Packaged Simulators and Simulation-Based Learning Environments: An Alternative to Model-Building That Can Expand the Audience for System Dynamics

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There is a traditional point-of-view in the System Dynamics field that the best way to truly understand systems and how they work is to build and use models. As someone who has spent the last 35+ years in the field, I appreciate and agree with that point of view. Working with System Dynamics simulation models will certainly give someone a much more visceral understanding of systems than simply constructing causal diagrams. However, requiring people to build models may unnecessarily limit the audience for System Dynamics. This is especially true in K-12 education. The large majority of teachers in US schools are overwhelmed by the demands on them and not ready to acquire a new skill set without understanding the value of those skills beforehand.

An alternative is to give teachers and students models developed by others. This is an improvement since it doesn't require modeling skills per se, but may fall short in attracting a larger audience to SD. Stock and flow diagrams that are very comfortable for those of us in the field may repel teachers for whom the symbols are unfamiliar. Without some background, it will also not be clear to them how to use the models to support learning.

Packaged simulators and simulation-based learning environments are an alternative that can convey an essential understanding of systems and do so without requiring prerequisite skills that limit the potential audience for system dynamics. A simulator puts a "user-friendly" interface on a model and enhances it with a carefully thought out set of activities that use the model to support learning. Well-designed, intuitive interfaces can make models accessible to people with no modeling skills and allow them to derive much of the benefit one can gain from a model. It's possible to simply hand students and teachers a pre-constructed model by itself, but a simulator embodying a model provides the following advantages:

- It can present the model and its results in a format that is familiar to students and teachers rather than using unfamiliar symbols dictated by SD conventions. A variety of graphical techniques and other media can be used to present models at appropriate levels of detail and move between an overview of a system and progressively greater levels of detail. A simulator can also present the model in varying degrees of transparency that expose a model in stages and keep the simulator from being a "black box".

- A simulator can also integrate other curriculum materials with a model and related exercises and present that material on a "just-in-time" basis in context-sensitive tutorials to support problem-solving as students work with the simulator.

- Simulators can support guided or "scaffolded" inquiry and self-directed learning by building an appropriate sequence of activities that establish a happy medium between open-ended experimentation and rote exercises. Simulators can function as laboratories in which students are able to do genuine exploration and develop intuition about systems rather than simply being fed pre-digested insights as many "interactive" programs seek to do. Guided rather than open-ended exploration may also be necessary to deal with teacher concerns about having to teach more in limited amounts of time. Certain techniques such as examining pre-configured simulations and using progressively more challenging problems can help students "get the hang of" the simulator initially and then learn at a comfortable pace.

The importance of thinking systemically and applying those insights can be a lesson woven into the simulators in addition to the curricular focus. Simulators can be attractive because they are easier for teachers to pick up and use. As a bonus, they may ultimately entice teachers to learn more about System Dynamics and modeling once they see the rich potential for learning. This would be a real victory for the K-12 SD community.

