choose from among such courses as:

SS1110. Introductory Microeconomics
SS1120. Introductory Macroeconomics
SS2117. Environmental Economics

SS2125. Development Economics

SS1401. Introduction to Cognitive Psychology
SS1402. Introduction to Social Psychology
SS1503. The Psychology of Decision Making and Problem Solving

SS1303. American Public Policy
SS1320. Topics in International Politics
SS2304. Governmental Decision Making and Administrative Law
SS2312. International Environmental Policy

MG2300. Organizational Science – Foundation
MG2200. Financial Management
MG3351. Organizational Science – Management of Change
MG3414. Management of Process and Product Innovation

Basic Science, Mathematics, and Computer Science Courses

System Dynamics students will be required to take a minimum of two courses in basic science. Students will be encouraged to take Physics 1110. General Principles – Mechanics and Physics 1120. General Principles – Electricity and Magnetism as preparation for ES3011 and ES4012, Control Engineering I and II, in order to gain a solid background in control theory.

Students will also be required to complete 6 courses in mathematics in order to obtain an understanding of the mathematics on which system dynamics modeling is based. The required math courses include one year of calculus, differential equations, and numerical analysis. In addition, students will take a minimum of two courses in computer programming in order to achieve an understanding of the programming principles that underlie system dynamics computer software.

Modeling Application Areas

Students will also complete a five-course sequence of applied courses in the area in which they choose to focus their system dynamics modeling. Thus far 12 application areas have been approved:

Economics
Project Dynamics
Engineering Systems
Public Policy
Environmental Policy
Fire Protection Engineering
Computer Science
Infrastructure Planning
Society-Technology Studies
Transportation Planning
Model Analysis
Electrical Power Systems Planning

Students will also be encouraged to develop and gain approval for new application areas according to their interests.

System Dynamics Faculty and Their Research Interests

The following WPI faculty are actively involved in the system dynamics major:

James K. Doyle, Ph. D., Associate Professor -- Social and cognitive psychology, mental models, knowledge elicitation, assessment of learning, judgment and decision making

Michael J. Radzicki, Ph. D., Associate Professor – Macroeconomics, regional economics, sustainable economic development, system dynamics, websims

Kent J. Rissmiller, Ph. D., Associate Professor – Environmental and energy law and policy, American politics, political theory, jurisprudence

Khalid Saeed, Ph. D., Professor and Department Head – System dynamics, sustainable economic development, infrastructure planning

Conclusion and Future Directions

This paper has described the rationale for and implementation of a new undergraduate degree program in system dynamics. Marketing of the program to students at more than 200 high schools in the U. S. will begin in the Fall of 1998, with the goal of enrolling between ten and twenty freshmen in the program in the 99/00 academic year. Given the uniqueness of the program and its importance to the future growth of the field of system dynamics, in the near future WPI intends to create an advisory board composed of leading system dynamics professionals from academia, industry, and K-12 education.

At this time the Social Science and Policy Studies Department at WPI would like to thank the many professionals both at WPI and in the international system dynamics community without whose encouragement and support this new program would not have been possible. The Department would also like to invite interested SD professionals from industry, higher education, and K-12 education to comment on the design, implementation, and marketing of the new major in order to assist its future development.

References

Andersen, D. L., Radzicki, M. J., Spencer, R. L., and Trees, W. S. (1997). The dynamics of the field of system dynamics. Proceedings of the 15th International System Dynamics Conference, (Istanbul, Turkey), pp. 811-814.

Kolb, D. A. (1984). Experiential Learning. Englewood Cliffs, NJ: Prentice Hall.