

Mistakes Made in the Early Years Teaching Students and Teachers to Create System Models

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A workshop at the March 1990 NCCE (Northwest Council for Computer Educators) Conference in Eugene, Oregon was the first exposure I had to system dynamics and the STELLA software. Within ten minutes I knew there was something different about this approach. The visual nature of the STELLA software seemed to clarify the problem characteristics. The following week I purchased the software and began to read the manuals, thinking I would try some problems in my second year algebra class the next month. What follows are the mistakes I made on the journey to teach myself, my students, and other teachers to create STELLA models to study dynamic phenomenon. (Note: Some mistakes relate to experiences in my classroom and others relate to team teaching experiences.)

Mistake: Thinking that I could fit a systems dynamics view into my current view of mathematics. As I tried to design models to replicate the functions that are taught at the high school level in math classes, naturally I relied on the generic function formula to guide me in the design. Unfortunately, I couldn't get the models to work correctly. I knew what graph should be produced. I created tables to check the values. But I couldn't make a natural connection between the function relationship and the model design. The problem was mind set. It wasn't until I began to view functions from the perspective of how they changed over time, from the perspective of the characteristic differential equation, that the pieces fell into place. It was necessary to continue to reread the STELLA manuals and other materials multiple times, trying to look for the common thread that meshed with my training in math. Functions at the high school level (preceding Calculus) are not taught from the perspective of (intuitive) differential equations, and rarely viewed from behavior over time.

Mistake: Thinking that a flow describes a component that causes a stock value to increase or decrease. In many simple models created for and by students it seemed natural to describe a flow as a cause. In some problems it is a description that leads to the desired design. But there are subtle problems with this interpretation that indicate a lack of understanding of the true nature of a flow. A flow is a rate of change of the stock value and so where births "cause" population to increase, acceleration does not "cause" velocity to increase. It must be clear in the mind of those designing the model that the use of causality in describing the flow function is not accurate and can be used only with the realization that it is a temporary crutch for model design, if it is used at all.

Mistake: Thinking that using data to dictate the design of the model would allow correct design for the system under consideration. We place a heavy emphasis on validation of models created. In our efforts to validate our models we began to rely heavily on data obtained for parts of the model being constructed. We came to view the data as the driving force behind how that part of the model should be constructed. This was an error. Using data to validate part of a model is not the same as using the data to dictate how that section of a model should be constructed. Since we had built system models for the major functions studied in high school algebra and calculus courses it followed that when a set of data exhibited a certain growth pattern, the function structure would be used to design the corresponding section of the model. This can be a deceptive analysis, because the pattern in the data, rather than an analysis of why the dynamics of that part of the model produce the given behavior, is dictating the model design. It is important to maintain as the primary focus the analysis of the system and the dynamics/interactions between components. The analysis should prompt the construction of a model which, when exercised,

exhibits the pattern of growth shown in the data. Additionally, the data may represent only a small domain of the behavior of the problem under study. The system may behave as shown in the data only under certain conditions and perhaps only for a given period of time.

Mistake: Thinking that using causal loops as a first stage in the design of a model was useful and necessary. I tried very hard to use causal loops at the beginning of my study of systems and in the introductory lessons I used with students. Most of the books I was reading used them as the first stage in analyzing a problem. What I found was that it took a certain amount of effort to construct an appropriate causal diagram and a considerable amount of effort to construct a STELLA model from a causal diagram. The lack of structure in the causal diagram was the primary impediment. Finally, I threw out the causal diagram exercises and went directly from the problem description to the design of the model using the structured STELLA diagrams. The model design, though still difficult, was much easier. Students who were familiar with the STELLA icons found it much easier to indicate the dependencies, the quantities, and the flows. The reduction in model building effort was significant with the removal of the entire use of causal diagrams in the design process.