Some Examples—Physics Simulators

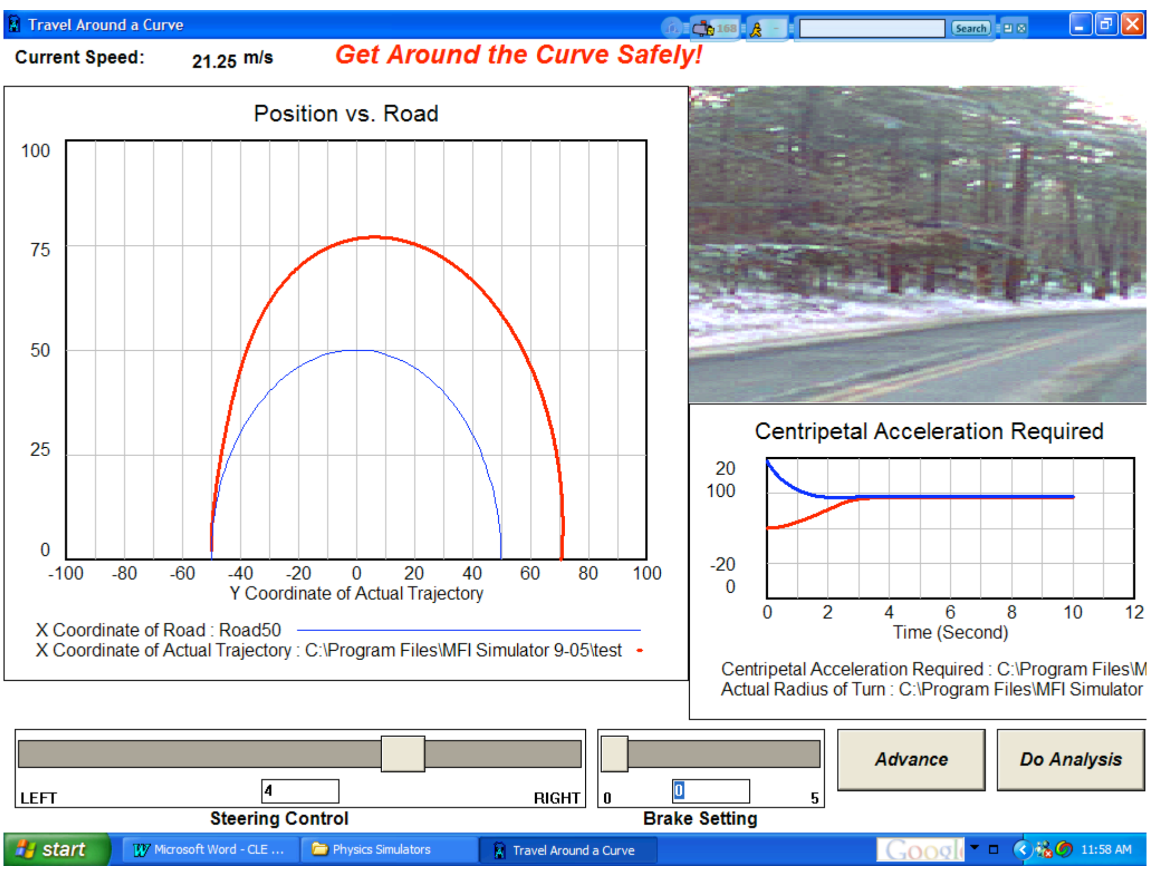

Figure 1: Screen from Travel Around a Curve Safely Simulator

I'll present a few examples that illustrate the potential breadth of applications. One is a set of simulators developed for teaching physics. I created these simulators together with a physics teacher, Jim Jones, working with the Vermont Institutes for Science Mathematics and Technology, funded by the National Science Foundation. Several simulators were developed to help students explore the physics of travel around a curve, collisions, heat flow in a house, and pole-vaulting. Though they were created with a curriculum called Active Physics in mind, they can also be used as freestanding teaching tools.

Figure 1 shows a screen from the Travel Around a Curve Simulator. The simulator enables students to set up experiments that can vary combinations of the radius of the curve, speed of the vehicle, road conditions (dry, wet, icy), angle of banking of the road, and its angle of incline (going up or down hill).   Students start by doing experiments with combinations of these variables alone and then move on to a more advanced version that allows them to use steering and braking to "improve" on a skid. They can see the results of their travel around the curve in graphs of the trajectory and key variables such as radial acceleration and velocity and in a simple animation that shows whether they are staying on the road or going off into the woods. (This has additional value for students at an age where they are learning to drive.)

