The MIT System Dynamics Guided Study Program: An Experiment in Distance Learning

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Abstract

During the summer of 1997, Professor Jay W. Forrester[1] discussed with the System Dynamics in Education Project (SDEP)[2] the idea of offering a tutoring class in system dynamics to a few members of the public to begin that fall. The tutoring would be accomplished electronically by e-mail. The class content would be centered around the Road Maps series,[3] a self-study guide for learning system dynamics which is the ongoing writing project of the SDEP.

The Guided Study Program (GSP) was announced by e-mail to two system dynamics lists and many people responded with interest. In September of 1997, fourteen people began the Program, though three soon dropped out because they were unable to devote the 15 hours per week that the program required. The GSP participants were from the United States, Spain, and the Netherlands. The authors of this paper were the tutors. As the GSP supervisor, Professor Forrester approved assignments and solutions before they were sent to participants.

In this paper, the tutors discuss the system principles covered, system dynamics skills developed by the participants, and extra independent model-building lessons that are not included in Road Maps, as well as logistics of the program and experiences of participants and tutors.

1. How the Guided Study Program Began

The System Dynamics in Education Project (SDEP) was founded at MIT in 1990 by Professor Jay W. Forrester as part of MIT's Undergraduate Research Opportunity Program (UROP). With funding from a private donor, he hired a number of MIT undergraduates to learn basics of system dynamics and write classroom curricula for high school use. The curricula would combine system dynamics principles with a learner-centered-learning approach.

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[1] Professor Emeritus and Senior Lecturer, MIT Sloan School of Management

[2] The SDEP is a group of undergraduate students at the Massachusetts Institute of Technology (MIT) whose main project is writing "Road Maps," an online, self- study guide to learning system dynamics, under the guidance of Professor Forrester.

[3] Available from http://sysdyn.mit.edu

It became clear after two years that asking MIT students to write lesson plans for teachers was too far removed from MIT student training and experience. MIT does not have a School of Education. Attempting to "test" the curricula with actual teachers and students was very time consuming. This initial phase was closed after four or five in-depth science papers were written.[4]

To continue with the primary focus of teaching system dynamics, Professor Forrester and the students began the Road Maps series in 1992. Road Maps is a self-study guide for learning system dynamics. Writing Road Maps remains the central research effort of SDEP today. Road Maps has no specific "target audience." The aim is to write chapters for teachers and high school students to gradually develop concepts that can be understood and used from high school age up.

During the summer of 1997, several people complained about scarcity of options available for in-depth study of system dynamics. In response, Professor Forrester proposed to the SDEP students the option of undertaking an interesting experiment to teach a correspondence course with Road Maps as the core text. Not only would participants benefit from being tutored, but the program would also be an educational challenge and opportunity for MIT undergraduates to prepare materials and interact with participants.

In July Professor Forrester wrote an e-mail to system dynamics mailing lists to see how many people would be interested in a distance learning course in system dynamics. By September a number of people had responded expressing interest, many more than had been anticipated. Some had taken a two-day introduction course using modeling software and wanted to build confidence and skill. Others had exposure to "systems thinking" ideas and discovered that they needed a more complete understanding of complex systems. The program started during the last week of September 1998, with fourteen participants.

2. What is the "Guided Study Program"?

The Guided Study Program is distance learning conducted by email for people with little or no prior knowledge of system dynamics. The foundation curriculum is structured upon Road Maps. Weekly (and occasionally biweekly) assignments include readings from papers in Road Maps, exercises based on those papers, additional questions on the topics of study, readings from the classic system dynamics literature, and modeling exercises.

The program was customized to interests and aptitudes of participants. The length and difficulty of assignments varied depending on performance of the participants on previous assignments. We, the tutors, frequently designed modeling exercises to fit

[4] Available from http://sysdyn.mit.edu

participants' backgrounds and areas of interest. Participants could reach us individually through e-mail and get feedback on questions and concerns.

After participants turned in assignments, they received solutions to the assignment. In addition, each participant received individual feedback. The individual feedback pointed mistakes and misunderstandings, and gave special suggestions that could help further improve insights and methods.

3. Material covered

Material covered in the Guided Study Program consists mainly of Chapters 1 through 9 of Road Maps. While preparing GSP assignments, we discovered the need to present Road Maps papers in a different order, or to modify papers to better suit program purposes. Participants were asked to read each paper, work through all exercises included in a paper, and then answer additional questions. Questions ranged from providing real-world examples of systems exhibiting a particular behavior, usually from their personal experiences, to extending and improving models presented in a paper, and running model simulations under different scenarios and assumptions.