Mistake: Thinking that tutorials would help students build models. The first exercise I used with students was one that I had received at the NCCE conference. It was a step-by-step tutorial to build a population model. It seemed easy to follow and the subject was familiar to all the students. It was a natural first exercise. Students were able to follow the directions with little assistance and build the model. There were even able, with some difficulty, to answer questions, analyzing their construction as they proceeded. It seemed deceptively easy. It was. The students followed the directions in the exercise and thought about the small questions they were to answer, but they did not have a broad view of what they were doing. This exercise did not engage them in the thinking that was necessary to create an original model. They viewed the exercise in small, disjointed pieces. Even requiring them to write a summary at the end, analyzing the model, was not sufficient to get them to see the picture in a way that would allow them to create even the simplest original model. Consequently, tutorials are used now only to help students learn to navigate in the software, or to develop small modeling skills, such as adding a new component to one part of a model.

Mistake: Thinking that students could build original models once they had seen a demonstration of such models, as an introductory lesson. As with the tutorials, demonstrating a model in its entirety and explaining how the model was constructed, no matter how intuitive the model, does not prepare students to build original models themselves. This was the way I started with students in the first modeling class that I taught. The students did not engage in the type of thinking needed to create original models when either of these exercises was provided. The exercises may be useful for other purposes. The only method I have found that works to enable my students to create original models is to have them actually create very, very simple models from some problem description and then explain the model that they created. Most students cannot create even moderately sophisticated models after being exposed only to tutorials and/or demonstrations. While there are always a few students who can jump to the creation stage, following a demonstration, we were/are interested in having ALL students in the class create original models. As a consequence, it was necessary to build into the lessons a sequence of exercises requiring students to create and describe simple models exhibiting certain characteristics (linear growth, exponential growth, convergent growth). Not only was this necessary, it turned out to be the first time in the class students began to exercise a creative vision. It continues to be a positive experience. The focus, then, was not only on the creation of the model, but equally on the explanation of the model, both of which were critical at this early stage.

Mistake: Thinking that students could build substantive models after carefully designed lessons that built their skill in the use of STELLA and model analysis and simple model construction. For the first three years, students in the systems modeling

class followed a sequence of carefully designed lessons that built their skill using STELLA to represent certain dynamic phenomenon, and exercised their skill building simple models and analyzing them. But the purpose of the course was to have the students build more substantive models to study a real problem of their own choosing. The transition from the sequenced lessons to the creation of a model for which they had no data nor much idea of a workable design dictated additional exercises. Students needed practice in order to deal with some of the ambiguity that would exist in the latter situation. Fortunately, Scott Guthrie at Wilson High School had created a set of four "STELLA Stories" that supplied the needed experience for the students. These stories describe four different situations: The workings of a hydro-electric dam, the dynamics of water level for a lake, the growth of a city, and the emergence of disease in a population. The story has the necessary data to complete a model but students must search for it and determine how to include each factor in the model. There is enough ambiguity in the story to require creative analysis that was not present in the previous exercises. The practice on a semi-ambiguous situation to model turned out to provide the transition between structured exercises and open-ended model construction for the students.

Mistake: Thinking that the process for creating a substantive original model (topic selection, data acquisition, expert availability) could be structured. As a math teacher, this was and is the most difficult part of the student modeling process to endure. By predisposition and experience, I instruct by attempting to carefully sequence exercises and labs so that students develop ever increasing skill in the analysis of problems they are to study. It has worked well for me in most of the math classes I have taught in my career. But it did not fit what I wanted students to be able to do when completing a modeling course. Since I was not confined to required curriculum, as in all of the other math courses I teach, I decided to experiment with a different approach my second year teaching the modeling course. Some mistakes I will discuss shortly (that occurred during the first year of the modeling course) indicated that, if students were to understand the real process of creating an original model to analyze a non-trivial problem, the process could not be controlled by the teacher. The process of model building involves choosing an appropriate problem that is accessible. Students are limited by their lack of experience and understanding of certain dynamics. If the scenarios presented are those that are precisely defined, they never understand that many good problems are not within their immediate grasp for various reasons. They need to identify what those reasons are, so next time they are able to choose problems more realistically. Next, having chosen a problem that seems within their scope, they need to know that finding data may be a problem. The data may not exist. If it does exist, it may be difficult to find. If it is possible to find, it may not be in a form that is useful to them. A teacher who allows students to choose their own problems cannot know what difficulties will occur with data acquisition in advance. Assuming the data can be located, students find next that they do not understand the system as well as they thought they did. They need someone to help them. Where do they find such a person? How do they communicate with that person? How often will the person be willing to communicate with them, given that it is not part of his/her job description to assist these students? All of these experiences are essential for students if they are to have a realistic view of the beginning of a modeling process. During this phase I just act as another member in each group, making suggestions for finding resources when the students exhaust their ideas. It is extremely important to allow students to "fumble" upon appropriate solutions. If they are ever to take their modeling skill outside of the classroom, they must know what is involved.

