DEVELOPING SYSTEM DYNAMICS SKILLS TO SUPPORT A CONTENT-BASED CURRICULUM

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Abstract

The most productive uses of system dynamics within the curriculum involve student construction or significant exploration of dynamic computer simulation models. This supports both the content development and the development of system dynamics skills transferable to other disciplines. A limitation to such uses, however, can be the time and effort required to bring the students to a meaningful level of competence with the simulation programming language being used. This is especially problematic in the typical modular curricular units of content-based term, semester, or year courses that characterize high school and college programs. How can an instructor cover the necessary material while also providing the instruction and support needed for students to become sufficiently proficient in modeling?

Our experience, primarily at the college level, but more recently confirmed as well at the secondary level, is that with care, curricula can be designed that allow a class to progress efficiently through the necessary content while simultaneously and progressively building the modeling skills of the students. In such cases, students experience a continuous process of building thinking skills and knowledge through a guided and graded set of modeling exercises.

Two illustrations of this are our recent courses "Plagues and People," in which we looked at the impact of epidemic disease on the course of human history, and "Population Dynamics and the Human Experience," where we looked at the interaction of population growth and the development of selected aspects of the economics, politics, and culture of human society. In each of these experimental, interdisciplinary courses, we carefully structured the development of the "content" of the courses so that the material being presented could be illustrated and explored with progressively more sophisticated and realistic models. In each course, early topics for exploration could be addressed and supported with relatively simple models. Student exercises simultaneously developed ever more sophisticated modeling skills as the content areas were sequentially developed.

While our experience has so far been limited to college and advanced secondary settings, where we desired that our students become reasonably proficient model builders, it seems likely that a similar approach could be productively pursued earlier in the educational experience. Use of

models and exploration of systems thinking concepts (as opposed to actual model construction) should also be amenable to similar structuring, where simple concepts would be developed and/or simple models explored during the early stages of content development, in whatever disciplines were appropriate. More sophisticated systems concepts would be developed later as study proceeded. If our experience at the college level is transferable, such carefully staged development of system dynamics will pay greater dividends than episodic and disjointed uses of models.

Introduction

Within the educational community System Dynamics is gaining increasing use as a tool for stimulating critical thinking skills; illustrating the nature of complex systems (e.g. causal or feedback loops and dynamic behavior over time); and, in its most powerful applications, in promoting so-called "learner directed learning" (Draper and Swanson 1990; Forrester 1992) by supporting students in actively constructing their own understanding of "the way systems work." Many of these applications of system dynamics within educational programs, however, are episodic, one time activities that utilize models or other activities that are largely structured by the instructor, even where they do provide significant opportunities for student exploration. More powerful applications, where the student is significantly involved with identifying and defining the relevant system parameters (boundaries, stock and flows, controlling feedback loops), constructing or significantly modifying the appropriate computer simulation model, and in interpreting the results, are rare.

One major factor limiting more wide-spread systematic use of modeling within educational settings is the time constraint of the typical semester, term, or academic year structure in which the instructor and students are expected to cover pre-determined content. If modeling is added to the list of skills that the students must obtain, then a certain amount of content learning must be sacrificed, according to the common mental model.

We wished to challenge that mental model through a series of curricular experiments initially conducted within a college curriculum, and later extended to the advanced secondary level. In these courses we identified an inherently interdisciplinary subject and designed, not just a series of episodic uses of modeling exercises, but an integrated and parallel development both of the content and of the students' ability to explore, modify, and build increasingly more complex and realistic computer simulations of the systems in question.

Curricular Illustrations

Plagues and People:

The impact of epidemic disease on the course of human history has not constituted a major theme within the traditional development of the field, although a number of historians have explored those dynamics (e.g. McNeill 1976; Zinsser 1965). We chose to explore this subject as our first major curricular experiment for a combination of reasons: 1) it seemed an interesting and relevant theme to attract student interest, especially given current concern about the HIV/AIDS epidemic; 2) it constituted a relatively unfamiliar facet of history; 3) it was an historical theme that clearly connected to important biological dynamics of population growth, disease transmission, and co-evolution of host and parasite, as well as connecting to significant social and economic dynamics; and 4) it seemed rich in progressively more interesting and complex feedbacks.