In addition to papers already published and distributed as part of Road Maps, we used papers that were still being worked on by SDEP students or papers that have been completed but are not yet part of a finished Road Maps chapter.

The participants also studied books that are recommended readings in Road Maps, such as "Introduction to Computer Simulation" by Nancy Roberts et al. and "Study Notes in System Dynamics" by Michael Goodman. One entire assignment was devoted to reading and study of "Beyond the Limits" by Donella Meadows et al. Other assignments used "World Dynamics" and several chapters of "Principles of Systems," "Industrial Dynamics," and "Urban Dynamics" (all by Jay W. Forrester), as well as some papers from the "Collected Papers of Jay W. Forrester."

Important concepts and skills were approached and explained through independent modeling exercises. At the beginning of the program, participants were given a list of variable names to identify as stocks, their associated flows, auxiliary variables and constants, and then were given instructions on how to build a stock-and-flow model of the system being studied. Finally, participants were asked to change parameter values and analyze observed changes in behavior. As participants gained modeling skills, less guidance was given in the model-building process, until participants were able to build a model from only a verbal description of a problem. In all these exercises, emphasis was given to analysis of behavior generated by a model and the structural causes of behavior. Examples of systems that were modeled include deforestation, demographics, CFC propagation, growth of the Internet, Fishbanks and the tragedy of the commons, addiction, a sector of the "Beer Game" distribution model, a yellow fever epidemic, and a heroin-crime model.

All the exercises approached a wide range of system dynamics topics. We started by teaching basics of positive and negative feedback, until participants gained an intuitive understanding of these two simple feedback structures. We then moved on to first-order systems combining positive and negative feedback, such as systems exhibiting S-shaped growth, and then to higher-order systems. We covered structures generating sustained and damped oscillations as well as overshoot and collapse. We also stressed importance of delays and non-linearity in systems.

High standards of system dynamics modeling practice were maintained throughout the program. For example, dimensional consistency, documentation of models, and dimensionless inputs and outputs of table functions were emphasized. We explained why it is not correct to link one flow to another flow, and gave the participants guidance on naming their variables by following "Vensim standards," and using variable names that convey the meaning of the variables clearly.[5]

4. How we do it

Two of the four tutors took responsibility of preparing assignments and general solutions. The other two tutors read responses from participants and prepared individual feedback. Each week tutors met to discuss future assignments. After a tutor wrote a draft of an assignment, we all reviewed the assignment and then gave it to Professor Forrester who made final comments and corrections.

Assignments were sent to participants as e-mail attachments every Friday. Participants sent back solutions ten days later, on Monday. Each assignment took participants approximately 12 to 15 hours to complete, although some participants spent up to 20 hours on certain assignments. Participants often contacted us before the assignment was due with questions or comments. Each Monday two of us printed out responses and worked on individual feedback to participants. While reviewing responses, tutors edited the general solutions, emphasizing how to avoid errors that some participants made. Professor Forrester then reviewed the general solutions and individual feedback, which were sent to participants once the material met his approval.

5. Our challenges

The Guided Study Program presented several challenges. As we wrote assignments and solutions and read responses sent by participants, we realized that several Road Maps papers needed to be rewritten or restructured. As we went through Road Maps, we realized that some concepts had not been fully developed; our assignments and solutions, therefore, tried to compensate for shortcomings of the papers.

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[5] Modeling was done using the Vensim PLE software that can be downloaded from <http://www.vensim.com>.

The initial challenge was to solve lack of compatibility between different computing environments used by various participants and us. Various versions of word-processing software presented the biggest problem. Graphics in Microsoft Word 6.0 documents for PC's would freeze our Apple Macintosh computers, Word 97 documents would not open on our Macs, and so on. After much experimenting, and scouting Microsoft's web pages, we decided to send out all correspondence in Adobe Acrobat format, so that the participants would not have to spend time converting our attachments. By using combinations of different computers and different software, we were able to view all participant's documents.

One major challenge was tailoring assignments to needs of all participants, who were working at different paces due to different backgrounds, and different work and family pressures. We tried to include work of varying difficulty so that all participants would learn something new from each assignments, without any participants falling behind.

Our on-going struggle, however, was to deal with time pressures associated with creating and teaching a correspondence course while taking a full course-load of demanding MIT classes. We began to fall behind with individual feedback to participants in December, due to approaching final exams and then the holiday season. We are still catching up at the time of writing this summary.

6. Our successes

Despite the challenges, the Guided Study Program was, for us, a very rewarding experience. In writing assignments, solutions, individual feedback and answering questions, we developed a much deeper understanding of system dynamics, as well as ability to explain system dynamics to others. In developing assignments and from reactions of participants to papers and assignments, SDEP found many ways to improve existing Road Maps. Individual responses of participants also provided many ideas for papers that address mistakes and misunderstandings that are commonly encountered in system dynamics.