Mistake: Thinking that a modeling project could be done by students in 3 weeks. When the first modeling course was taught at Franklin High School, it was only a one semester course. My goal, at that time, was that students would create an original model and write a short explanation of the model. After the series of exercises that were used to build their skill with STELLA and understanding the dynamics of the problems assigned, we had only three weeks left in the course. I thought this would be enough. The students chose fairly simple problems. They were told to use teachers as their only experts. Problems arose trying to collect data. It was difficult for some of the students to get the data in time to create the model for the question they wanted to

study. The questions, in some cases, had to be modified. The time constraint required more structure on my part, leading the students where they needed to go if they were to finish on time. This, although acceptable to the students, since they were used to teachers controlling the direction of instruction, was not what I wanted for the students. I petitioned the curriculum council in the school and was given permission to expand the course to a full year. If I were restricted to a one semester course again, I would follow the sequence of assignments for the first semester that I currently offer, culminating in the student creating a model from the STELLA Story packet. I would not try to have them create original models in a one semester course. Students could, after one semester, work to create original models as independent study assignments, if the teacher is willing to accept this extra responsibility. It is, however, not the desired situation, since most students will still need significant help creating their first substantive original model.

Mistake: Thinking that there were a few pre-selected model ideas that should be used to select as a student's first project. After my initial independent study of STELLA and systems, I came to see certain topics demonstrated repeatedly in the materials I was reading. I thought those were the problems from which the students should choose their original models. When the modeling course was expanded to a full year, and students were given the freedom to choose a problem to study (during the second semester), some students decided to strike out beyond the list of possible topics provided. I was unsure of their ability to find data, an expert, or create a model for their problem. I decided not to limit the students. It turned out to be the correct decision. After six years, students are still deciding to study problems that I have not studied nor seen in the material that I read on systems. I post the titles of previous student models (to help students decide on possible problems to study) and many students take it as a list of what they do not want to do. Many students seem to want to study what has not been done before. They want to make their own mark. So I interfere with their choice only if, after three weeks of effort to get the necessary pieces in place, they are not far enough along to actually be able to finish a model within the required time.

Mistake: Thinking that students could produce a technical explanation of a model without a process to guide them. I found that the explanations given for the students' final model during the first year were inadequate to allow me to determine how well the students understood their models and whether they had tested and analyzed the model performance in various situations. By reflecting upon what I wished students had provided me in their explanations, I developed an outline of what seemed to be a reasonable sequence of questions students should answer when explaining their models. It guided the students in testing their models as well as describing how their model was constructed and how it functioned. It seemed naive of me to think that even our best students would have an intuitive idea of what would make an appropriate explanation. Since the first paper outline was developed, a more extensive outline was created by the Sym*Bowl¹ committee, comprised of an English teacher, a research scientist, and a professor of system science at Portland State University. This outline seems overwhelming at times and is used only in the third quarter, when the students are preparing for the Sym*Bowl modeling competition. Both paper outlines have been very useful.

