

# Guided Study Program in System Dynamics

System Dynamics in Education Project

System Dynamics Group

MIT Sloan School of Management

Solutions to Assignment 1

September 28, 1998

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## ***Reading Assignment:***

*Please refer to Road Maps 1: A Guide to Learning System Dynamics (D-4501-4) and read the following papers from Road Maps 1:*

- *Systems 1: An Introduction to Systems Thinking*<sup>1</sup>
- *System Dynamics and Learner-Centered-Learning in K-12 Education (D-4337-1)*

*We recommend that you read Systems 1 carefully. The book describes some of the most important concepts of system dynamics that we will revisit many times throughout the program. We also encourage you to read the Appendix; some of the questions in this assignment are based on the Appendix.*

*Also read the following:*

- *Principles of Systems*,<sup>2</sup> by Jay W. Forrester, Chapter 1

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<sup>1</sup> Kauffman, Draper L. J., 1980. *Systems 1: An Introduction to Systems Thinking*. Instructions for obtaining this book are provided in Road Maps 1: A Guide to Learning System Dynamics (D-4501-4).

<sup>2</sup> Forrester, Jay W., 1968. *Principles of Systems*, (2nd ed.). Portland, Oregon: Productivity Press. 391 pp.

**Exercises:**

All of the following exercises should be answered with a short paragraph. In this assignment, there are no right or wrong answers. We are trying to help you understand the principles covered in the readings by identifying the presence of dynamic systems in your everyday life.

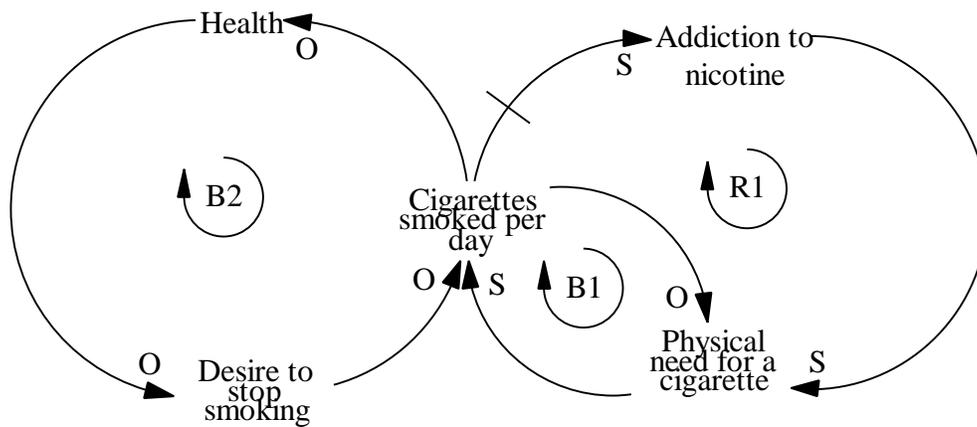
1. Systems I: An Introduction to Systems Thinking

A. Chapter One: What is a System?

Choose one of the following systems. Describe its different elements and how they interact with each other in terms of feedback.<sup>3</sup>

- quitting smoking
- procrastination
- learning a new skill
- dieting
- studying/goofing off

Quitting smoking:



The “quitting smoking” system can be described by looking at each of the three feedback loops R1, B1 and B2.

Start by considering the reinforcing loop R1 on the right. This loop shows that an increase in the number of cigarettes smoked per day leads to an increased addiction to nicotine, all be it with a delay. Increased addiction to nicotine in turn leads to an increased physical need for a cigarette, which leads to an increase in the number of cigarettes smoked per day.

<sup>3</sup> This exercise is based on: *Conceptualization Exercise* (D-2610-3), 15.873: Principles of Dynamic Systems II, Sloan School of Management, Massachusetts Institute of Technology, based on an exercise by Alan Graham, revised by John Sterman.

