

# Design of a Master of Science Degree Program in System Dynamics at WPI

James K. Doyle, Bob Eberlein, Andy Ford, Jim Hines, James M. Lyneis, Ken Parsons, Oleg Pavlov, Michael J. Radzicki, Khalid Saeed, Kim Warren

Department of Social Science and Policy Studies

Worcester Polytechnic Institute

## ABSTRACT

Graduate degree programs in system dynamics are rare and thus of critical importance to the future of the field of system dynamics. However, to a large extent such programs have not yet been made transparent to the system dynamics community as a whole. The present paper describes the design and rationale for one such program, WPI's M. S. degree program in system dynamics. The goal of the paper is to invite feedback from the SD community about our specific program as well as to facilitate wider discussion about the appropriate content, design, and pedagogy of degree programs and courses in system dynamics.

## I. Introduction

System dynamics courses are taught at dozens of universities throughout the world. However, only a small number of institutions offer graduate degree programs with substantial training in system dynamics. In most cases, the system dynamics curriculum is part of a larger curriculum in a school of, for example, Business or Public Policy, and the primary means of educational delivery beyond a few introductory courses is research mentorship with individual system dynamics faculty. In a few cases, the system dynamics curriculum is part of a larger "system sciences" program that covers a wide variety of different modeling approaches. Those programs

that offer substantial coursework in system dynamics (say, half a dozen courses or more) and a graduate degree titled “System Dynamics” can be counted on one hand.

At the same time, there has long been interest within the International System Dynamics Society in examining and understanding the nature and quality of university curricula in system dynamics. Certainly, the growth and well being of the Society depends on the availability of high-quality graduate education in system dynamics. However, various efforts over the years to develop curriculum guidelines have thus far not been successful. An alternative approach may be to encourage programs to voluntarily make available to others the design and rationale behind their programs, which would open them up to scrutiny and constructive criticism from peers. Thus far there has been little published literature in the system dynamics field describing the actual or recommended design, content, or pedagogy of either system dynamics courses or programs (although, see, e.g., Andersen and Richardson, 1980; Barlas, 1993, 1995; and Hovmand and O’Sullivan, 2009).

The present authors believe that, given their rarity, university programs in system dynamics have a special responsibility to the field to make the content and design of their programs transparent. Thus, the purpose of the present paper is to describe the development and design of WPI’s Master of Science degree program in System Dynamics, as a way of encouraging the field to begin to substantially address more general issues of curriculum design. For example, how should an M. S. program in System Dynamics, any program, be structured and taught? What topics, in what sequence, should be covered? What pedagogies should be emphasized? What topics beyond the field should a system dynamics student be familiar with (e.g., business, economics, psychology, mathematics)?

## II. System Dynamics at WPI

WPI’s M. S. program in system dynamics was the culmination of more than a decade of strategic planning and curriculum development on the part of several faculty. System dynamics was established at WPI by Prof. Michael Radzicki, who began teaching a two-course undergraduate sequence in system dynamics in 1990. By 1996 Prof. Khalid Saeed had joined the WPI Faculty as Head of the Department of Social Science and Policy Studies, the department that administers WPI’s system dynamics programs. Soon thereafter Profs. Saeed, Prof. James Doyle, and Prof. Radzicki established the world’s first Bachelor of Science degree program in System Dynamics at WPI in 1998 (see Doyle et al., 1998). Professor of Practice James M. Lyneis joined the WPI system dynamics faculty in 2001, followed by Prof. Oleg Pavlov in 2002. In 2003 WPI began offering its first graduate courses in system dynamics. Some of these courses had previously been taught as distance learning courses at MIT, and several of the faculty involved in that program (Bob Eberlein, Andy Ford, Jim Hines, and Kim Warren) were brought in as adjunct faculty at WPI to continue them. By 2004 nine graduate courses as well as a six-course graduate

certificate program in system dynamics had been established. In 2006 the M. S. program in System Dynamics was approved by the WPI Faculty and Trustees. The first four graduates of the program were awarded their degrees in May of 2007.