Mistake: Thinking that students needed a higher level of math training/ understanding to be able to build substantive models. When the modeling class was first designed, the prerequisite for students was concurrent enrollment in second year algebra. This seemed a natural audience, and proved to be a reasonable level of mathematical sophistication for success. After a time it seemed there were some students slipping into the course who did not have this level of mathematical experience and yet seemed to be successful in the course. This year the prerequisite was changed to allow freshmen (approx. 13 years old) to enter the class if they had completed first year algebra with an above average grade. These students have performed

¹Sym*Bowl is a systems modeling competition for high school students, sponsored by Oregon Health Sciences University under the direction of Dr. Ed Gallaher, research pharmacologist. It started in 1996.

exceptionally well in the course. They appear to have no trouble building models, and write reasonably well. This first group of freshmen had to apply for entrance into the course so were not from a typical freshmen student group. We feel lessons involving student creation of models could be introduced to students as young as 11 years old, given an appropriately trained teacher and modified lessons. (STELLA models have been used with students as young as 11 years, but those exercises have involved mostly the manipulation of models.) Additionally, we believe students who are older but not comfortable with math (those not on the college bound track in high school) can benefit from a systems approach to problem analysis. We will have a better sense of systems approach viability in courses for these students in the next few years, since we have some teachers of alternative education classes who will be in our CC-SUSTAIN² program this summer.

Mistake: Thinking that systems concepts are best learned in a lab situation, with students building models individually. In addition to the dynamics studied in a modeling course, STELLA models are being incorporated into traditional classes to assist student exploration of concepts that were not well understood using previously available resources. Originally it was thought that students must create the models from scratch to be able to understand what dynamics are involved. While this has continued to prove true in traditional mathematics classes, algebra through calculus, it has not proven to be the case in some other classes. Ron Zaraza³ reports that certain concepts in physics can elude students if not strongly reinforced by the teacher. In these situations he has found that construction of the early parts of a model as part of a class exercise, in conjunction with the students, is essential to guide students to observe or even consider subtle dynamics. For example, when constructing a model to study the thermodynamics of a cooling cup of coffee, the interplay between heat lost via radiation, conduction and convection could easily become confused or missed entirely. Additionally, Mr. Zaraza has found that when students run models and answer questions, even following packets guiding students to build the model, there is no guarantee that they really understand the connection between the building of the model and the concept they are exploring. He ran an experiment where he developed 5 models on special relativity and tested different approaches with two of his physics classes. The two classes had test averages within a few points of each other previous to this experiment. With one class he had the students work with a "special relativity" packet and answer questions requiring model manipulation. With the other class he built the special relativity models with the students as a group using the overhead projector in the classroom. The second class discussed the models as they were being built. On a test over special relativity, the group that had worked as a class building and discussing the models scored an average 15 points higher than the class that used the packet.

Other useful experiences have occurred when the teacher builds, with the students, a minimal core structure, and then lets the students build upon the structure themselves in a lab. Bear in mind the outcome of these exercises is not to prepare students to create their own original models but to help them understand one desired concept in more depth.

Mistake: Thinking that better math students would more readily accept the use of STELLA modeling over students with less math ability. Having experimented with students who are very successful in traditional math (calculus and pre-calculus classes) and those who have more difficulty or less traditional math knowledge, I have found that the better students seem more resistant to alternate methods of problem representation. I anticipated that students comfortable with traditional equations and mathematical concepts would be comfortable with the concepts regardless of representation; that they would understand the process as well using a

²CC-SUSTAIN is a National Science Foundation grant (Cross-Curricular Systems Using STELLA: Training and Inservice, 1997-2000) that trains high school math, science, and social science teachers to create original STELLA models and accompanying curriculum. It is the sequel to the NSF CC-STADUS grant (Cross-Curricular Systems Thinking and Dynamics Using STELLA, 1993-1997).