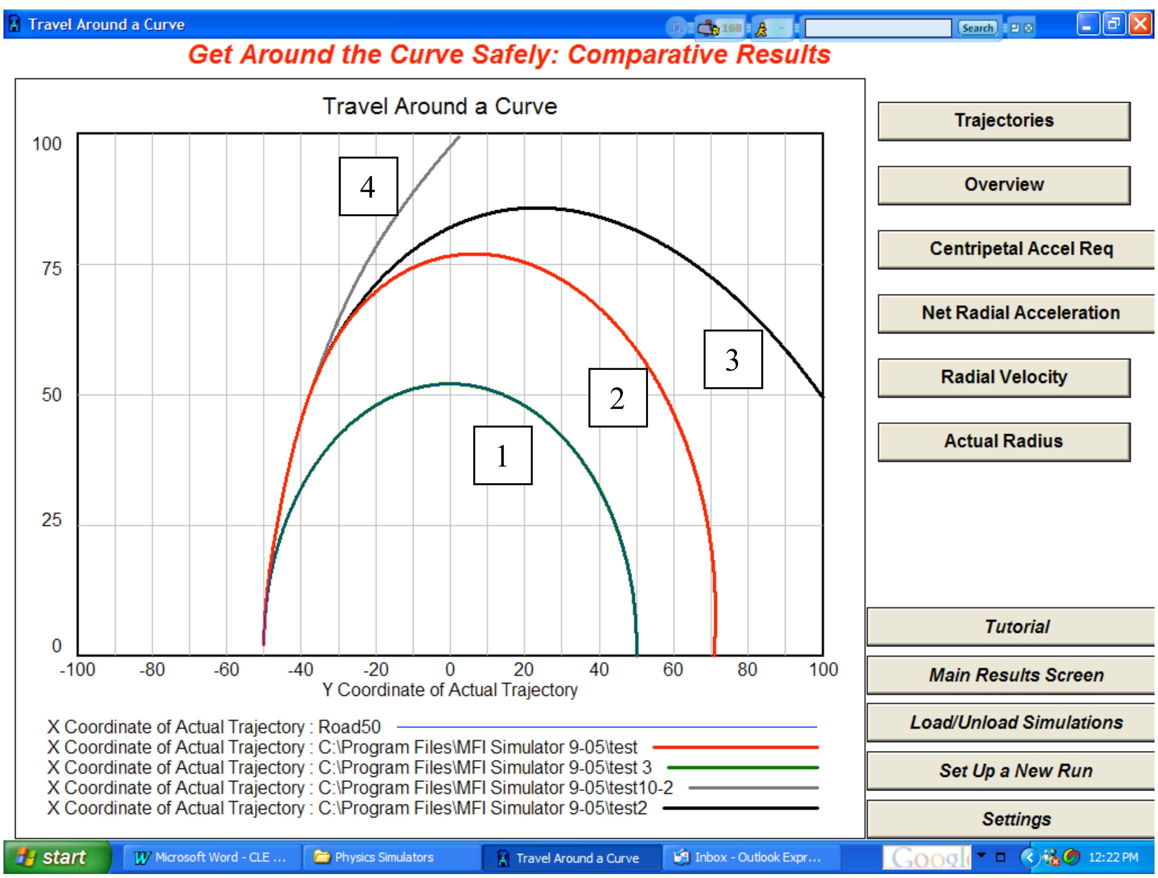

Figure 2: Comparative Graph of Trajectories from Four Experiments

Figure 2 shows comparative graphs with trajectories from four experiments: 1) travel at a slow enough speed to stay on the road, 2) a speed that is too great and causes the car to skid off the road, 3) traveling at this higher speed and trying to “correct” by steering back toward the road, and 4) traveling at this speed and jamming on the brakes as the car begins to go off the road. Built in tutorials help students understand what they are observing and explain how steering and braking can make things worse. There are also suggested experiments and a design problem that helps students integrate what they have learned.

The heat flow simulator similarly allows students to set up a wide range of experiments with varying combinations of house characteristics (size, style, draftiness), location and month of the year, whether heating or cooling is provided, and thermostat settings. A more advanced version lets students experiment further with such energy-saving measures as insulation and solar heating. Tutorials help students design experiments, interpret what they are observing, and relate the physics of heat flow to the economics of energy conservation by teaching them to do payback calculations. An illustration from a tutorial that helps students calculate the required size of the heating and cooling systems is shown in Figure 3. Again, two design problems help students integrate what they have learned.