Left unchecked, this reinforcing loop would give rise to exponential growth in the number of cigarettes a smoker smokes per day; clearly, this is not the case as even the heaviest smoker probably smokes less than one hundred cigarettes per day. The balancing loop B1 on the right of the diagram limits growth in the number of cigarettes smoked each day. This balancing loop acts to limit the growth from the reinforcing loop by saying that eventually, as the number of cigarettes smoked per day increases beyond a certain level, the physical need is diminished, the desire is satisfied. Putting these first two loops together might suggest an increase in the number of cigarettes a smoker smokes each day up to a certain point when the balancing loop kicks in to level off this growth.

Looking at the balancing loop B2 on the left, we see that as the number of cigarettes smoked per day increases, health deteriorates, desire to stop smoking increases, and the number of cigarettes smoked per day falls.

Because of the delay between cigarettes smoked and addiction, however, the smoker still has the physical need for a cigarette, and the balancing loop B1 is acting in the opposite direction to B2, i.e. to increase the number of cigarettes smoked per day. It is the strength of loop B2 relative to B1 that will determine whether the smoker can hold out long enough to successfully quit smoking.

Procrastination: My model of the procrastination system contains five elements and demonstrates positive feedback. The elements include avoidance behavior, inactivity, absence of results, stress, and paralysis. The initial *avoidance of behavior* results in *inactivity*. A consequence of *inactivity* is the *absence of results*. This contributes to *stress*, which increases *paralysis* and thereby exacerbates *avoidance behavior*. The system is an example of positive feedback because the interaction between the elements tends to generate higher levels of procrastination.

Dieting: The simplest elements of dieting would be the decision to lose weight, the amount of weight to lose, and the act of dieting to lose the weight. In the simplest form of feedback loops described by Forrester in *Principles of Systems*, you would make the “decision” to lose weight based on the information available to you (your current weight). You would then take the necessary “action” of reducing food intake and/or increasing exercise that would hopefully affect your total weight “level”. Using the information from your new current weight level you would decide to continue the dieting/exercise action or quit when desired weight is reached.

There are numerous other elements that would affect this system such as body metabolism, time commitment, personal activity level, willpower, money, food sources, outside support, and your overall commitment to the task of losing weight.

## B. Chapter Two: Stability

*Give two examples of “self-regulating” systems and explain briefly how they work.*

Both fish and scuba divers attempt to maintain neutral buoyancy in water. Both (usually) have pockets of air or other gasses. As they descend, these pockets, which are now under increased pressure, get smaller and thus decrease the overall buoyancy of the

individual, causing him to sink even further. Without some sort of compensation the individual would keep sinking (positive feedback). Of course the opposite is also true. As the individual rises in the water, gas, now under less pressure, must be released or the expanding gas will rapidly increase buoyancy and force the individual to the surface. Both fish and scuba divers must adjust their buoyancy by adding or releasing gas to maintain a fixed buoyancy (or a fixed volume for their weight). They sense their current buoyancy (positive or negative) and add or release air accordingly. This sensor is a pressure gauge that measures small volume changes.

In the human digestive process with respect to insulin production, an oversimplified view of the system starts with the ingestion of food. As the food is digested, blood sugar level goes up, which stimulates the creation and release of insulin into the blood stream. Insulin helps cells to make use of the blood sugar as a source of energy, thus causing the blood sugar level to drop. As the blood sugar level drops, the creation of more insulin slows down, which completes the self-regulating feedback.

### *C. Chapter Three: Things in Common*

*Choose two of the following types of systems. Think of a real-life example of each and explain briefly:*

- *loose systems*
- *systems with time limits*
- *systems that anticipate warnings*
- *counter-intuitive systems*
- *hidden systems*
- *vulnerable systems*

Loose system (with time limits): The grade report system in public schools is a very loose system. Students are performing every day in school. They can be improving or heading in unproductive directions such as when they stop studying, skip classes, or engage in less effective study techniques. Unfortunately for the students and parents, grade reports are one of the only ways that feedback is received. This is especially true in high school, where teachers cannot send home notes as is done in elementary school. This nine-week cycle of feedback is sometimes WAY too long to appropriately cope with declining performance. Of course, the system could be made less loose by increasing evaluation and feedback cycles, and thus reducing the effect the time limit has. This would not be a really practical solution because high school teachers already are overworked, and staffing increases to handle the increased workload are not likely in the current economic climate. I also wonder sometimes about parents' REAL commitment to their children's success...