### III. The M.S. Program at WPI

#### A. Students

The students enrolled in WPI's graduate system dynamics programs are primarily mid-career professionals who enroll in courses part time. They are not necessarily looking for a brand new career, but for the most part want to do their current job better by incorporating the tools and techniques of system dynamics. More than half of the students are above the age of 35, and they are 90% male. The students are widely geographically dispersed around the U. S. and the world, with only about 15% residing in WPI's home state of Massachusetts. Our student body as a whole is already highly well educated. Most of the students in fact enter our program having already obtained an advanced degree in another field (e.g., M.B.A., M.S. in Engineering).

It should be noted that in addition to our primary population of part-time M.S. students, the program also serves a small number of B.S./M.S. and interdisciplinary Ph. D. students.

#### B. Faculty

There are currently 5 full-time faculty in the Dept. of Social Science and Policy Studies at WPI who teach in the WPI M.S. program. In addition, there are 5 adjunct faculty who regularly teach in the program. Collectively, the system dynamics teaching faculty bring a wealth of experience and expertise to the program, and include 3 winners of the Jay Forrester Award as well as 5 past Presidents of the International System Dynamics Society. The list of faculty and their research interests appear in Appendix A.

#### C. Enrollment

Enrollment in system dynamics graduate courses at WPI has been steady at between 90 and just over 100 students per year since 2003:

<u>Academic Year</u>	<u>Course Sections</u>	<u>Total Enrollments</u>
2003-04	8	99
2004-05	10	91

2005-06	7	97
2006-07	10	101
2007-08	8	107
2008-09	9	91

The number of students enrolled in degree or certificate programs has steadily increased in the past few years:

<u>Academic Year</u>	<u>Total Graduate Enrollment</u>
2005-06	5
2006-07	10
2007-08	16

#### D. Distance Learning

WPI's graduate courses in system dynamics are implemented exclusively in a distance learning format through WPI's Advanced Distance Learning Network (<http://cpe.wpi.edu/Individual/Distance/>). There are no classroom sections of the courses. The course materials are delivered through WPI's web-based course delivery system, myWPI, <http://www.wpi.edu/Academics/ATC/Collaboratory/HowTo/MyWPI/whatismywpi.html>, powered by [Blackboard](#) Learning System with Community Portal version 8.0.

The courses are taught on the same semester schedule as WPI's classroom courses and students receive regular deadlines for completion of homework assignments and other tasks. The courses are just as challenging as classroom courses at WPI, often requiring 15-20 hours per week of effort or more from students. Course lectures, including supporting material such as Powerpoint files, are posted in streaming video files. As in a classroom course, students receive detailed and timely feedback on their work. Faculty-student and student-student interaction takes place primarily via electronic discussion board and email. WPI's distance learning students are full members of the WPI community and have electronic access to all services available to on-campus students (e.g., library, bookstore, and technical help).

#### D. Degree requirements

Students are required to complete 30 credit hours for the M.S. in system dynamics. At least 21 of these credit hours (7 courses) must be in system dynamics. The remaining 9 credit hours may be taken in mathematics, management, economics, or additional system dynamics courses. Six of these 9 credit hours may also be supervised research. Students are required to file a plan of study with their academic advisor before completion of the first semester of the program.

The specific course requirements are as follows (full course descriptions appear in Appendix B):

1. Required courses (6 credits)

- SD 550 System Dynamics Foundation: Managing Complexity (3 credits)
- SD 551 Modeling and Experimental Analysis of Complex Problems (3 credits)

SD550 serves as our basic introductory modeling course and is a prerequisite to all other courses in the program. SD551 serves as an advanced modeling course, introducing more advanced skills and more challenging and more open-ended modeling assignments. SD551 also serves as a prerequisite for most of the advanced methodology courses.

2. 6 to 9 credit hours of course work selected from the following courses:

- SD 552 System Dynamics for Insight (3 credits)
- SD 553 Model Analysis and Evaluation Techniques (3 credits)
- SD 554 Real World System Dynamics (3 credits)
- SD 555 Psychological Foundations of System Dynamics (3 credits)

These courses serve as advanced, specialized “methodological” as opposed to “topical” courses which develop important basic skills in greater detail than is possible in the introductory courses. SD552 is designed to build students’ modeling skills by increasing their ability to identify and adapt generic structures. SD553 covers basic topics in model evaluation and analysis, including use of subscripts, achieving and testing for robustness, use of numerical data, sensitivity analysis, and optimization/calibration of models. SD554 in many ways serves as a “capstone” course for the program. In this course students, under the direction of an experienced system dynamics consultant, work throughout the term on a consulting project in their own organization that they design and implement from start to finish. SD555 examines a variety of topics at the interface of psychology and system dynamics, focusing on methodological topics such as group model building, quantifying soft variables, and knowledge elicitation.