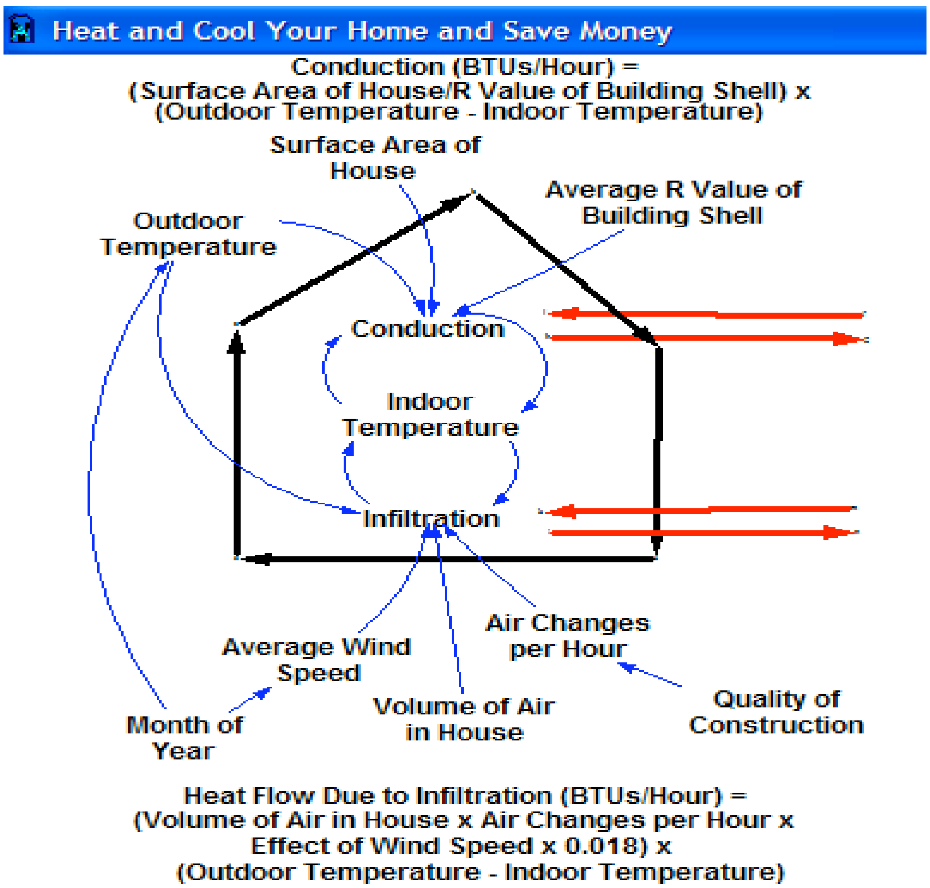

Figure 3: Illustration from Heat Flow Simulator

Learning Economics by Running a Retail Store

Another simulator lets students learn some basic economics by running a retail store that sells electronic devices popular with people their age such as cell phones and ipods. They can make decisions each quarter about pricing, the range of products they offer, staffing and salaries, and the advertising budget. Finding the right combination is very challenging and students learn the importance of combining several elements in an effective strategy rather than focusing on just one or two dimensions.

Figure 4 shows an overview screen that combines the sliders for controlling these variables with the results as they emerge in each simulation. This format enables students to get the "big picture" and see at a glance what is happening and relate changes in different variables to each other. The graphs on this particular screen reflect an aggressive strategy in which the student attempts to offer a wide range of merchandise while cutting price to beat out the competition. An initial surge of new customers quickly subsides as the store runs out of cash with which to restock inventory. Service quality also suffers because the store did not hire enough staff. This layout enables students to understand the relationship between a system's structure and its behavior.