We have offered this course twice, once to a group of Trinity College undergraduate students and a second time to a mixed group of high school teachers (as a graduate level Education course) and honors-level high school students (for undergraduate college credit). In both cases we structured the course so that we began the content development with relatively simple themes that were deliberately amenable to comparably simple modeling applications. For instance, the first exposure to the disease transmission process was a physical simulation (Glass-Husain 1991) that led immediately to a basic model of two stocks (Uninfected and Infected Individuals) connected by a flow controlled by the number of person-to-person contacts and the likelihood that any individual contact would lead to infection. While it was clear that this simplified depiction would rarely if ever represent the whole disease dynamic, it did serve as the foundation on which every subsequent, more realistic disease model was built. In addition, the basic compound growth dynamic of the human population constituted a similarly basic building block for the course and allowed us to use our STELLA Tutorial (Heinbokel *et al.* 1995; Potash and Heinbokel, these Proceedings) to support both the course content and the development of modeling skills in our students.

Given these basic conceptual and modeling foundations on human population growth and on disease transmission, we were then able to explore a variety of historical and contemporary scenarios with the reasonable expectation that our students would be able to utilize ever more sophisticated modeling exercises to support their learning and understanding. Scenarios relating to the impact of an epidemic (of unknown identity) in Athens during the Peloponnesian Wars, smallpox during the reign of Marcus Aurelius in Rome, bubonic plague (Black Death) of medieval Europe, the transmission of European diseases to the native American populations, and the contemporary HIV/AIDS outbreak were all explored. Not only were the specific historical and biological elements of these stories supported by the modeling approach, but the models provided gateways for connecting these dynamics with 1) other vital and related dynamics of the period in question (e.g. the economic implications of a major Roman smallpox epidemic which rippled all the way to the ultimate fall of the Empire and the urban-rural demographic dislocations of the Black Death that contributed to the demise of the feudal social system); 2) comparison of the historical episodes with related contemporary dynamics (e.g. the similar economic responses of Aurelian Rome and the Vietnam-era United States to simultaneous domestic and foreign military pressure or the modern eradication of smallpox); and 3) consideration of purely contemporary dynamics (e.g. the economics of preventative health care or the relative leverage of various HIV/AIDS policies and programs).

Population Dynamics and the Human Experience:

A second experimental course focused explicitly on the dynamics of human population growth and the mutual interactions of that growth with the historical development of social, economic, and political systems. As with Plagues and People above, the course was carefully designed so that development of the content themes could be consistently supported by students' increasingly able computer modeling skills. Here, especially, the availability of "A STELLA Tutorial," with its primary focus on human population growth, constituted an important resource in freeing class time from instruction on the mechanics of modeling, allowing that time to be devoted to exploring the implications of the modeling exercises.

During the first portion of the course, while students were developing their basic modeling skills, we explored historical and contemporary rates of compound population growth and their implications, examined the types of negative feedback loops that tend to provide limits to population growth both through catastrophic change (e.g. the Black Death, native American exposure to European diseases, and the Irish potato famine) and more gradual adjustment to changing realities (e.g. the change in attitudes in Japan between 1720 and 1870, and the migratory aftermath of the Irish potato famine), identified the impact of population age structure on population inertia, and constructed and compared conceptual maps of Malthusian and non-Malthusian projections of population growth (e.g. Livi-Bacci 1992).