3. 9 to 12 credit hours of course work selected from the following courses:

- SD 560 Strategy Dynamics (3 credits)
- SD 561 Environmental Dynamics (3 credits)
- SD 562 Project Dynamics (3 credits)
- SD 565 Macroeconomic Dynamics (3 credits)

These courses are advanced topical courses that focus on the application of system dynamics in a particular domain of inquiry.

4. 3 to 9 credit hours of elective coursework selected from the following, or additional courses from the previous lists:

- SD 590 Special Topics in System Dynamics (credit as specified)
- Graduate independent study courses in System Dynamics (credit as specified)
- MA 510/CS522 Numerical Methods (3 credit hours)
- MA 512 Numerical Differential Equations (3 credit hours)
- Approved graduate coursework in an application area (e.g., economics, psychology, management, engineering, or applied sciences)

These elective courses allow students the flexibility to take more system dynamics courses, explore new topics through one-on-one collaboration with a faculty member, improve their math skills, or develop expertise in an application area of system dynamics.

5. Up to 6 credit hours of directed research

This requirement allows students to undertake an optional Master's Thesis.

#### IV. Program Design

##### A. Mission Statement

The WPI System Dynamics teaching faculty have adopted the following mission statement for the graduate program:

System dynamics is a methodology for understanding and changing the behavior of systems. The methodology centers around the development and use of *formal computer models* that:

1. Apply the accepted system dynamics theory of structure (endogenous behavior, positive and negative feedback loops, accumulations and delays, and representation of decision-making);
2. Are constructed following the scientific method (problem defined in terms of a reference mode of problem behavior, dynamic hypothesis as a theory of that behavior, formal computer model of the hypothesis, testing of the model/hypothesis against data, extensive analysis, and policy design); and
3. Use best practice tools and techniques (system dynamics software, units checking, standard formulations, generic models and building blocks, graphical functions, etc.).

These three components collectively define rigorous *system dynamics*. Further, in real world applications:

4. Models should be developed so as to achieve client confidence and acceptance (using various approaches including “group model building”).

## B. Course Design

The System Dynamics courses at WPI emphasize building modeling skill through homework assignments that receive prompt and detailed feedback from the instructor. Variations in approach and emphasis are encouraged in the belief that students benefit from learning how different faculty may approach a given problem or topic differently, and why. In all of our modeling courses students gain hands-on experience with reference modes, hypothesis formulation using causal and stock-flow diagrams, equation-writing, and model analysis. We believe that lasting, generalizable learning is best obtained by returning to the same topics again and again, with different instructors, in different courses, while studying different problem domains. Our goal is to turn students into experienced modelers who, upon graduation, will be able to manage a modeling project in a real organization from start to finish.

Rather than focus on the topics a course covers, when we design (and redesign) courses, we place more emphasis on skill achievement. Each lecture, assignment, or activity is considered in relation to the general “skill” categories described in our mission statement. These “skill grids” help instructors plan their courses and help them keep track of what other instructors are doing. They also allow us a high-level view of the entire program, which helps us assess the amount of overlap and redundancy across courses (while keeping in mind that a certain degree of redundancy is desirable) as well as to identify important omissions in our program.

Each instructor maintains a skill grid for the courses they teach. The following is one example of such a skill grid, for our introductory course SD550. It constitutes a statement of what we think is important to include in an introductory system dynamics course, with an emphasis on skills taught in various goal categories versus the traditional linear format of a course syllabus:

### **System Dynamics Skills Taught in SD550**

<p style="text-align: center;"><b>System Dynamics as a Theory of Behavior</b></p> <p>Positive and Negative Feedback, Stocks &amp; Flows, Delays, Basic Structures, Characteristics of Complex Systems, etc.</p>
---

Policy Resistance / Unintended Consequences

Fundamental Behavior Patterns

Causes of dynamic behavior: feedback and accumulation

Basic Archetypes (success to successful, limits, fixes that fail, shifting burden)

First-order positive systems (analytical solution, rate-level graph, doubling time)