Systems that anticipate warnings: An example would be the system of keeping my car running by never running out of gas. I monitor the gas gage of my car casually while at least three-quarters of the tank are left. As the tank drops below a quarter of a tank I start to become anxious and watch the gage even more closely. The lower it gets

the more anxious I get. When the “check gage” light comes on my anxiety increases to a level that leads me to find the nearest gas station. With my tank full of gas the system of checking, warnings, and filling my tank starts over again and I never run out of gas.

Counter-intuitive system: The stock market adage of buy the rumor, sell the news is an example of a **counter-intuitive** system. One would think that good news for a stock would propel it to new highs. Quite often, however, the rumor of good news is sufficient to propel a stock to new highs, such that the announcement itself is an anticlimax. Thus, the good news promotes selling from short-term investors looking for the next short-term win. The selling depresses the stock price at a time it would seem logical it should rise.

Vulnerable System: In the Environment, Health & Safety (EHS) department at work, the entire organization is a vulnerable system. There is one section manager (a manager of managers) who is very influential in the daily performance of the department. This woman pays particular attention to each and every person in the department, always ready to lend a hand, help to solve a problem, or to pitch in with whatever needs to be done. She is the caring “glue” that holds the department’s system together. Although the department is large, this one woman’s influence is critical to the success of many other people’s work. She is especially helpful in assuring that communication is flowing. She connects senior management to the professional staff. She interprets business climate changes, and offers coaching to EHS staff to respond to these changes. Interestingly, this woman is NOT the head of the department. Her boss is the antithesis of the facilitator role. To paraphrase from the reading, if a bug flies in the eye of this system (doing something that would reduce her effectiveness) the department would certainly crash.

#### *D. Chapter Four: Change and Growth*

*Discuss the explosive growth of the internet by identifying its positive feedback loops.*

The Internet assists in the consolidation and dissemination of information, which is something people appear to desire. I define information broadly in this context. For example, I consider Internet commerce a subset of all the types of information flowing over the Internet. If people did not desire the information there would be no explosive growth. One positive feedback loop depends on the fact that the Internet is a more economical means of providing information than means previously utilized. As the use of the Internet spreads, its price declines further, making it even more economical. This declining price makes the Internet more attractive. So, the cycle feeds on itself. This is a supply-side argument.

Now on the demand side, compared to the world’s population, there are a relatively small number of Internet users. Assuming that the current non-users are also desirous of information, they will be attracted to use the Internet. These people will be more likely to want to use the Internet if they know someone who is already using it. The more people who use the Internet, the more likely that someone who is not already using the Internet will know someone who is using it. This “word-of-mouth” marketing serves as a positive feedback loop.

There is also positive feedback between the supply and the demand side. The more people who have Internet access the more information suppliers will want to convey information over the Internet. The more information is on the Internet, the more people who will be attracted to use the Internet.

At least two categories of positive feedback appear to contribute to the growth of the Internet. First, several examples of positive feedback can be directly linked to the consequences of market competition. Some of these feedback processes include the imitation that market success inevitably invites (if Toyota develops a successful web site, Honda, and Ford can be expected to also design sites), the role of market competition in putting downward pressure on prices (this applies to both internet services as well as personal computer hardware), and the range of product innovations that continue to make the internet increasingly accessible. A second category of positive feedback involves the exponential growth of use based upon word-of-mouth communication of the benefits of Internet use.