We utilized our modeling skills in the second portion of the course to explore the development of modern agriculture in the United States as population growth interacted with waves of migration and expansion and with distinct pulses of technological innovation. This progression from primitive hunting-gathering, to more secure but still primitive, subsistence agriculture (such as characterized colonial America), to American westward expansion, to mechanical innovation, and finally to the current state of intensive scientific farming utilizing modern pesticides, fertilizers, and crop hybridization, was intimately tied, as both cause and effect, to the growth of the population and to the simultaneous development of urban and industrial sectors in the population and in the economy. The use of simulation models to explore the interactions of those causes and effects (the feedbacks) was very powerful in merging the demographic, economic, social, and biological components of this complex sequence of developments.

Finally, we asked our students to use their understanding of Western development to explore and project the likely or possible course of events in a country that had not yet progressed through the demographic transition and associated social changes that characterize more developed countries. We utilized our models of Western development to examine and to project conditions in Malawi, a small developing country in south-central Africa. Until recently Malawi was a net exporter of food, but rapidly growing population and social/political policies have resulted in uneven distribution of land and encouragement of non-food export crops; Malawi no longer feeds itself.. The students' models of Western development were particularly powerful in revealing the dilemma facing developing countries today. In short, the historical models did not "work" for Malawi, since the necessary demographic safety valves (European emigration or American western expansion) are simply not currently available to bridge the transitional period needed to develop the agricultural practices, the industrial development, and the low population growth rates that characterize currently developed countries. Depressingly, the Western models did not reveal any likely scenario that would allow a "soft landing" for countries such as Malawi. We did not have time to try to build "non-Western models of development that might provide more positive outcomes.

Summary To Date

The integral inclusion of a systems modeling orientation in these courses resulted in a number of benefits: 1) it provided a precise and unambiguous language with which to develop and discuss the relevant relationships, 2) it supported enhanced development of connections between several disciplines not normally associated in secondary or college courses, 3) it facilitated the application of historical lessons to contemporary problems, 4) it fostered the identification and exploration of relationships and dynamics not normally developed in texts and monographic treatments of these subjects, and perhaps most importantly 5) it provided both a stimulus and a means for students to direct and control their own explorations of the subject material.

Development of sufficient modeling skills in a single course, however, could not have happened without careful forethought to the structure of the course. Simply adding modeling exercises to an existing course structure is less likely to be effective. Careful consideration was given to developing the content material in a sequence that allowed continuous application of modeling exercises. A simplified disease transmission model and simple population growth models were developed, explored and refined so that the growing modeling sophistication of the class could be utilized in defining and exploring the content areas that were, simultaneously, growing more realistic, complex, and interesting. In addition, strict attention was paid to integrating the available tools for developing modeling expertise on the part of the students; use of "A STELLA Tutorial" provided a self-paced and out-of-class vehicle for the students to develop mechanical modeling skills (Potash and Heinbokel 1997). Content-related modeling geared to the students' growing modeling skills allowed them to practice those skills and to develop an appreciation of the dynamic relationships that characterized the systems being studied.

Better Questions and Future Directions

To date our curricular experiments have been primarily pursued in a collegiate environment in which we have a gratifying freedom to pursue experiments which interest us -- choosing the material we wish to develop and defining the tools with which to engage our students. We recognize that this is a freedom that most pre-college educators do not have and that our students are at a developmental level where building models and extrapolating from one scenario to another is a very reasonable expectation. We have, however, had the opportunity to experiment with this approach in one setting where high school students and high school teachers were combined in a single setting. This was very positive in its outcome. In addition, we believe that this approach of introducing a very simple system's concept or generic structure at the start of a course or curricular unit and using it purposefully and progressively as a foundation on which to build more complicated and sophisticated understanding is one that can contribute to a student's education even if it does not constitute a primary focus of the unit. Use of models (as opposed to construction of models) and of pre-modeling activities (such as causal loop diagrams or behavior over time graphs) would also achieve a greater power as instructors develop greater experience and comfort with system dynamics approaches. They could then begin to plan systematic and cohesive sequences of system dynamics exercises, so that their students are regularly and continuously moving from the familiar to the novel in their understanding of the behavior of systems just as they currently do with their understanding of the content.

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