First-order negative systems (analytical, rate/level, half-lives)

Draining processes, Goal-gap

Exponential average

First-order system with inflow and outflow (all linear)  
S-shaped Growth (carrying capacity)  
Overshoot and Collapse (resource depletion)  
Growth feedbacks from Sterman Ch. 10  
Product Diffusion Model  
Epidemic (SI and SIR)  
Stock Management with 3-stock delay  
Material Delays (1st, 3rd, 6th, pipeline)  
Second-order systems and oscillations (role of minor and major loops)

### **System Dynamics as a Scientific Modeling Process**

Conceptualization (Problem definition, dynamic hypothesis),  
Formulation (model construction, testing, validation), Use (testing and understanding, policy design)

System Dynamics "Standard Method"

*Conceptualization exercise -- Peer-to-Peer*

"Truth & Beauty"

Calibration and Detailed Models

*Tragedy of Commons/Fishbanks Modeling and Policy Design Exercise*

...

*(formulation incl. carrying capacity, graphical function, first-order stock control,*

*analysis of each loop's parameter sensitivity, policy design focused on info*

*from system and when action needs to be taken)*

*Material delays exercise (relative peaks of inflows, outflows, stock; equilibrium;*

*distribution relative to average)*

*Exercise -- explaining oscillations via "shifting disequilibria"*

*"MBM Case" Exercise -- two major negative loops (identical), each with 3 minor*

*negative loops and one minor positive loop*

*1 -- dynamic hypothesis*

*2 -- equations*

*3 -- analysis (parameter sensitivity testing to confirm role of major and minor*

*loops in oscillations*

*4 -- Policy design*

<b>SD Tools and Tricks: Model-building nuts and bolts</b>
---

Software, diagramming tools, catalog of structures, formulation good practices, graphical functions, analysis tools
---

Vensim

Causal-loop diagramming (basics and conventions, link/loop polarities, etc.)

Problems with CLDs

Stock-flow diagrams (as means of building models)

Graphical integration

*Calculating equilibrium and setting up model in equilibrium using equations*

Units checking

Graphical Functions (normalization, etc.)

First-order stock control

Test inputs (step, pulse, cycle, ramp, exponential, noise)

Sensitivity testing

Loop knockout

<b>Applications</b>
---------------------

Market Growth Model (lecture)

"Fishbanks" (assignment)

Commodity (but not Meadows, JDS)

(lecture)

Project models (but not ala JML) (lecture)

Kaibab model, some World Dynamics

(lecture)

### C. Future directions

During a recent retreat, the WPI system dynamics faculty settled on the following priorities for program development, all of which are underway:

1. It was determined that the course SD554 Real World has proven to be such a valuable capstone to the program for many students that it should be required for all students rather than optional. Effectively, the course will now serve as students' "final examination" before they graduate from WPI and go on to conduct modeling projects on their own in real organizations.

2. Our current advanced modeling course, SD551, is taught with applications almost exclusively in the area of public policy. As an alternative, we plan to develop an equivalent course aimed at developing the same skill set but with applications to business policy. Students will be required to take one of the two courses, but encouraged to take both as a way of reinforcing basic skills through applications in very different domains.

3. An important recent topic of discussion in the system dynamics community has been the relationship between system dynamics and other modeling paradigms (e.g., agent-based modeling). The WPI SD Faculty are agreed that it is important for system dynamics students to be exposed to alternative modeling paradigms and to learn their comparative advantages and disadvantages to system dynamics. In the Summer of 2009 we will therefore offer a new course, Introduction to Agent-Based Modeling.

4. One important gap in our program is imparting to our students the skills of identifying the generic systems that create policy resilience and learning to formulate policies that can effectively address the underlying causes of problems rather than their symptoms. In the Spring of 2010 we will offer a new course titled to “Dealing with Policy Resilience” to address this gap.

## V. Conclusion

In this paper we have tried to give an overview, in some detail, of the design of and rationale for our M. S. degree program in system dynamics. Of course, no academic paper can possibly do justice to the full realization of a degree program as represented, for example, in course syllabi, assignments, lectures, instructor feedback, and class discussion. The WPI system dynamics faculty have therefore resolved to move toward an “open courseware” policy in which selected course syllabi, assignments, and video lectures will be made freely available on the. While this initiative is under development, interested parties may approach individual faculty members with requests for information.

