Modeling in the Educational Environment - Moving from Simplicity to Complexity

Ron Zaraza
CC–SUSTAIN Project
Co–Director
Wilson HS
1151 SW Vermont
Portland OR 97219
(503) 235–2745
rzaraza@pps.k12.or.us

Tim Joy
CC–SUSTAIN Project
Core Team member
La Salle HS
11999 SE Fuller Ave
Milwaukie OR 97222
(503) 659–4155
lasalle4@northwest.com

Scott Guthrie
CC–SUSTAIN Project
Core Team Mmember
Wilson HS
1151 SW Vermont
 Portland OR 97219
(503) 916–5280
sguthrie@teleport.com

For many educators, dynamic modeling is a seductively exciting approach to exploring problems. It allows formerly unapproachable problems to be addressed. It brings the power of numerical results (although sometimes of questionable validity) to disciplines and problems that normally are non–quantitative. Further, it allows a problem to be explored in exhaustive detail without having to do lengthy and involved calculations – the computer and software do the drudge work, the modeler merely designs and outlines the process. Using higher level software like PowerSim and STELLA, even the little computer programming done is fairly simple compared to traditional line–code based software.

These factors lead teachers to adopt model building and model use practices that may actually be counterproductive:
- When building models, teachers tend to begin with models that are too complex. They put in details before they understand how the model truly behaves. As a result, their understanding of model behavior is often questionable.
- To get the "right results", they tend to use converters and involved computation rather than models of real dynamic behavior. Model behavior is controlled by exogenous rather than endogenous factors.
- Teachers often have students work only with completed models, that is, they neither build the model in front of the students nor guide students through building the model. This does not allow students to understand the development of the model. Understanding the development often helps them understand the system the model represents.
- Students may be given detailed instructions for either building or using models that some have characterized as nothing more than "electronic worksheets", little more interesting or effective than the much maligned "dittos". Students complete the task, but what they have learned is not clear.

Perhaps even more dangerous than these questionable practices, however, is the tendency to develop models with an unnecessarily high level of complexity that are then used in whole class or individual student situations. In many cases, these more complex models become little more than "black boxes" in which input values are mysteriously converted to a graph or data table whose values are used to answer questions. These models are difficult to understand because of their complexity.

When used to deal with specific problems, such models do little more than produce numerical results. They often do not aid in understanding the problem's solution. Further, they do nothing to build understanding of the system. When used in activities designed to explore a system, their complexity drives students away from attempting to understand the system. The model diagram is as intimidating as a problem expressed in differential equations would be to the average humanities major. The model confuses through its complexity rather than clarifies through its structure. In spite of these difficulties, the lure of complex, detailed models is powerful. The sense is that greater complexity indicates more accuracy, a better model, more validity, and a more complete understanding of the system involved. While the last trait may be true for the builder of the model, complexity often results in the exact opposite for the user. This reality is a strong argument for adopting a simple rule for both using and building educational models: **Always begin with the simplest model and build complexity gradually, ending with the simplest model that serves your purpose**. And of course, be clear about your purpose. Don't make it too ambitious. Additional complexity may provide ego-gratification, but is of questionable utility as a teaching or thinking tool.

This approach is valid whether developing models to be used later in class, building models in a group environment with students, or directing student work. The progression of models from extremely simple to higher and higher complexity allows both modeler and user to fully understand the entire model. When this practice is included as part of the group development of a model of a system, the class interaction can develop greater depth of understanding of the system than building only the final model would. The progression allows model boundaries, levels of aggregation, leverage points and feedback loops to be understood by developing their functional importance step by step. They can be discussed as they come into play.

Each discipline in which models are used has topics which lend themselves to this approach. Consider a classic problem in thermodynamics which is often modeled:
> *You are given a cup of very hot coffee. You have to run a quick errand down the hall and will drink the coffee when you return in 10-15 minutes. You drink cream with your coffee. Should you add the cream now, or when you return? You want the coffee to be as hot as possible when you drink it.*

The temptation is to try immediately to build a model which includes all three types of heat flow, convection, conduction, and radiation. Doing so, however, actually can result in less understanding of the process than is really desirable. What makes the problem more complex is the fact that each of the rates affects how the other rates change. This is only clear if each heat flow is looked at separately. Building conduction, convection, and radiation models separately shows how much heat is lost in a given time period by each process. Combining all three processes in a single model (which, incidentally, almost always results in a simpler model than one built from scratch to show all three processes) reveals that the actual heat loss from each process is less than the single models show. This result is not intuitive or obvious for most students. The interrelationships of the system becomes more obvious. The understanding gained is greater.