*E. Chapter Five: Putting the Pieces Together*

*Is there a limit to internet growth? If so, what are some of the limiting factors? What is the effect of competition on internet growth?*

There are limits to the number of people who can use the internet. It costs money to play in this game. ISPs must invest in capital equipment, and users must invest in computers and the monthly ISP fees. In tight economic times, fewer people will have the required amount of cash to spend on internet use. The amount of time is a limit to internet use. As a person gets busier, there is less time available to be on the net. I think people have a limit to the amount of information they can process. Unless we develop better "smart agents," people will max out pretty soon. I know that I don't surf that much-partly because of slow hardware/time issues-but also because I already feel like I have enough information stimulation.

As far as competition goes, I think we are in the mode where competition is fueling use, not limiting it. If the internet gets SOOO big through competition that the positive feedback loops like speed and quality of information declines, then that could produce a negative feedback dynamic into internet growth.

While the Internet has grown explosively, that growth cannot go on forever. The problems experienced by AOL provide an example of the effect of overloading the system. If growth in demand outstrips the available technology, users become disenchanted. So the pace of Internet growth is will be limited by the pace of development of technology. The number of potential users also limits internet growth. As computers become as common as television sets in households and as they become an absolute necessity in the workplace, growth in the number of computer users will slow--there simply will not be a large source for new users. Internet sites will then be competing for the attention of a limited number of users rather than attracting new ones. In addition, the Internet will be subject to competition from other newer technologies-as they develop.

*F. Chapter Six: Complex Systems*

*This chapter describes ten characteristics of complex systems. Choose three and illustrate with a real-life example of each.*

Goal Seeking: Fund raising groups are very typically goal seeking. If they are a long way from their goal they will increase their efforts. As they approach their goal they will typically start limiting their actions.

Program Following: Process to Cut an Accounts Payable Check: This is truly an example of branching. There are specific steps one takes to process an AP check. The trigger for the entire system is receiving an invoice that requires payment. Throughout the entire process a number of decision diamonds (decision points) must be made. Depending on how the decision one makes, the process is a bit different.

Self-reprogramming: Scientific experimentation can often take the form of self-reprogramming (although individual experiments would be more like “program following”). An overall series of scientific experiments will base the newest experimentation on the results of those just completed. Thus the fifth experiment in series could not have been predicted by the first because modifications have been made at each step. That is, the research goals are refined as the experiments are completed.

Self-Reprogramming: Road Construction Detour: For the past two weeks the highway interchange by my house has been under construction. The construction sign reads: “Ramp closed for construction 9/8 – 9/21, 8 a.m. – 6 p.m.”

When I drove to work on 9/8, I noticed the sign but didn’t really process it because I *always* was off to work before 8:00 a.m. This continued until 9/12 when I was headed to a client site for a meeting that began at 9:30 a.m. I left my house at 8:45 a.m. for a 9:30 a.m. meeting. The meeting location was 15 miles away. I headed off to the highway and was confounded because the ramp was closed. After a bit of cursing, I found an alternate route and was ten minutes late for my meeting. I made a mental note to avoid this in the future. On Friday, 9/18, I had another meeting at the same client location, same time (9:30 a.m.). Before departing, I recalled the mental note regarding construction closure.

Self-Replicating: The Hutterites, a self-supporting religious community that held all property in common. A colony occupies 6000 acres of land. They maintain their strong hierarchical principles by dividing their community when it reaches a population of 150. At this point, they draw up two lists of the people who will constitute the two new communities of Hutterites. On a given morning everyone then draws lots to see which people will leave to form another colony and move away, forever, and which people will remain behind.

Self-reorganizing: A family must be a self-reorganizing system in order to function well. As children grow from infants to toddlers to schoolchildren to teenagers to

adults, the family must constantly reorganize itself-altering the relationships among its parts-in order to meet changing needs. For example, when a child goes away to college, not only do that child's relationships with the other members of the family change, but the relationships among the remaining family members will be altered. The aging of parents may call for family reorganization as a child takes on the role of caretaker. Births and deaths, opportunities and illnesses, marriages and divorces and many other changes require the family system to be adaptable and self-reorganizing.