We hope that by sharing this information about our program, we will obtain feedback from the system dynamics community about what we are doing wrong . . . and perhaps, occasionally, feedback on what we are doing right. We also hope to encourage the field of system dynamics to more fully and collectively address the question of what a graduate of an M.S. program in System Dynamics should know and be able to do and how best to achieve those goals. In addition, we hope that by sharing our experience, other universities will be encouraged to travel down the long and difficult path of turning a few system dynamics courses into a substantial degree program.

## References

- Andersen, D., and Richardson, G. P. (1980). Toward a pedagogy of system dynamics. *TIMS Studies in Management Sciences*, 14, 91–106.
- Barlas, Y. (1993). Formal system dynamics education in universities. In *Proceedings of the 1993 International System Dynamics Conference*, Cancun, Mexico.
- Barlas, Y. (1995). Academics of system dynamics: its core definition, topics, and terminology. *International Journal of Policy Modeling*, 7(1), 1–15.
- Doyle, J. K., Radzicki, M. J., and Saeed, K. (1998). A Bachelor of Science degree program in system dynamics at WPI. *The Creative Learning Exchange*, 7(5), 9.
- Hovmand, P. S., and O’Sullivan, J. A. (2009). Lessons from an interdisciplinary system dynamics course. *System Dynamics Review*, 24, 479-488.

## Acknowledgments

The authors would like to thank the newest members of the system dynamics faculty at WPI, John Morecroft and Jim Thompson, for their collegiality and support. In addition, the authors would like to acknowledge the important role played by Pam Shelley, WPI’s Assistant Director of Distance Learning, in guiding the development of the program and making sure it meets the needs of our students.

## Appendix A: WPI System Dynamics Teaching Faculty

**James K. Doyle**, Associate Professor of Psychology and Department Head (Ph. D., University of Colorado, Boulder, 1992), applied social and cognitive psychology, judgment and decision making, risk perception and communication, psychological foundations of system dynamics, mental models of complex systems ([doyle@wpi.edu](mailto:doyle@wpi.edu))

**Robert Eberlein**, President, Ventana Systems, Inc. (Ph.D., Massachusetts Institute of Technology), system dynamics software design and development, model analysis and evaluation, sensitivity analysis, optimization ([bob@vensim.com](mailto:bob@vensim.com))

**Andrew Ford**, Professor, School of Earth and Environmental Sciences, Washington State University (Ph. D., Dartmouth College), energy modeling, environmental dynamics and policy, regional planning ([forda@wsu.edu](mailto:forda@wsu.edu))

**James M. Lyneis**, Professor of Practice in System Dynamics (Ph. D., University of Michigan, 1974), system dynamics modeling, project dynamics and management, economic dynamics, market and industry behavior, deregulation, forecasting, business strategy ([jmlyneis@wpi.edu](mailto:jmlyneis@wpi.edu))

**Michael J. Radzicki**, Associate Professor of Economics (Ph. D., University of Notre Dame, 1985), post-Keynesian economics, institutional economics, heterodox economics, system dynamics modeling, agent-based modeling ([mjradz@wpi.edu](mailto:mjradz@wpi.edu))

**Oleg Pavlov**, Associate Professor of Economics and System Dynamics (Ph. D., University of Southern California, 2000), system dynamics modeling, computational economics, economics of information systems, economics of telecommunication, complex economics dynamics ([opavlov@wpi.edu](mailto:opavlov@wpi.edu))

**Khalid Saeed**, Professor of Economics and System Dynamics (Ph. D., Massachusetts Institute of Technology, 1981), sustainable economic development, system dynamics modeling and methodology, development planning and policy design, economic dynamics ([saeed@wpi.edu](mailto:saeed@wpi.edu))

**Jim Hines**, Senior Consultant, Ventana Systems, Inc. (Ph. D. Massachusetts Institute of Technology, 1988), system dynamics modeling, insight from models, software development, system dynamics consulting methodology ([jim@ventanasystems.com](mailto:jim@ventanasystems.com))

**Jim Thompson**, Independent Management Consultant (Ph.D. Univ. of Strathclyde, Glasgow, Scotland, expected 2009), system dynamics modeling, forecasting and policy analysis, health care dynamics, dynamics of the pharmaceuticals industry ([james.thompson@strath.ac.uk](mailto:james.thompson@strath.ac.uk))