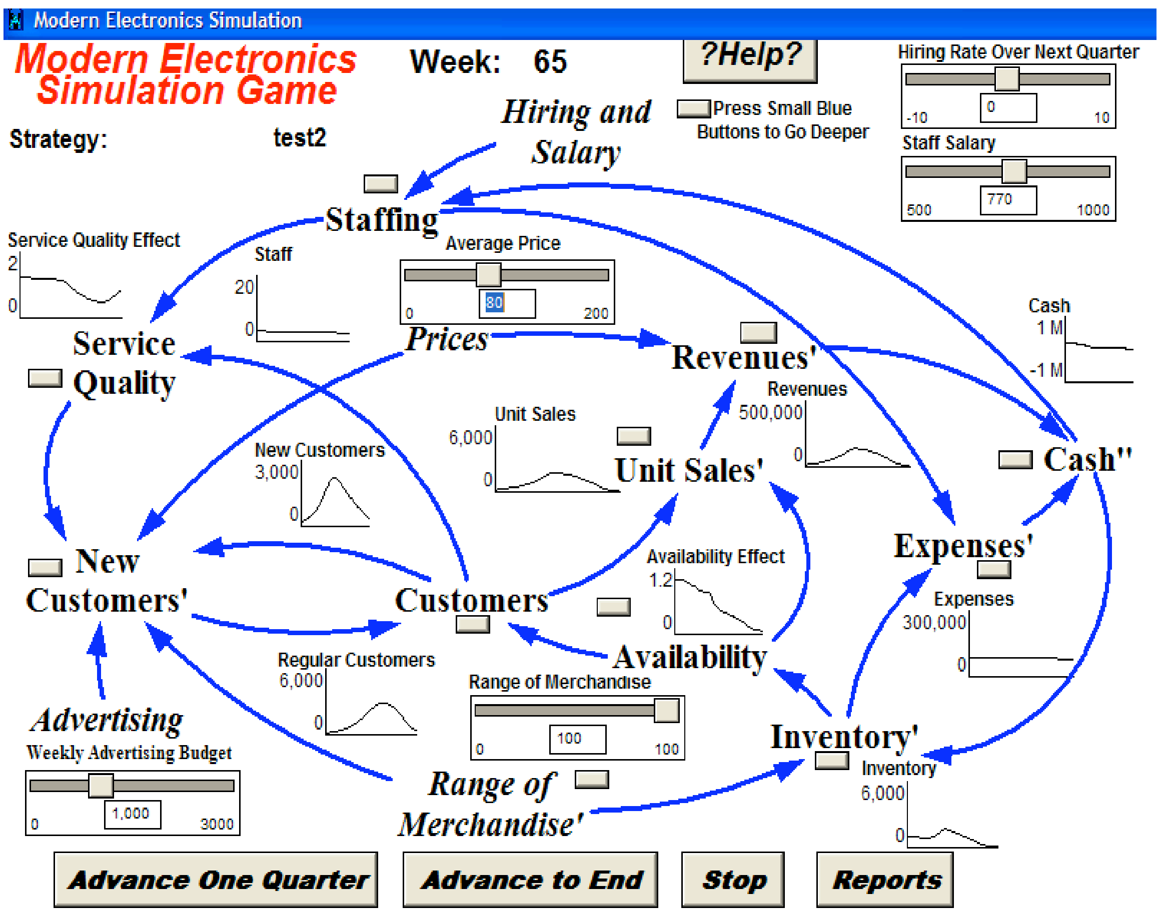

Figure 4: Overview of Retail Simulator

The buttons on the screen enable students to "drill down" and understand what is going on in various parts of the system in more detail. For example, students can examine the determinants of service quality and on the next simulation, hire staff in anticipation of increased customer visits. Students can also get information in other formats such as profit and loss statements and management reports. Once students have a strategy that seems to work, they can do a "torture test" (the polite term is sensitivity analysis) and vary some assumptions to see whether the strategy will hold up against a stronger competitor or worse economic conditions.