*G. Appendix: System Notes*

*Choose three out of the twenty-eight system notes. For each, give an example that demonstrates the rule. Explain briefly.*

Obvious solutions do more harm than good: most people think no further than their nose and no further into the future than tomorrow (me too!). If my child leaves a mess in her room the obvious thing is either for me to clean it up because that is fast, or get her to do it-which is better-but still the motivation is external. The real trick is getting her to want to clean her own room because it is HER space and she likes a clean and tidy space. So thinking longer term I would say and do deeds that reinforce that HER room is HER responsibility-but she can create the space that SHE WANTS in it!

Nothing grows forever: The work of Herman Daly and the emerging transdisciplinary field of Ecological Economics insightfully point out the problems in traditional macroeconomic thought because too many economists fail to recognize the physical limitations of unlimited expansion of the human economy. Donella Meadows and her co-authors also provide excellent analysis of this flaw in mainstream economic thought in their system dynamics-inspired work *Beyond the Limits*.

Don't fight positive feedback, support negative feedback instead: If an academic program in a university is particularly successful (or if jobs in the field are particularly desirable and available), eventually the number of students wishing to enter the program may come to exceed the number the university has the resources to serve. One solution is a cap on enrollment, but raising entrance standards for the program will also serve to limit the number of students in the program and will provide conditions favorable to further improving its quality.

Don't try to control the players, just change the rules: Students should not be cheating at the exams. But, if consequences are small students will still try to cheat. There can even happen extreme situation where almost every student on every exam is cheating. Teachers will loose their enthusiasm about teaching students. Students will believe that knowledge is not important. Therefore, consequences for student that is cheating should be hard-e.g., if a student is cheating, he or she should start the course all over again.

Don't make rules that can't be enforced: I learned that in Germany well. Here what drives me nuts is the proliferation of stop signs to slow drivers down-not really to stop-really to slow them down-and who is checking? The rule is silly because the stop

signs are being misused. And nobody is checking often enough. As a matter of fact driver stop less, and the stop signs become yield signs in the real world because there are too many of them. Too many signs reduces the value of the sign to do what it is intended-actually stop drivers!

Every solution creates new problems: Therapies with long term side effects provide an excellent example of the principle that solutions generate new problems. For example, among the possible causes of peripheral neuropathy is the long-term use of certain drugs, including the analgesics and therapeutic drugs used in controlling rheumatoid arthritis. Consequently the solution to managing one potentially crippling disease contains the problem of the risk of developing another.

Don't be fooled by system cycles: Analysts' inability to recognize that a business cycle downturn is almost certainly likely to occur before the end of the decade is but one example of how quickly people forget (even the experts) that our economy has a long tradition of functioning in a cyclical fashion.

Don't be a boiled frog: Most leaders in industry do not see the crazy systems around them-the crazy and convoluted ways that work is getting done in their organizations. I think this is because they have been there for many years and have slowly adapted to "the ways things are done around here." When these managers are asked to remember their first few days and weeks in a new job and to remember all the ideas they had about making the system better, they tend to remember many of these ideas-and especially how hard it was to get others to accept the ideas even when they made perfect sense. Most people remember that the ideas were never accepted and they are now in the same position of doing the job the same old way and telling the new people that "it won't work around here."

## 2. System Dynamics and Learner-Centered-Learning in K-12 Education

*Give a source of educational ineffectiveness from your personal experience. You do not have to restrict yourself to a K-12 setting. Propose a learner-centered-learning alternative.*

As a high school teacher, I am painfully aware that the basic design of classroom curriculum serves the needs of society more than the individual. Teachers are expected to conform to curriculum standards which set schedules for mastering learning or desired behaviors, ready or not. Much of what is important is glossed over. Much of the trivial is accentuated with little relevance for the individual student. When traditional classrooms are over-saturated with students, we are presenting a detrimental environment for these people as individuals. Classrooms are generally packed with 23 to 25 persons per session. What kind of feedback can be provided? How do we know how each student is doing through other means of evaluation?

