Creating Content Specific Lessons Incorporating System Dynamics Models

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Lessons designed to incorporate system dynamics models provide students another means to explore, absorb, and retain core content in various subjects (specifically mathematics, social science, biology, and physics[1]) taught at the secondary[2] level of instruction. The type of lesson used depends upon various factors, and should be expected to produce testable results consistent with the purpose of the lesson. At this point lessons seem to group into four categories.

<u>Level 1 Lessons:</u> In the first category are those introductory system dynamics lessons designed to reinforce a content topic which easily lends itself to SD analysis. One such topic is the observation of growth or decay patterns over time. This is basic to the study of algebra and especially calculus, to biology, environmental science, and the physics of motion, among others. Lessons in this category will usually include analysis of graphical representations of the change of important characters[3] being studied. Students at the secondary level should be very comfortable analyzing graphs, since this is a skill developed long before grade 9. At the secondary level, however, the analysis is refined by the attention paid to the type of growth or decay being represented for different segments of the domain of the graph and, if the pattern changes, why it changes

For example,

figure 1.

In these lessons students might be given a brief scenario and asked to identify the important characters in the sketch, choose one character and sketch a graph of the growth or decay of that quantity over the course of the time frame suggested in the scenario. Or students could be given a graph and a suggestion as to context and be asked to explain what could be happening to create a given pattern of growth and decay.

Still in the level one lessons a modeling tool, such as STELLA, would probably be introduced. In these lessons simple generic structures that produce simple growth and decay behaviors would be included. The lessons would require students to learn to design the structure to match a given pattern of behavior (as explained in a written description or displayed in a graph). Students may or may not be taken to a lab to execute the design. The structure would be introduced in parallel with a traditional method of identifying the behavior pattern. For some classes the traditional method might be just a graphical display. In mathematics it would be identification of the equation as well as use of a graphical display. The purpose of the lesson is to introduce an alternative representation for expressing the structure underlying the behavior pattern. The lessons usually concentrate on having the student demonstrate skill in using multiple representations of core (simple) patterns.

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[1]There are more subjects to which system dynamics analysis has been applied at the secondary level, but the ones mentioned are those with which I am the most familiar.
[2]grades 9 - 12 (ages 15 to 18)
[3]By characters I mean the most important entities involved in the scenario, not specific people.

For example: in biology student might be given the following structure and asked what behavior would be produced, and why:

> figure 2.

In math students might be given the following description and be asked to build the structure and indicated what each component of the structure represented and how each should be defined. Then they would be required to write the corresponding mathematical equation.

> figure 3.

In introductory lessons simple variations in growth and decay would be explored. For instance, what is the difference, over time, between doubling a linear growth rate versus doubling an exponential growth rate? What part does altering the initial amount of a quantity play in it's pattern of growth or decay? What effect does time duration play in growth or decay? Comparisons of different simple patterns of growth/decay, such as money added to a bank account versus money added that does not accrue interest, might be made in an algebra class.

In each of these initial lessons students would be expected to perform simple well-defined tasks similar to the lessons they experienced. No previous experience with the pattern concepts or modeling software would be necessary for students to complete assessments.

Level 2 Lessons: A second category of lessons involves the study of behaviors that are no longer simple growth or decay. In this category content concepts graduate to a level requiring more sophisticated interaction between characters. In biology, a carrying capacity might be considered, or some cap on a resource that changes a growth pattern over time. In any event, some discussion of feedback, whether identified as feedback or not, will be incorporated into the scenario. In math, although convergent, logistic, and oscillatory equations are studied in some second year algebra classes, most scenarios of this type are reserved for pre calculus, since the equations are so difficult for many students to manipulate. Using SD modeling structures, second year algebra class lessons can include these more sophisticated patterns.

It is at the level two lesson that the few system dynamics concepts and model structures introduced in the level one lessons begins to reap reward. Using the modeling structures students now have a vehicle for conceptualizing how carrying capacity might actually play out in an environment. In a social studies classroom a simple resource structure can be added to a population structure and multiple scenarios can be simulated.

For example: A global studies class at Franklin High School in Portland, Oregon was broken into groups, each choosing a different country. A simple population structure was created for each country. One resource, available land, was added to the model to determine what might happen over the next hundred years, if the population grew at its current rate. Then another resource, potable water, was added. Although the third component was added, it was never made into a working model. The point of the sequence of lessons centered around the discussions about which resource components to consider, what the constraints might be on that resource, and how the resource availability might affect the overall population over 100 years.

The students did not build the model initially, but rather the class began with a discussion about factors that affect the growth of a population. A simple population model was built as part of the discussion. Topics about factors limiting growth ensued. Students were then given assignments to choose a country and find some data pertinent to the discussion. Then another class discussion occurred two days later as the model was enlarged to include the land component. Students then formed groups and built their population & land models, altering factors to determine how outcomes might be affected. Another class discussion occurred the following day where the suggestion that amount of potable water be added to the model. This was the last lesson, since the time allotted for this activity had expired, but students were beginning to get a feeling for the number of factors that were acting to affect population growth.

figure 4.