Simulators for Grownups Too—School Reform

Simulators aren't just for kids. They can help grownups think about how to manage schools better. Figure 5 shows the overview screen for a simulator designed to help communities think through some of the complexities of school reform. People using the simulator are "running" a small district with 2500 students that is facing the typical pressures of demands for greater accountability and more testing while working with the same limited budget. They can change a number of variables along with launching a major curriculum redesign and implementation of new student evaluation and scheduling systems. People using the simulator quickly learn that they must take some action, but that many actions create new problems that undermine efforts to change. Changing the way students learn rather than just making students and teachers work harder is key to coping with all of these pressures.

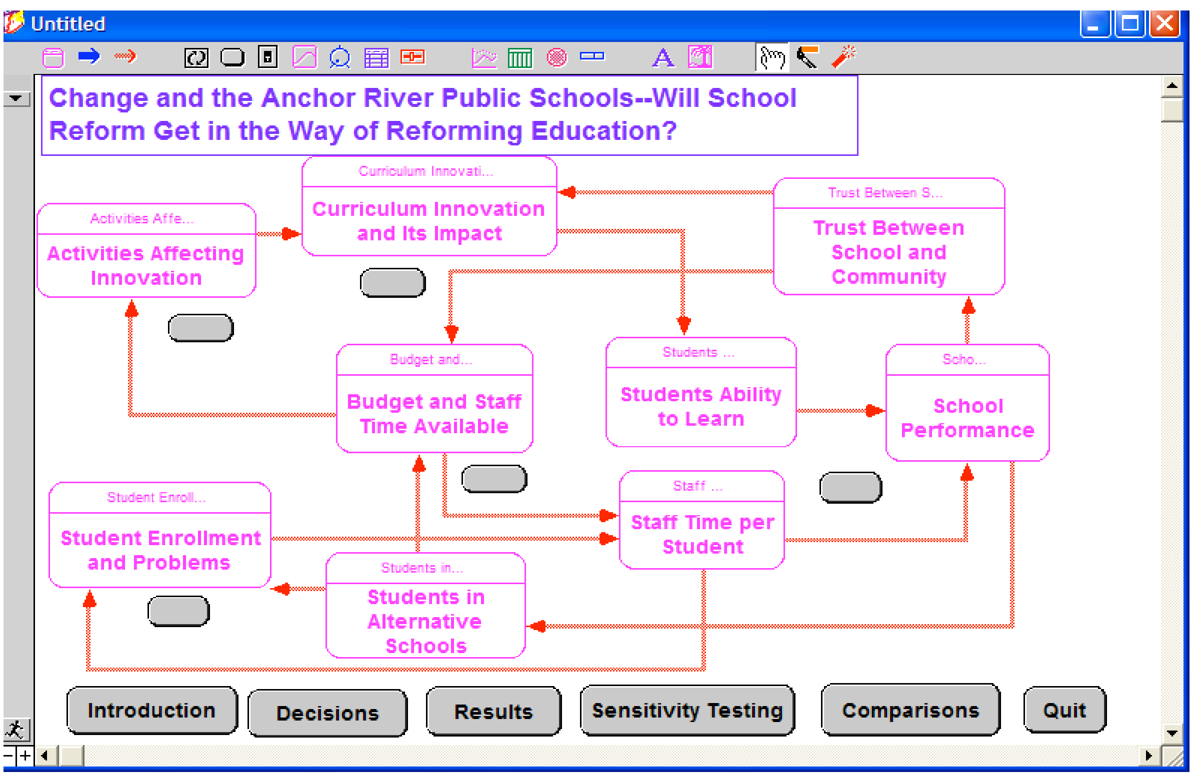

Figure 5: Overview of School Reform Simulator

As with the previous simulator, the buttons on the screen let users drill down and understand what is going on in greater detail. Information is available from two kinds of graphs—ones that compare a single variable across several simulations and others that relate several variables in the same simulation—as well as in tabular form. The purpose again is to help users understand the structure of the system they are managing and the effects of different interventions on its behavior.