³Ron Zaraza is a physics teacher at Wilson High School in Portland, Oregon and co-director (with Diana Fisher) of the CC-SUSTAIN project.

different vehicle for analysis. The reverse was almost the case. It seems that more than a few of the successful students had become successful by mastering the system of instruction used throughout the previous math courses. They seemed less capable in analyzing problems than of mimicking patterns of solutions. They were more resistant to new representations because it took them away from their practiced mode of success. Alternately, those students who were less successful with the traditional approach to studying problems seemed very open to the use of a visual tool like STELLA. These students had less to lose, and the reward in understanding something that had been difficult for them reinforced the use of the tool and the new approach.

Mistake: Thinking that all students would learn better using STELLA because it is visual. When a tool, such as STELLA, provides dramatic opportunity for students to analyze numerous problems that have been previously inaccessible to them, it is easy to forget that not all students are visual learners. Some students just didn't understand the purpose, nor appreciate the visual diagram information that STELLA provided. They were more comfortable in a traditional classroom with a traditional approach. They did not enjoy the systems exercises, nor did they seem to understand the point of analyzing problems from this perspective.

Mistake: Thinking that most teachers would be open to a system dynamics approach. Some teachers were as excited to learn about system dynamics as we were. Those teachers, primarily in science, saw the value of the approach with very little prompting. Other teachers were somewhat interested but, since there were few materials available for direct use in the high school classroom, decided the effort was more than they wanted to expend. A last group was never going to be convinced to consider the possibility of a new approach to teaching their subject matter. We knew early in our efforts to train others that there would be a great deal of energy expended teaching and supporting those professionals who were willing to explore the new approach. These teachers knew that they would need to create the materials to use in their classroom. We knew that once materials became available some of the second group of teachers could be convinced to try a systems approach to some topics in their subject area. We decided not to expend energy on the group that had no interest. Contrary to most educational reform efforts that are enforced from an administrative level, we had the luxury of focusing only on those teachers who were interested. A few years attempting to convert various members of our departments led us to believe that the most effective way to bring systems into high school was to infect those teachers (and students) who were interested and willing to learn. A long term, systems view of infection became our approach. It has worked for us.

Mistake: Thinking that showing teachers system dynamics models and how they are useful is enough to get them to use them in class. Before we received our first National Science Foundation grant, we—my partner Ron Zaraza and I—were giving numerous one hour and three hour presentations/workshops. We wanted to show other teachers the power of the systems approach in math and science. Although some teachers expressed an interest, the small exposure was not enough to get teachers to a level where they understood enough and had practiced enough to take these ideas into their classroom. Teachers needed repeated exposure, time to live and play with the new ideas. They needed materials to use; they needed the software; they needed emotional support. Our efforts would have been near futile had we not received our first NSF grant. The original NSF training time was 3 weeks (which has been reduced to 12 days). We also provided an alternate two day training and have provided one week trainings. We believe 12 days is the minimum time needed for a teacher to have the chance of assimilating a systems approach sufficiently to create original models. This, of course, excludes the fact that some teachers are willing to learn a new concept on their own. Still, it takes repeated practice building models and rethinking problems from a systems perspective to cause a real change in one's approach. The training has proven successful in launching a significant number of teacher into the systems arena. What is needed now is reviewed, published materials appropriate for the grades 7 through 12.

Mistake: Thinking that math, science, and social science teachers were behaviorally similar but with difference primarily in their area of knowledge.

When we first started our training we decided that teaching the early model development with STELLA should be done in separate discipline groups. The rationale was that teachers learned better in their comfort zone, using vocabulary they were familiar with. This proved to be true. What we did not expect was to see how differently each group of teachers learned and how they reacted to the new concepts. I expected that a structured approach would work in each discipline. I expected that each group of trainers would develop a sequence of lessons similar in form, not content, to those developed for the math teachers. Since we had math teachers teaching the math participants, science teachers teaching the science participants and social science teachers teaching the social science participants (for the first two and a half days) the original guidelines became fuzzy immediately upon implementation. Each year we noticed that the behavior of each group was similar to the group the year before but different from each other. The math teachers sat in straight rows and took copious notes, following the lectures and computer lessons carefully. The science teachers would pay only partial attention to the instructor, were determined to sit at the computers during the instruction, and worked on expanding the lessons immediately, before further instruction was provided. The social science teachers wanted to discuss the lessons before working on the computers. We came to realize that each group could not have been instructed, effectively, the same way.