Population models present a variety of options to explore increasing complexity. In particular, they provide an excellent example of a simplicity —>complexity progression that can be developed when starting with a system–focused problem that serves as a

trigger for exploration of a complex system. Some global studies classes begin with a simple population model (figure 1) that shows incredible growth. The model can then be modified to look at land per person over time (figure 2) by the simple addition of converters. The graphs produced by this model usually generate more questions. These can be addressed by further modifying the model to include types of land (arable, forest, infrastructure, desert, etc.) or simply discussing these land types. Students may want to develop stock-flow diagrams to deal with transfer of land from one category to another. Either option leads to more detailed understanding of the role of land in population problems.
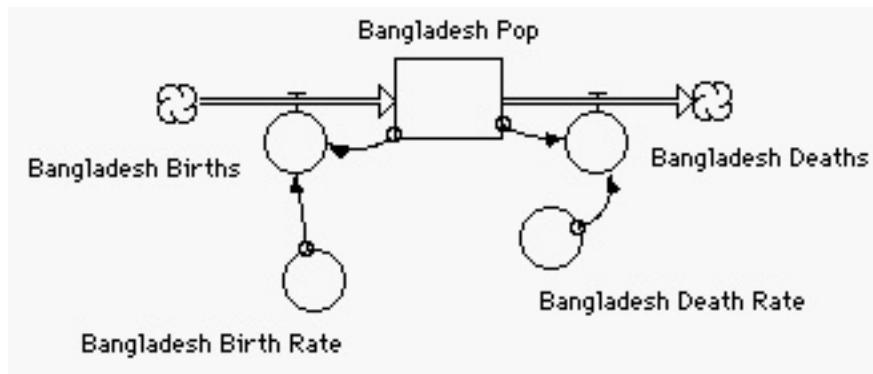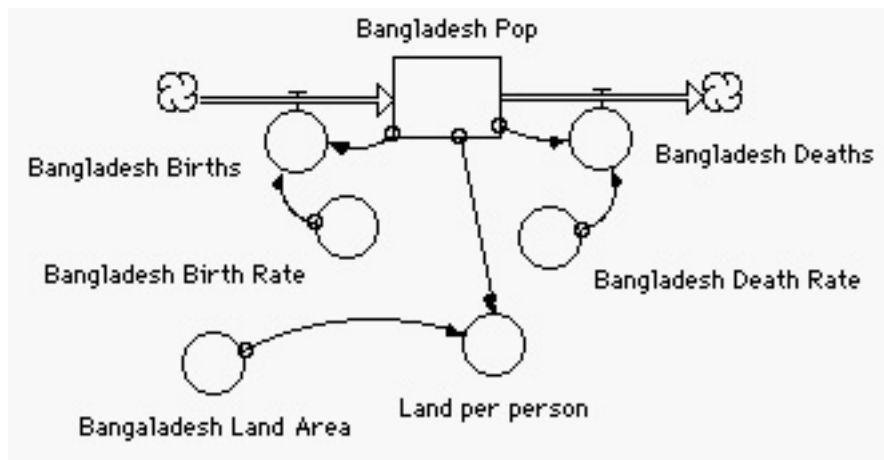
Figure 1

Figure 2

Similar patterns can be followed with food consumption and production. Again, whether through discussion of additional modeling or a simple population model with a few converters (figure 3), the system is explored in more depth.
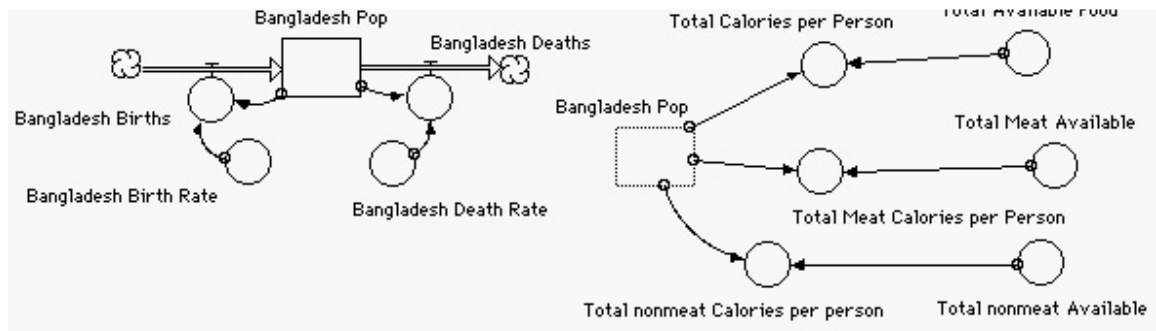
Figure 3

Other pieces, as required, can be added to the model, while some may be removed. Teachers and students have included simple converters or stock–flow diagrams to represent immigration and emigration, industrialization, political and religious movements, shifts in cultural biases, shifts in diet, and other factors. The options are only limited by the time and effort allotted for exploration. Extremely complex and information–rich models can grow out of a very simple beginning.