Participants also gained a lot from the Guided Study Program. In the assignments, we gave participants opportunities to apply system dynamics to their personal lives and the environment around them. Individual feedback and suggestions helped to point out the strengths of each participant as well as identify areas for improvement. We have received comments about how participants realized that their understanding of a certain system had been wrong for years. Using a systems modeling approach showed up flaws in their understanding and helped them understand the system better. One participant said that system principles taught him that a major problem his company faced was due to the very structure of the company's operations. The solution was exactly the opposite of what the company had been doing to solve the problem. Over the past few weeks, some participants have expressed disappointment due to the delayed individual feedback, but the overall response has been very encouraging for us. Below are some comments from participants:

"… I have really learned a lot from the GSP… the most valuable component has been all the modeling we have done. I am no longer intimidated by system dynamics software, but feel comfortable just sitting down and doing it.. the GSP has been a great learning opportunity."

-- Paul Newton <paulnewton@ibm.net>

"If you tell me that I have done it all wrong, I will cry... but understand"

-- Anonymous, regarding his answers to an assignment.

(PS: His solutions were absolutely correct)

"… Great stuff, taking a lot of time but that's no problem because of the interesting material. Feedback is too much delayed to get optimum learning results, still learned a lot of good model building practice…"

-- Egbert Roos <Egbert.Roos@nl.origin-it.com>

"… I didn't understand how to diagram this until today. The confusion you felt was real which brings me to some feedback on your feedback. You have been extremely consistent and precise in you criticism (good and bad). When I am not clear or presented "one side" it was because I was either unclear in my own thinking about that example or had gotten lazy (after long hours). Thanks for keeping me honest. The feedback quality and insight far exceed my expectations."

-- Anonymous, while building causal loops diagrams.

"… I wanted to acquire a basic but solid initial formation in dynamic models, something more difficult to obtain without the help or guide of experts on such field and also on the learning of such field… I think that one of the main elements of the GSP is - and it should be in a greater extent - the active interaction and feedback between the participants and the GSP tutors."

-- Julia Martinez Fernandez <maesteve@fcu.um.es>

Active involvement and feedback from participants has helped us improve the program through the year, and as we design and modify the program for future years.
The participants quoted above have graciously agreed to answer questions from anyone interested in the GSP.

7. The Future

The first year of the Guided Study Program ended in July 1998. We and the participants all found the Program to be a rewarding and educational experience. The System Dynamics in Education Project will be holding a similar Guided Study Program for the 1998-1999 school year. The material covered will be the same as the first year, but lessons and experience we gained this year will serve to improve next year's program.

The Guided Study Program is currently seeking potential participants for the upcoming year. Participants must possess a computer and have access to the internet, and be willing to devote at least fifteen hours per week to the program.

The success of the first Guided Study Program also led to many inquiries regarding a second-level program next year. The second-level program would run in parallel with the original Guided Study Program, and cover more complex systems. The second-level program would focus on in-depth, independent projects spanning several weeks. The curriculum would include select papers from Road Maps, classics in system dynamics literature, and advanced modeling exercises.

The System Dynamics in Education Project hopes that the Guided Study Program will provide people an the opportunity to benefit from a careful study of the methodology and applications of system dynamics. We hope that participants will take away valuable lessons and will be able to continue to use system dynamics methods in their work.

8. Bibliography of mentioned books

Roberts, Nancy et al, 1983. *Introduction to Computer Simulations: A System Dynamics Modeling Approach,* Portland OR: Productivity Press. (recheck)

Goodman, Michael R., 1974. *Study Notes in System Dynamics,* Portland OR: Productivity Press. 388 pp.

D. H. Meadows, D. L. Meadows and J. Randers, 1992. *Beyond the Limits: Confronting Global Collapse, Envisioning A Sustainable Future,* Post Mills VT: Chelsea Green.

Forrester, Jay W., 1971. *World Dynamics* (1973 2nd ed.), Portland OR: Productivity Press. 144 pp.

Forrester, Jay W., 1968. *Principles of Systems* (2nd ed.), Portland OR: Productivity Press. 391 pp.

Forrester, Jay W., 1961. *Industrial Dynamics,* Portland OR: Productivity Press. 464 pp.

Forrester, Jay W., 1969. *Urban Dynamics,* Portland OR: Productivity Press. 285 pp.

Forrester, Jay W., 1975. *Collected Papers of Jay W. Forrester,* Portland OR: Productivity Press. 284 pp.

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