Learner centered learning allows for a critical process of discovery to help a learner know, understand, and apply what he has learned and used. Any knowledge divorced from

experience cannot become part of what the learner has learned in the long run. On the other hand, if a learner studies about the dynamics of a certain system, understands what those dynamics are, and then applies what he has learned to practical applications, he will take an active part in his own training. The teacher becomes a facilitator in that process, while the learner becomes more responsible for his own progress. System dynamics helps students see how all of the pieces fit and work together. Computer simulation also helps students to visualize and run models in order to analyze what ways they work and how they might further be able to modify them for other projections.

Students learn conventionally taught information as unconnected facts which are not linked together with one another. As things are in the real world, system dynamics is learner linked.

My best example of educational ineffectiveness comes from my own teaching as a first-year teacher years ago. While my graduate education had included training and mentoring for the teaching of freshman composition and of courses aimed at English majors, I was completely unprepared for sophomore-level general education courses in literature. I quickly learned from my student's glazed over responses to my lectures-and from their failure to read their assignments-that a traditional teacher-centered approach was not going to work-or at least that it worked only for some of the students. Borrowing from techniques used in composition courses, I began putting kids in discussion groups, giving them a list of issues to explore related to the work under consideration. In some classes, the new approach worked fairly well, but in some it was a total disaster. In a typical class, some groups worked well together, some were carried by individual students whose teammates had not read the assignment, and some just wouldn't stick to the task. So both the lecture and the discussion-group structures were ineffective! What is a new teacher to do?

Over the years, I have examined and reexamined my techniques in an attempt to make them more effective. Clearly, I had moved from a method that was too structured to one that was too unstructured. One thing the teams needed was an expected outcome. So instead of asking all the teams to discuss a comprehensive list of study questions, I now give each group a separate task. Whenever possible, I ask two of the groups to take sides on a debatable issue. The teams prepare reports for the entire class, and each team report is followed by general discussion, allowing all students in the class an opportunity to express their ideas. I learned over time that it is important for me to set up groups that are representative of the makeup of the class rather than letting students choose their teams. And to ensure that all members participate, the team report is made by a student that I choose; all members of the team must be ready to make the report. After refining my approach to group work, I have been gratified to find groups of my students sitting in the lounge before class heatedly discussing issues in the literature they read. By providing the teams with clearer goals for their learner-centered activities and by providing a context that made them responsible for their learning, I was able to improve the effectiveness of my sophomore courses.

To answer this question I am going to present the alternative first, then the educational ineffectiveness of this situation. In 1970 my daughter entered the public school system in Seattle, WA. At the time, the traditional classroom was the standard in

the area. The grade school my daughter was to enter was an old school that had been designed and remodeled for an experiment in team teaching. The first-grade classroom held 60 students and about 6 teachers. The students divided into smaller groups at different times of the day based on where they were in the lesson plans. My daughter was an advanced reader, and worked with other students at her same reading level. The advanced students worked on their own, using the teachers for support rather than “teaching.” They would take tests at the end of each session for comprehension. My daughter finished the first grade reading requirements in the first 6 weeks of school. After that she was free to read everything she could from the library. This program left the teachers free to work with less advanced students in even smaller groups.

Now for the problem. The following year we moved to another school district. My daughter was placed in a traditional classroom where she was required to do the assigned lessons and not go beyond. I talked to the teacher about this problem and was told that my daughter could not advance any faster than the teacher was going “to teach.”

When my daughter was in the first grade she was really excited about “learning.” She actively participated in increasing her knowledge. When she reached the second grade, this excitement sort of died off with the traditional “teaching” method.

When I was a K-12 student, Foreign Language learning meant studying grammar rules and doing all sorts of grammar exercises. If you were lucky you would learn a lot about the theory of the language and nothing much about how to use the foreign language in real life.

Project work is one of the student-centered approaches that are being used now in foreign language classrooms. Basically the teacher offers the student a set of tasks to do (for instance, prepare a leaflet describing your town facilities) and the steps to follow in order to get the task done. The students work at their own pace, and the teacher’s role is to provide them with the tools to complete the task.