Systems Thinking and System Dynamics in the CC-STADUS High School Project
(How High School Students Become System Thinkers)

Scott Guthrie
Science Teacher, Wilson High School, Portland, Oregon
Diana Fisher
Mathematics Teacher, Franklin High School, Portland, Oregon

Introduction

This paper will be written from two perspectives, that of a science teacher teaching a year long course in system dynamics modeling, and that of a math teacher teaching the same type of course in another school. The difference in the approach will become evident in this paper. Both authors have been involved with the CC-STADUS Project for many years. Both teachers use STELLA II as the software for designing models.

Introducing Students to Systems Modeling

Mr. Guthrie does a few activities at the beginning of the year to get the students familiar with the STELLA II software. Then they begin building a model interactively, with the teacher. The model is one of a typical money jar system of saving and spending cash. He likes to start with this model because it allows him to introduce exponential input and output in an intuitive manner. It also allows him to promote modeling style early. He has his students follow what he refers to as "The Five Steps of STELLA": (1) What are the objects being manipulated by the model? (2) What are the STOCKS? (3) What are the FLOWS? (4) What information do they need? (5) How are they related?

As the class continues with this activity students are forced to alter the equations in the flow repeatedly to accommodate new factors as they are introduced in the model. He likes this activity because students soon discover the utility of adding parts of equations as converters, connecting them to flows, making the likely equations of a model visually apparent to everyone. By the time the class is through modifying their first simple model, it has become quite complex. This activity is followed by a second model of a hydroelectric dam operation. It also starts simply and becomes increasingly more complex through a series of assignments. Using these two assignments, students discuss the basic objects of STELLA: linear growth and decay, exponential growth and decay, s-shaped growth and decay, and goal seeking.

Mrs. Fisher starts the class with a few weeks of data analysis and curve fitting experiments/exercises. There are four lessons. They are examples of linear, exponential, and quadratic phenomenon where the student either gathers data or is given data that do not fit an exact mathematical equation. The fourth example is one where the student is not told beforehand what type of relationship exists in the data and must use some analytical techniques to decide which type of function might best describe the data. Following this, introductory concepts in system dynamics are introduced and STELLA is used to model a human population in a tutorial format. Students do not learn the necessary skills to build original models using tutorial lessons; however, it is a good method for teaching them to navigate STELLA and shows them an example of a model that makes sense as they build.

Next, students are given the assignment to build a linear, exponential, and convergent model of their choice. Many students develop original topics to use for their models but topic suggestions are provided for those students who seem to be at a loss for ideas. This is their first experience building an original model. Students must explain why the model exhibits the behavior it does and how that translates to the physical description of the problem they were modeling. This is followed by another tutorial, with significantly less direction than the first, where students build a model of the population of the natives of Easter Island during the years 1000 to 1600 AD. Part of the strategy of these early lessons is to expose students to models whose topics are found in other disciplines.

Increasing the Stakes

After working on the Dam model, Mr. Guthrie's class plays the Fish Banks, Ltd. game. This game is one demonstrating natural resource depletion. Students are owners of fish companies competing to maximize their assets. Students eventually over fish the ocean, wiping out the fish and driving their company into bankruptcy. After the game is played through once, he has the students suggest ways to modify the game so they don't deplete the fish. They then play the game a second time, using the student suggested modifications. The second time they manage to save the fish about half of the time. This activity is followed by one where the class builds the Fish Banks model together. The students easily identify the main objects (fish, ships) and build each independently as a "population" model. They put the two model parts together and, after they have it working, they are required to have the fish survive for 100 years. This is the point where the students are actually required to think about the problem in terms of the systems involved. During the construction of the Fish Banks model Mr. Guthrie introduces his students to his four basic steps of model construction: (1) start simple, (2) make it work, (3) add a piece, and (4) repeat steps 2 and 3 until the model represents the situation they are trying to model.

It is also during the construction of the Fish Banks model that Mr. Guthrie introduces his students to the idea of STELLA "objects:" those model structures that seem to repeat themselves in models. Using this approach, the students not only learn to use these structures, but to also recognize them in other models. After they get used to doing this, the conceptual leap to model "archetypes" becomes almost intuitive for them.

The students practice building models using the Five Steps of STELLA and the four basic steps of model construction repeatedly for the rest of the first semester. Examples of other models Mr. Guthrie uses can be found on the CC-STADUS web page (http://www.teleport.com/~sguthrie/cc-stadus.html). They are located under the "Train Yourself to Use STELLA" section.

Mrs. Fisher's class continues in a more structured fashion, as you might expect of a math teacher. Her students complete a series of lessons called "Rainbarrel Activities." These activities were created in collaboration with Dr. Edward Gallaher, a research pharmacologist at the Veteran's Administration Hospital, and professor at Oregon Health Sciences University. The "Rainbarrel Activities" were Dr. Gallaher's idea for introducing a wonderful example of systems modeling using STELLA for the study of pharmacokinetics. Mrs. Fisher developed the curriculum for the class and the students spend almost a month working through various situations involved in filling and emptying a rainbarrel, including simulating faucets, pumps, spigots, rainfall, etc. However, one month is too long to spend on this set of exercises, and it will be allocated less time in the future. The climax of this activity is a set of two real medical situations created by Dr. Gallaher that require students to develop, modify, and analyze models.

