Experiences in Developing Single–Discipline and Cross–Curricular Models for Classroom Use

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Abstract
In the three years of the CC–STADUS Project more than thirty cross–curricular and one hundred single discipline models have been developed by project staff and participants. These models and their accompanying curriculum are intended to expose students to the use of system dynamics as a problem-solving tool, as well as to address the problems presented in their specific content. Patterns have emerged that point out the dangers and advantages of both types of models. In part, these patterns are a result of the techniques used to teach the teachers basic modeling skills, as well as their needs in the classroom. The experiences of the CC–STADUS staff and participants lead to recommendations and suggestions for model development, model documentation, and training programs for teachers.

Increased use of system dynamics in the K-12 educational environment has been a goal of many in the system dynamics community for a number of years. The rationale has been that learning to think from a systems perspective and to problem solve through understanding the system being studied, when begun at an earlier age, would allow students to become better thinkers and learners, as well as to become system thinkers.

The CC–STADUS (Cross Curricular Systems Thinking and Dynamics Using STELLA) Project is one effort to introduce systems concepts to teachers and students in the pre-college environment. Its focus and methodology are good reflections of assumptions that seem rather widespread among educators working with system dynamics. These assumptions can be summarized rather simply:

- Teachers and students learn new concepts and tools best by actually using them to address problems.
- Models are most likely to be used by teachers if they are actually involved in building or modifying those models.
- The highest and most important use of systems concepts is in a multi-disciplinary environment, or as a second-best case, examining a multi-disciplinary problem in a single discipline course. This use emphasizes the complexity and inter-connectedness of real world problems. It also demonstrates the unique ability of systems dynamics to address such problems.

These assumptions directly affected the evolution of the CC–STADUS program. A major goal was to develop basic modeling skills in our teachers, allowing them to build and understand relatively simple models. In the three-week institute teachers spend most of their time “hands-on", being directed through the building of models or building models of their own design. Another goal was to develop a “library” of major cross-curricular models for use in the classroom. Teachers leave the summer institute with a major multi-disciplinary model that they constructed with a team of other participants, as well as other cross-curricular models developed by previous participants in the project.

Our expectation has been that participants in the summer institute will use modeling in their classrooms the next year. The success rate has been high (70%+) when compared to patterns of implementation experienced by many NSF institutes. What has been surprising, however, has been the type of model used by the teachers. We anticipated that the large models developed in the summer would be used by most of their creators. In fact, that has often not been the case. While teachers who have developed a specific cross-curricular model are more likely to use it than other participants, all teachers are more likely to use much simpler models that are specific to their content areas. Many of these models are similar to or based upon those models that teachers built in the earliest part of the summer institute, while working in their own content group.

Emphasis on simple models with one, or at most two stocks, and on basic concepts within a discipline, may appear to some as a step backward from learning about systems. The models may be so simple that they can be easily explained with linear or quadratic equations. The systems described have so few links as to scarcely seem to be true systems. However, it is important to remember that the focus should be on developing an understanding of both the tools and process of systems thinking. Most classrooms are still single–discipline environments. Working with models in that environment, teachers can build their expertise within their own "comfort zone", their field of specialization. The increase in the expertise with which they use modeling concepts and language makes possible communications with other disciplines through the language of modeling. The focus on both tools and process can be enhanced by looking at the simplest cases first, an approach reflected by the first few days of the CC–STADUS summer institute. When teaching an adolescent to drive, putting them in a complex Formula 1 car, part of a race at speed up to 300 km/hr, would not be the best first step. Instead, we start them out in simulators, parking lots, enclosed courses, or quiet residential streets. The same is true of systems dynamics. Our students can start by using larger models to explore complicated situations. However, in doing so they are frequently using the model as a "black box", a device that yields results without involving students in understanding the model itself. They may learn a little about the system portrayed by the model, but they do not necessarily learn about that system in depth, nor do they learn about systems in general. By starting with simpler systems, they learn how systems work. Then, when confronted with larger problems and models, their understanding is enhanced because they can see the systems within the systems. This seems to be a powerful argument for emphasizing use of simple systems with students and, at least initially, ignoring the very exciting larger models that have been developed.

While systems may allow us to address the large problems facing society in our classes, it is important not to lose sight of the process of problem solving. The tools that system dynamics gives us seem so powerful that we have a natural temptation to immediately try to use them on problems "worthy" of their power. This tendency has been observed by every group that teaches modeling. Students, whether eighth graders, high school students, college students, or teachers, begin trying to model far too complicated systems as soon as they learn how to connect a flows to stocks. Rather than concentrating on models of simple systems, novice modelers attempt to model complex systems, "interesting systems", with far too much detail. The result is a sense of frustration and can lead to dissatisfaction with the idea of modeling. The focus of the CC–STADUS project on the cross-curricular models has lead to an emphasis on these more complicated models. While excellent representations of fairly complex systems, they are comparatively hard to understand in detail, and hard to explain to students. Additionally, they are not very adaptable within the current curricular environment. It appears that teachers who have gone through the institute intuitively move away from the models when confronted with the need to use them with students. Instead they focus on simpler models and simple systems.