**Kim Warren**, Teaching Fellow, Strategic and International Management, London Business School (Ph. D., London Business School), strategy dynamics, human resource development, marketing strategy, simulation-based learning ([kim@strategydynamics.com](mailto:kim@strategydynamics.com))

## Appendix B: WPI Graduate Courses in System Dynamics

### **SD 550. System Dynamics Foundation: Managing Complexity**

Why do some businesses grow while others stagnate or decline? What causes oscillation and amplification - the so called “bullwhip” -- in supply chains? Why do large scale projects so commonly overrun their budgets and schedules? This course explores the counter-intuitive dynamics of complex organizations and how managers can make the difference between success and failure. Students learn how even small changes in organizational structure can produce dramatic changes in organizational behavior. Real cases and computer simulation modeling combine for an in-depth examination of the feedback concept in complex systems. Topics include: supply chain dynamics, project dynamics, commodity cycles, new product diffusion,

and business growth and decline. The emphasis throughout is on the unifying concepts of system dynamics.

### **SD 551 . Modeling and Experimental Analysis of Complex Problems**

This course deals with the hands on detail related to analysis of complex problems and design of policy for change through building models and experimenting with them. Topics covered include: slicing complex problems and constructing reference modes; going from a dynamic hypothesis to a formal model and organization of complex models; specification of parameters and graphical functions; experimentations for model understanding, confidence building, policy design and policy implementation. Modeling examples will draw largely from public policy agendas. Prerequisites: SD 550 System Dynamics Foundation: Managing Complexity

### **SD 552 . System Dynamics for Insight**

The objective of this course is to help students appreciate and master system dynamics' unique way of using of computer simulation models. The course provides tools and approaches for building and learning from models. The course covers the use of molecules of system dynamics structure to increase model building speed and reliability. In addition, the course covers recently developed eigenvalue-based techniques for analyzing models as well as more traditional approaches. Prerequisites: SD 550 System Dynamics Foundation: Managing Complexity and SD 551 Modeling and Experimental Analysis of Complex Problems

### **SD 553 . Model Analysis and Evaluation Techniques**

This course focuses on analysis of models rather than conceptualization and model development. It provides techniques for exercising models, improving their quality and gaining added insights into what models have to say about a problem. Five major topics are covered: use of subscripts, achieving and testing for robustness, use of numerical data, sensitivity analysis, and optimization/calibration of models. The subscripts discussion provides techniques for dealing with detail complexity by changing model equations but not adding additional feedback structure. Robust models are achieved by using good individual equation formulations and making sure that they work together well through automated behavioral experiments. Data, especially time series data, are fundamental to finding and fixing shortcomings in model formulations. Sensitivity simulations expose the full range of behavior that a model can exhibit. Finally, the biggest section, dealing with optimization and calibration of models develops techniques for both testing models against data and developing policies to achieve specified goals. Though a number of statistical issues are touched upon during the course, only a basic knowledge of statistics and statistical hypothesis testing is required. Prerequisites: SD 550 System Dynamics Foundation: Managing Complexity and SD 551 Modeling and Experimental Analysis of Complex Problems, or permission of the instructor

### **SD 554 . Real World System Dynamics**

In this course students tackle real-world issues working with real managers on their most pressing concerns. Many students choose to work on issues in their own organizations. Other students have select from a number of proposals put forward by managers from a variety of companies seeking a system dynamics approach to important issues. Students experience the joys (and frustrations) of helping people figure out how to better manage their organizations via

system dynamics. Accordingly the course covers two important areas: consulting (i.e. helping managers) and the system dynamics standard method - a sequence of steps leading from a fuzzy “issue area” through increasing clarity and ultimately to solution recommendations. The course provides clear project pacing and lots of support from the instructors and fellow students. It is recommended that students take SD 554 Real World System Dynamics toward the end of their system dynamics coursework as it provides a natural transition from coursework to system dynamics practice. Prerequisites: SD 550 System Dynamics Foundation: Managing Complexity and SD 551 Modeling and Experimental Analysis of Complex Problems