The final activity of the first semester is use of the Fish Banks, Ltd. game. As in Mr. Guthrie's class, students play the game and learn that, seemingly "common sense" solutions do not always apply if not applied at the right time, or if not farsighted. The game is only played once, but students are warned of the immanent danger of fish depletion in about the fifth round. Sometimes the class agrees to work as a unit and other times they do not. Invariably, the students want to replay the game and try different strategies, knowing what they learned from the first pass. Instead, Mrs. Fisher suggests building a STELLA model, which is a guided lesson building the MIT Fish Banks model. Students then use some of the activities developed by MIT to accompany the model. They must then devise a solution that maintains the fish population at a stable level and maintain a profit for the fish companies of at least $5000 each year for a period of at least 100 years.

The Second Semester

The main activity of the second semester of each modeling class is the creation of original models by teams of two or three students. Students must determine a problem to study, find data, design a working model, and write a technical paper. This activity reflects the purpose of the course: that students become independent modelers, able to identify the relevant components of a problems, locate the needed resources, design a model, and explain what they have done to someone else. The explanation must contain indication of assumptions, reasons behind the design, and validation of the model.

Mrs. Fisher gives the students a six week schedule to follow in developing their model. The first week, the student is to choose a team, research topics for a model, determine the question the model will try to answer, and locate an expert on the topic. The second week, students are to begin sketching the model diagram, communicate with the expert to get a better idea of how the system operates and a better understanding of the topic, and determine how the data might be useful. Each of these weeks students keep journals of what they accomplish each day. The next two weeks students create their STELLA model, document the equations, and turn in the model, equations, and a complete explanation of how the model works. Each student is responsible for an independent explanation of how the model works. The model is returned with suggestions, especially if it is not working correctly. Students then write their paper (this took over two weeks this year). Finally, their papers are returned and students must make the final corrections.

At various points throughout the modeling process students are graded independently as well ascollectively. The journals are written independently as is the explanation of the model the third week. The paper is written as a team, with each student indicating (on a separate paper) the percent of work they felt each member contributed. The paper is graded but the grades for each student may be different based on the amount of effort expended in completion of the paper. The students are quite honest in their assessments. They know from the outset that this will be part of the evaluation. Also, it is not difficult for the teacher, who has been working with the students through each stage of the process, to know whois doing his/her share of the work. The final week students polish their paper for additional points, producing an impressive product. Students have taken their papers and models to college interviews.

Mr. Guthrie follows much the same strategy, allocating the last quarter for the formal modeling activity. During the third quarter, Mr. Guthrie's class conducts a team building activity using the game Stratagem (by Dennis L. Meadows). The object of the game is to build your country into a First World industrial powerhouse from a Third World agrarian society. The students form teams which run 5 key Ministries of the country. The students then play this game while identifying and diagraming the systems involved in a team effort. After they have played the game, each team builds a model of their sector of the economy. When all of the teams have completed their models, they are then combined, making a working model of the game. This was the first year that Mr. Guthrie used this specific exercise, and it was, unfortunately, cut short by the surprise announcement of the First Annual Sym*Bowl competition (see below).

Mrs. Fisher has her students try to locate an expert on their modeling topic in addition to the otherrequirements. This requires establishing a network of community resources that takes quite a while to develop. Often students want to do models other students have not done, requiring new resource persons to be located each year. Additionally, students must find someone willing to look at their model diagram. Of course, there are not many professionals who are familiar with formal system dynamics nor with the STELLA icons. Finding someone willing to donate the time necessary to learn enough about these topics to communicate with the students is an obstacle; however, it's not insurmountable and it is worth the effort. Fortunately, after a conversation with Dr. Ed Gallaher who had similar needs, a partial solution was developed. He created a short five page paper that gives the layman a quick overview of systems. Mrs. Fisher made some slight modifications to this document and has her students use it to help bring their experts on-line.

Sym*Bowl

A new development this year was the First Annual Sym*Bowl (STELLA System Dynamics Competition) held at Oregon Health Sciences University in Portland, Oregon on April 26, 1996. In preparation for this competition, the organizers, Dr. Ed Gallaher, Mr. Timothy Joy (an english teacher at La Salle High School, Portland, and CC-STADUS trainer), and Dr.Wayne Wakeland (a professor in System Science at Portland State University) created student and teacher outlines of the format for the papers presented in the competition. These documents have helped students produce a well-developed paper and also brought to the fore topics that are essential for students to consider in the design of a worthy model.

Conclusion

Mr. Guthrie and Mrs. Fisher communicate regularly about their successes and frustrations. Mr. Guthrie's students experience the most frustration in the early part of the course when they are trying to learn STELLA and designing their first models. He wants to produce some documents that will ease this transition. Later, however, when students are ready to work on their models in the second semester, they have very little difficulty getting started. Mrs. Fisher's students, on the other hand, have little frustration during the first semester, gaining skill using STELLA and creating small models. There is, unfortunately, a high level of frustration building their first model in the second semester. There needs to be a smoother transition between the activities of the first and second semester. Mr. Guthrie and Mrs. Fisher will work on these problems during the summer.