The Challenge to the K-12 SD Community

In addition to these simulators, there are some others available such as Fly a Cell and Food Chain from isee Systems. However, there are no simulators for the large majority of subject areas. As I've suggested, having more of these simulators can help us reach the many teachers who sense that there is real value in SD, but don't have the time or motivation to learn the techniques. Their initial interest is in materials that help them teach their own subjects better. Having these simulators may meet their immediate need and, in the process, draw them into SD.

The challenge to the K-12 SD community is to create more of these materials that teachers can use. The tools are there. The popular SD modeling packages such as Vensim and Stella all have interface capabilities. Existing models may be a good starting point. Creating simulators around them will help them to gain greater acceptance among other teachers. When new models developed by members of the K-12 community, packaging them as simulators can be thought of as the ultimate goal. I call this approach "Design from the Ground Up". Thinking about the end-product as a simulator should affect the way a model is developed as well as how it is packaged.

The potential reward for having more simulators available for teaching a variety of subjects is a greater impact of SD on the quality of teaching and more potential recruits to the K-12 SD community.

Resources

The simulators described in this article and papers about them by me are available at no cost. The physics simulators (PC version only) can be downloaded from the web site of the Vermont Institutes (http://www.vermontinstitutes.org/science/simulators). A paper on the physics simulators, "Using Dynamic Simulation to Teach Physics in a Real-World Context", presented at the 2002 System Dynamics Conference in Palermo can be found at (http://www.systemdynamics.org/conf2002/papers/Hirsch1.pdf). Those of you with access to the magazine Science Teacher can also find an article on the simulators in the December, 2002 issue. As I indicated above, the Food Chain and Fly a Cell simulators were developed by and can be obtained from isee Systems (www.iseesystems.com). There are also a number of simpler simulators available from CIESD as part of the "Demo Dozen" at http://www.ciesd.org/influence/info-dd.shtml .

A paper on the retail store simulator, entitled "*Modern Electronics*: Teaching Economics to High School Students with a System Dynamics Simulator", was presented at the 2003 system Dynamics Conference in New York and can be found at (http://www.systemdynamics.org/conf2003/proceed/PAPERS/199.pdf). I can send copies of the simulator itself to anyone who is interested. You can reach me at GBHirsch@comcast.net.

Another simulator for teaching about business is one I helped middle school teachers Dan Barcan and Leah Zuckerman develop. This simulator is part of a unit on newspapers and has students running a local paper. This work was funded by the Gordon Stanley Brown Fund and written up by Deb Lyneis and is at http://clexchange.org/search/cle_docsearch.asp?searchstring=newspaper&search=1&Go3.x=13&Go3.y=11. I've also created a simulator for a "grownup" newspaper and a paper about it is "A Strategy Simulator for Newspapers: Overcoming the "Silos" to Do Whole-Enterprise Planning" that can be found at http://www.systemdynamics.org/conf2003/proceed/PAPERS/225.pdf

A paper on the School Reform simulator entitled "Can Education Reform Get in the Way of Reforming Education? A Simulator for Exploring Reform Strategies" was presented at the 2002 ST/DM Conference in Durham, NH and can be found at (http://clexchange.org/ftp/conference/cle_2002/33_Hirsch.pdf) The simulator itself can also be obtained by e-mailing me.

A presentation at the 2005 System Dynamics conference entitled "Designing Simulation-Based Learning Environments: Helping People Understand Complex Systems" describes the idea of "Design from the Ground Up" and may also be of interest. It is at (http://www.systemdynamics.org/conf2005/proceed/papers/HIRSC476.pdf). Another paper about a health care simulator that also has a number of pointers about design is "Design of Simulators to Enhance Learning: Examples from a Health Care Microworld" and can be found at http://www.systemdynamics.org/conf1998/PROCEED/00018.PDF .