The simple population model can also be a starting point for dealing with a very specific problem. A student participating in SyM*Bowl, a dynamic modeling competition for high school students, chose to explore the impact of China's "One–Child per Family" population policy. Initially his work was designed to see if the policy was truly being implemented and whether or not it would be successful in controlling or reducing China's population. The simple model and a slightly more complex one tracking population by gender, revealed that culturally driven demographic shifts would have much more impact than the actual reductions in crude birth rate achieved by 1992 would imply. That required a significantly more complex model in which the male and female population models were broken into submodels based on population cohorts. The student's final model appears quite complex (one of the six sub-models is shown in figure 4). His work is an example both of the idea that complexity is best built from a simple start and that the "appropriate level of complexity", that is, the level demanded by the problem, can end up being quite high.
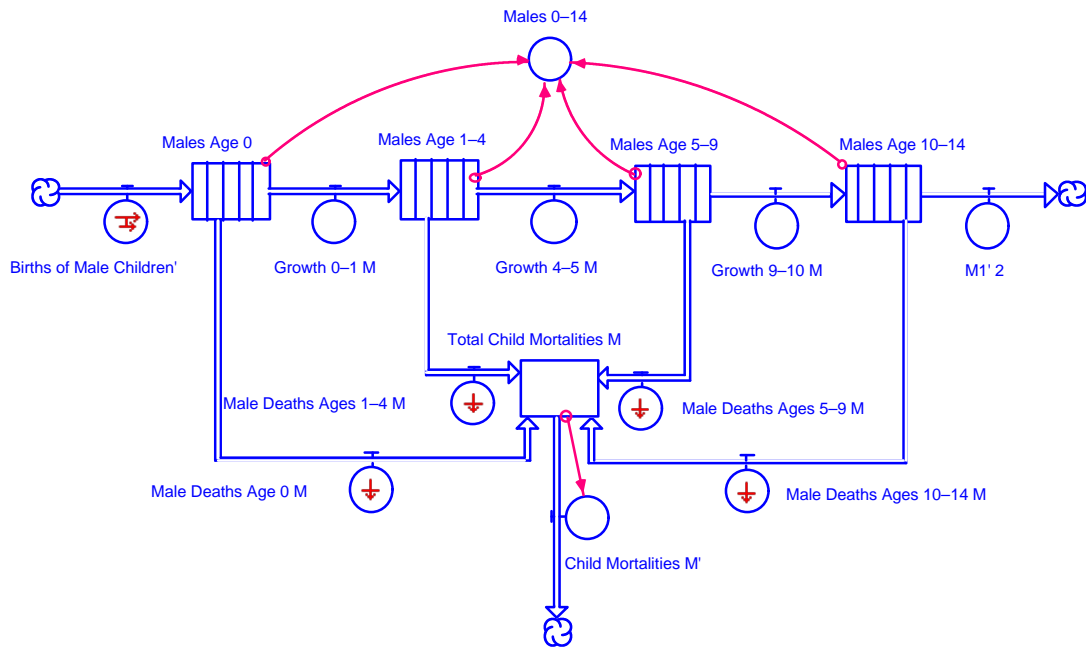
Figure 4

All content areas taught at the secondary levels have similar examples of problems and systems that can begin simple and have complexity added gradually. The process of moving from simplicity to complexity has an obvious cost—more time is needed to cover a problem or idea. The gain is greater comprehension of both the problem and the system. An additional gain is a gradually increasing understanding of the basic concepts of system dynamics, a goal that underlies all educational work with systems.

Emphasis on beginning with simplicity should not be construed as advocacy against complex models. They have their place, but that place is not as common as current practice might suggest. The purpose of using models in the classroom is to explore ideas, problems, and systems. The ability to generate numerical values sometimes blinds teachers to the fact that learning, when using models, occurs two ways. Model results answer questions and can pose new questions. However, the structure of well designed models can build an understanding of the model and the system they are designed to represent. Complex models frustrate this process. Simple models progressing to appropriate complexity facilitate the process.