This tendency does not weaken the development of modeling and systems in their classes. By working with simple systems, students begin to look at even simple problems from the analytical perspective of system dynamics. They will begin to look at more complicated problems as combinations of systems. The key is to use the language of systems in approaching the simple problems. This will effect a shift in the way we think about problems. This shift is consistent with the reform recommendations currently being proposed in most disciplines. If models are simply used as a substitute for traditional mathematics or presentations without developing the understanding of the system (as might be the case when models are a “black box”), then there is no development of systems thinking. However, even simple linear models, when used in conjunction with systems language and concepts, can lead to a growing mastery of systems thinking.

This was beautifully illustrated in a Conceptual Physics class taught by one of our Principal Investigators. Students were looking at the differences between classical and relativistic mechanics at near light speed. They looked at a simple linear model of relativistic momentum, then one of relativistic momentum. The core of both models was the same, a **force** flow that increased momentum over time. However, the relativistic model included converters that adjusted the velocity for relativistic changes in mass. Students looked at the output graphs of momentum, which were identical, and the velocity graphs, which were different. They immediately began to talk about what had to be different *in the relativistic* ***system!*** They concluded that something had to be happening to the mass, namely, that the mass must be increasing. Their reasons focused on the fact that the system as a whole (the momentum) appeared to be reacting the same in both cases, so something that was not obvious within the system had to be changing. They arrived at a very sophisticated conclusion by looking at the system result.

Increasing emphasis on introducing students to system dynamics through simple models does not mean that the more complex cross-curricular models of the type developed in the CC–STADUS institute should be ignored. Their power and interest are what may actually attract teachers to look at system dynamics. However, they should only be used after some basic understanding of systems has been attained. Otherwise, while interesting and useful in themselves, they may contribute little or nothing to students' understanding of systems. It takes some time and experience for teachers to transfer what they know about their discipline to systems.

Interest in the development of these more complicated models has been driven by the work of Frank Draper, commercial products like Fishbanks, and the set of Plagues and People models developed by Heinbokel and Potash. These models deal with complex and important issues, and encourage use of system dynamics to address other vital and interesting issues. However, the use of other complex models often focuses students on the problem, rather than the system. They are often content rich and very specific, limiting their utility. Most documentation in these models has focused on the specifics of the problem being addressed, rather than on the structure of the system.

Documentation of models remains the weakest link in the process of learning systems. The documentation for most models, whether simple or complex, tends to focus on the content of the model. Thus, it consists of information like “the growth fraction of .035 is based on data from…” Actual explanation of the model structure, as well as numerical model details, is necessary for others to use models. In single content area models, the implicit assumption seems to be that anyone competent in this field understands the structure. Too often that assumption is made by a person who is probably more advanced in systems than the prospective user, and quite possibly more skilled in the content as well. It is essential, on all models, that documentation be improved so that both content and systems information are provided to the user. Additionally, more emphasis must be put on validation of models. It is vital that models accurately represent the system being modeled. It is equally important that behaviors are the result of the model design rather than artifacts of the integration engine.

The three years of work done by the staff and participants in the CC–STADUS project allow us to draw some general conclusions about appropriate model development. Our plan and instincts divided our emphasis. It was clear that teachers first had to master basic modeling before they could take on more ambitious projects. However, once a very basic level of mastery was attained, our focus shifted strongly to more complicated models. The experiences of our teachers show that more emphasis must be put on continually developing simple, content specific models. These are used far more often than the cross-curricular models, and in fact are the building blocks that will develop an understanding of system dynamics, allowing students to maximize the benefits of the cross-curricular models when they finally see them. It is also necessary to increase support of teachers during implementation of systems in their classroom.

As a reflection of this realization, in the summer 1995, participants were encouraged to start a simple model before leaving the institute. Our work with individual teachers during the year has focused on developing such simple models for use in their classroom. Additionally, in this interim year for the project, experienced modelers will be developing sets of simple, content specific models for physics, chemistry, earth science, literature, and history. This should yield a base of usable, easily modified models that will facilitate teachers getting started in systems in their classroom. These models will include suggested answers which will provide a basis for comparison with class results.

The summer 1996 institute will feature slightly altered training. The session will be reduced from fifteen to twelve days. During the school year participants will attend three Saturday sessions. These sessions, held in the fall, winter, and spring, will deal primarily with the problems of implementing systems in the classroom, There will be particular emphasis on building, modifying, and using simple models. These meetings will provide an opportunity for participants to discuss their successes and problems.

This does not suggest that a continued emphasis on larger, cross-curricular models should be abandoned. Those models are valuable once a teacher or group of teachers has used system dynamics with students long enough for systems thinking to begin to develop. However, these models are difficult for a single individual to develop. Most have neither the varied expertise, nor the time to construct a larger model. Institutes and workshops like the CC–STADUS project and the work done at Trinity College in Vermont present ideal environments for developing such models. Work on those models should continue, providing a wide range of models available for use as teacher and student sophistication grows.

For pre-college use of systems to grow more rapidly, there must be a significant emphasis on developing and releasing simple, content specific models and curriculum. At the same time, those projects that can actually assemble groups of modelers must continue to develop cross-curricular models so they will be available as the need and demand grow with the spread of systems thinking.

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