Another example of a second level lesson in several second year algebra classes at Wilson High School in Portland, Oregon involved two simple growth patters (linear and exponential), connected to allow the students to study pharmacokinetic[4] models. Students work through simple lessons for two days in an all-class discussion, culminating with the sequential development of a two compartment pharmacokinetic model. Then they are given a packet that describes alcohol consumption. Students are to build the model in the lab and test and explain the behavior caused by altering certain parameters. The scenario is reasonably accurate and provides students an exposure to body metabolism that would be beyond their reach with equations at second year algebra level.

figure 5.

Assessment here could involve writing an explanation, given a scenario similar in structure to one studied, where students would describe limiting factors on population growth. Or students could be given a population model structure and be asked to select an important resource structure and draw the resource structure, connecting it correctly to the population structure. They might be asked to explain their reasoning for the final structure. This could be a paper and pencil assessment.

An assessment for the algebra experience could require the students to describe factors that affect blood alcohol level (BAC). Students could be given a BAC situation not included in their packet, but related, and be asked to sketch a comparative graph if a key parameter were changed, explaining why they thought the graph would be accurate. Alternately, a scenario could be idescribed, such as, a police officer stops a motorist who is believed to have been drinking. A breathalyzer test is given and the person registers above the legal limit for driving. The person argues that he just left the bar, he only had 6 beers over the past two hours, and so his BAC level is dropping quickly. What facts should the police officer consider when writing his report to fully describe the intoxication level of the driver in this incident?

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[4]Thanks go to Dr. Ed Gallaher for his work designing pharmacokinetic models using STELLA for his drug research and instruction to medical students at Oregon Health Sciences University in Portland, Oregon. Dr. Gallaher has work with the CC-STADUS and CC-SUSTAIN NSF grant participants to teach high school teachers to build and use simple pharmacokinetic models. The models used with the second year algebra students were developed based on his information.

In the second level lessons emphasis is on interaction of characters and understanding how and why behavior is altered due to the interaction. Assessment then would concentrate on explanations of the interactions.

Level 3 Lessons: A third level of lesson is one where students have had enough experience with simple first and second level behavior patterns that they can, when given a scenario, create a simple model to explore the dynamics of the interactions. There are not many secondary school classrooms where this level is evident. One way to operate at this level is to have the course content taught hand in hand with modeling throughout the class. Schools that have had system dynamics modeling courses have students who are capable of learning at this level when entering a more traditional class. But students who have not had previous experience with system dynamic analysis of behavior, nor had modeling experience with tools such as STELLA can function at this level if the class is covering a significant amount of content. Rather, classes where level 3 lessons occur usually focus on some "few" foundation concepts over the course of a year (or semester) and explore those concepts in more detail. Examples of classes of this type are the Environmental Biology class and the Science, Technology, and Society class taught at Wilson High School in Portland, Oregon. For a more complete discussion of the design of these classes please see the paper "   " by Ron Zaraza.

Although having a course taught as described above is a desirable way to reach this level, it is not the only way. If students have had experience via level one and level two lessons, or have had a year of system dynamics modeling, it is possible to provide projects for students to do outside of class. Those projects would require the building of system dynamics models and analysis of behavior and interactions involved in the project scenario. Such lessons would describe a scenario in enough detail that the student can reasonable build and analyze the model in a few weeks working outside of class. It is not possible to provide the needed time for this level of lesson within the class period (in most classes).

Some examples of this type of lesson would be:
in math: bank account (checking with savings) models, bank account and loan models, predator/prey models, epidemic models, supply/demand models.

figure 6

in biology: predator/prey models
in physics: skydiver models

figure 7

Level 4 Lessons: The fourth, and final level of lessons involves the ability to summon a (non-trivial) generic structure, when a discussion of certain behavior patterns appear, regardless of context in which it is presented. In this type of lesson a student would be requested to create scenarios and structures that would reasonably replicate the (non-trivial) behavior of a given type and explain why it should work that way. In class, students might be asked to read an article pertinent to course content and be asked to proceed to create a model structure on the spot that might serve as the core of the behavior demonstrated. This would mean that the student has internalized the modeling process enough to use it as a ready tool of analysis. The student would start with the creation of some reference behavior graph and, perhaps from discussions with other students, formulate a structure that would be a reasonable core model. Typically the structure

would emanate from a group of generic structures the student has studied. This type of lesson could reasonably be part of a social studies, political issues or environmental studies class. It would not be likely to occur in any mathematics class at the secondary school level. Students in some first and more second year system dynamics modeling courses experience lessons at this level. To reach this lesson level in other, more traditional classes, a more system dynamics saturated curriculum across disciplines would be required .

Not every subject would start with level one lessons. Mathematics would. Environmental science might. Physics might. Social studies probably would start with level two lessons.   This points to the need for a multi-disciplinary approach. Not only because system dynamics is inherently multi-disciplinary, but because one needs to enter a traditional curriculum at the highest leverage points. Those points were SD strategies and tools fit most naturally and produce the most significant, short term results. The long term results will take care of themselves as long as there are continual exposure points. Start small.

A final note: There is a specific need to conduct analysis of retention and depth of understanding using accepted research strategies for comparison of a new method of instruction, using new tools, like system dynamics models. This would be the task, perhaps of some doctoral candidates. At this point those of us who have incorporated such techniques and tool into our instruction DO see a difference, but yet do NOT have the data that will convince the general community of secondary educators.