### **SD 555 . Psychological Foundations of System Dynamics Modeling**

This course examines the cognitive and social processes underlying the theory and practice of system dynamics. The errors and biases in dynamic decision making that provide the primary rationale for the use of system dynamics modeling will be traced to their root causes in cognitive limitations on perception, attention, and memory. Group processes that influence the outcome of modeler-client interactions and appropriate psychological techniques for eliciting and using mental data to support model building will also be addressed. Additional topics will include the reliability of alternate data sources for modeling, techniques for quantifying soft variables, design issues in group model building, the relative advantages of qualitative and quantitative modeling, and client attitudes toward modeling. Prerequisite: SS550 System Dynamics Foundation: Managing Complexity or permission of the Instructor

### **SD 560. Strategy Dynamics**

This course provides a rigorous set of frameworks for designing a practical path to improve performance, both in business and non-commercial organisations. The method builds on existing strategy concepts, but moves substantially beyond them, by using the system dynamics method to understand and direct performance through time. Topics covered include: strategy, performance and resources; resources and accumulation; the ‘Strategic Architecture’; resource development; rivalry and the dynamics of competition; strategy, policy and information feedback; resource attributes; intangible resources; strategy, capabilities and organization; industry dynamics and scenarios. Case studies and models are assigned to students for analysis. Prerequisite: SD 550 System Dynamics Foundation: Managing Complexity or permission of the instructor.

### **SD 561. Environmental Dynamics**

Environmental Dynamics introduces the system dynamics students to the application in environmental systems. The course materials include the book *Modeling the Environment*, a supporting website, lectures and the corresponding power point files. Students learn system dynamics with examples implemented with the Stella software. The course includes a variety of small models and case applications to watershed management, salmon restoration, and incentives for electric vehicles to reduce urban air pollution. The students conclude the course with a class project to improve one of the models from the text. The improvements may be implemented with either the Stella or the Vensim software. Prerequisite: SD 550 System Dynamics Foundation: Managing Complexity.

### **SD 562. Project Dynamics**

This course will introduce students to the fundamental dynamics that drive project performance, including the rework cycle, feedback effects, and inter-phase “knock-on” effects. Topics covered include dynamic project problems and their causes: the rework cycle and feedback effects, knock-on effects between project phases; modeling the dynamics: feedback effects, schedule pressure and staffing, schedule changes, inter-phase dependencies and precedence; strategic project management: project planning, project preparation, risk management, project adaptation and execution cross project learning; multi-project issues. A simple project model will be created, and used in assignments to illustrate the principles of “strategic project management.” Case examples of different applications will be discussed. Prerequisite: SD 550 System Dynamics Foundation: Managing Complexity.

### **SD 563. Health Care Dynamics**

Why would people go to the doctor more (or less) tomorrow than today? In this course students will explore and learn to simulate behaviors of health care providers, patients, and payers in the U.S. health care system with the goal of better understanding how macro-level patterns emerge from micro-level behaviors. A suite of system dynamics models is developed to explore problems of controlling health care costs and patient utilization. The smaller system dynamics models merge into a larger policy system model that can be used to explore proposed improvements and policy resistance in this sector of the economy. In addition to developing a policy-level model of the health care system, models will be developed on such topics as the spread and control of contagious diseases including SARS, AIDS, seasonal influenza, and pandemic flu, and the dynamics of medical centers of excellence. The objective of the course is to enable the student to develop a system-wide perspective and a framework for health care problem-solving. Prerequisites: SD 550 System Dynamics Foundation: Managing Complexity..

### **SD 565. Macroeconomic Dynamics**

There are three parts to this course. The first acquaints a student with dynamic macroeconomic data and the stylized facts seen in most macroeconomic systems. Characteristics of the data related to economic growth, economic cycles, and the interactions between economic growth and economic cycles that are seen as particularly important when viewed through the lens of system dynamics will be emphasized. The second acquaints a student with the basics of macroeconomic growth and business cycle theory. This is accomplished by presenting well-known models of economic growth and instability, from both the orthodox and heterodox perspectives, via system dynamics. The third part attempts to enhance a student’s ability to build and critique dynamic macroeconomic models by addressing such topics as the translation of difference and differential equation models into their equivalent system dynamics representation, fitting system dynamics models to macroeconomic data, and evaluating (formally and informally) a model’s validity for the purpose of theory selection. Prerequisites: SD 550 System Dynamics Foundation: Managing Complexity.