Mistake: Thinking that social science teachers needed to be treated with kid-gloves because they were uncomfortable with numbers. It was true that many of the social science teachers were uncomfortable with the idea that they may have to determine the equations to use in their models. We told them early in the training that this would not be required of them beyond the simplest model construction. What we did not expect was their quick appreciation of the diagrammatic approach to model design. Additionally they were excited to have a method to study the system issues that abound in the social studies curriculum. Some of them had latent or dormant numerical ability that emerged as they practiced creating models. These teachers do not, however, often create original models for subsequent classroom use without the help of a math or science teacher. The social issues that the social science teachers want to tackle are often so involved, they tend to create models that are too large, initially. It is usually necessary to have them backtrack to a simple core model, define the components appropriately, and add to the model in small, incremental steps.

Mistake: Thinking that math teachers would be eager and excited about working in cross-discipline teams. The math teachers brought us the most surprises. We did not anticipate, the first year of the training, that the math teachers would balk at joining any of the cross-discipline teams for the creation of the final model project. We thought that math teachers would be interested in learning applications of modeling that were not directly within their scope. We thought that these teachers would find the function structures, which comprised subparts of the model, useful for their purposes. What we found was that the math teachers were uncomfortable working with applications about which they knew little. They wanted to remain in the abstract world of functions and/or create models that had direct connection to their math classroom. These teachers were not used to playing a secondary/supportive role in model building. Eventually, we found that we needed to prepare math teachers for the realization that, when dealing with cross-discipline modeling, no topics were going to be within the narrow scope of the traditional mathematics curriculum. Most of the modeling topics were going to come from the science or the social science curriculum. The math teachers had to accept that their main function was to get the model constructed properly so it would work appropriately. This was no insignificant task, but it was not what they expected. Eventually, these teacher found ways to use the cross-discipline models for their purposes. They needed to be the most resourceful of all the teachers in applying the final model to their curriculum. They needed to be the most courageous because more was expected of them out of their comfort zone.

Mistake: Thinking that math teachers would see the simplicity in the approach and the consistency between system dynamics and calculus. The math teachers who participated in the summer NSF systems training had less difficulty with this issue than other math teachers who were just attending a short systems workshop or those who had just heard others talk about this approach informally. Math teachers are a stubborn lot. I should have remembered how long it took me to change my view of functions. Of course, I thought it took so long because I had no one to talk to about the new perspective. I only had books. I thought that explaining what I discovered to other math teachers would make them as excited as I was about this new approach. The summer participants came with the expectation of learning something new and were more open to the systems perspective. Within the math department at Franklin it has taken seven years to convince a majority of teachers in the department to try this new approach. What convinced these teachers was not what I told them. It was what they were seeing the students accomplish. The students are the best advocates for a systems approach. One rather traditional, excellent teacher, queried one of my modeling students about her model. This student had been in his class the previous year and was a good, but not exceptional student. As he questioned her about her model she was able to answer his questions without effort. He came to realize that she really did understand what she was doing, and came to appreciate that there may be something to the creation of systems models (with a visual interface). He is taking the training this summer. Getting math teachers to give up an equation interface to problem analysis is not easy. They have to see both the diagrammatic and equation representations together before they will even consider the former a valid avenue of study. Then it is necessary to convince them that they should provide students experience using both representations to analyze problems. The tide appears to be turning in math. Interest has grown in significant proportions the last two years.

This list represents some of the more significant mistakes that have been made in an effort to bring system dynamics modeling into the pre-college classroom. Unfortunately, I continue to make mistakes, just different ones. Hopefully, this list will help others who are trying to expand the use of this powerful approach. It continues to be a worthwhile journey. I need only look at what my students can do to keep me going.

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