# Implementing the Trojan Horse Strategy

Process and Techniques for Accelerating the Rate at which

System Dynamics Penetrates the Mainstream Education System

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*Abstract:* By recommending the infusion of system dynamics concepts into the type of curriculum materials that educators currently seek, the "Trojan Horse Strategy" aims to accelerate the rate at which the mainstream education system adopts system dynamics. Drawing on principles from lesson plan development, system dynamics, and application design, "Implementing the Trojan Horse Strategy" describes process and techniques for helping teachers build student understanding of subject matter and system dynamics simultaneously. This practical guide for educators includes an overview of the strategy, an analysis of the activities space within which these tools must operate, and a presentation of a four-step process for building educational tools that support the strategy.

The spread of system dynamics knowledge into the mainstream education system has long been a shared vision for many in the system dynamics community; however, progress toward achieving this objective has been slow. The slowness, in large part, is because the effort that is currently underway stimulates opposing forces that serve to directly counteract the effort. Constraints imposed by state and federal mandated teaching agendas in conjunction with limited time available to achieve those objectives serve as significant barriers to the spread of system dynamics knowledge. The successful spread of system dynamics knowledge depends critically on the effective implementation of a strategy that works in accordance with, not against, current cultural forces. By embedding system dynamics inside types of educational lessons and tools that are currently accepted by the mainstream education system, the rate at which the institution assumes a systems perspective can be accelerated. Drawing on principles for effective lesson development, system dynamics, and application design, this paper lays out a process for creating tools that support the strategy and presents examples of techniques from an actual tool developed at High Performance Systems, Inc.

Limited teaching time, cultural values placed on discipline specific substantive knowledge over discipline transcendent critical thinking skills, and the significant time investment required to scale the number of system dynamics learning curves work together to constrain the spread of system dynamics within the mainstream education system. Given the current tools, the space available to teachers for teaching system dynamics within their discipline specific curriculum is too limited to make any real progress.

There may be, however, a way to increase the use of system dynamics by creating a toolset that works in accordance with the current educational culture. Process and techniques for creating these tools, however, depend on an understanding of both the strategy these tools should support and the activities space, within which these tools must operate.

The "Trojan Horse Strategy"[1] aims to accelerate the rate at which the mainstream educational community takes up system dynamics by embedding system dynamics concepts within the types of educational materials that teachers currently seek. As teachers currently seek tools that communicate discipline specific subject matter, effective tools would infuse system dynamics concepts into existing hard sciences, social sciences, and humanities courses through educational resources that communicate subject matter through system dynamics principles. Teachers, school boards, administrators, students and parents would accept these sorts of tools because they would be consistent with current cultural goals. Implemented skillfully, tools of this type would not only help students build critical thinking skills on top of substantive knowledge, but due to the benefits of applying a systems perspective, would simultaneously help deepen students' subject matter understanding.

[1] The "Trojan Horse Strategy" was developed by Barry Richmond

## Process and Techniques

The process for creating tools that support the "Trojan Horse Strategy" draws on techniques for effective lesson development, system dynamics, and application design. Tools should support lessons that have all of the qualities of effective lessons. They should support the current learning objectives, be developmentally appropriate for students, etc. System dynamics knowledge plays a role in filtering subject matter for content that is dynamically interesting and presenting that content operationally. If the vehicle for delivering the lesson is computer software, basic application design principles can help teachers deliver the content and build thinking skills effectively. The following section is a description of process and techniques for developing effective tools, particularly within an electronic medium.

Based on experience building software-based educational tools at High Performance Systems, Inc. below is an outline of a process and examples of techniques designed to help anyone who is interested in creating this type of tool. While the process is presented linearly, in actuality, the process is iterative. Insights generated in one step of the process often result in changes to decisions made in previous steps. There is, however, a rough progression from the first step to the last.

### Step 1: Select the Substance

In order to select the substantive knowledge to be communicated in a system dynamics based lesson, filter the course topics using an understanding of dynamic concepts. Begin with a topic, biology, for example. From the set of facts and concepts within this topic, select processes that involve interesting dynamics. Processes should be described in terms of behavior over time, stocks and flows, delays, and feedback loops. Dynamics that lead to unintended consequences and results that are difficult to intuit are usually most effective.

<u>Example</u> Within the topic biology, lessons about algae blooms, predator prey interactions, and cellular respiration would be dynamically interesting. Lessons focused on identifying the seven characteristics of life or understanding the classifications used by taxonomists would probably not benefit from system dynamics.

## Step 2: Make Preliminary Learning Objectives Explicit

After the substance has been identified, establish the substantive and critical thinking (including system dynamics) learning objectives. Clear and explicit objectives will help focus the tool development process. Here is an example of the learning objectives from one challenge in *Food Chain*, a product from High Performance Systems, Inc.

*Biology/Environmental Science*

1. Understand the interdependencies between the four trophic levels in an ecosystem.
2. Understand the relationships governing births and deaths of various plant and animal species within an ecosystem, and the concept of steady-state (both how it's achieved, and how it's maintained).
3. Understand $O2$, $CO2$ and nutrient dynamics within an ecosystem.

*Critical Thinking Skills*

1. Build capability in applying the scientific method, to include: formulating and articulating hypotheses, designing experiments to test those hypotheses, and analyzing experimental outcomes to understand why results came out as they did.
2. Build capability in analyzing behavior-over-time graphs, using trajectories to construct chains of cause-and-effect.
3. Build first-level fluency in the language of stocks and flows for representing species and activities within an ecosystem.
4. Build capability for recognizing counteracting and reinforcing feedback loops, and for understanding how these loops work.
5. Build an understanding for how shifts in dominance between feedback loops can cause changes in dynamic behavior patterns.
6. Build a capability for recognizing and anticipating "unintended consequences."

As in any lesson development process, emphasis should be placed on developing clear learning objectives. While filtering content for concepts that are dynamic is a good step toward creating a lesson or tool, that step does not necessarily allow you to clearly identify the dynamics. For example, the topic "algae bloom" might be selected for a lesson, based on the understanding that excess nutrient runoff into a body of water often leads to a bloom and subsequent collapse of the algae population. This overshoot and collapse, as well as the associated impact on the ecosystem, plays out over time and has historically resulted in devastating unintended consequences for those communities who have allowed nutrients to leach into the water. So the "algae bloom" topic would pass the filter for dynamic processes, but without producing an explicit model, the relationships may not be clearly and operationally defined. Having clear explicit assumptions about relationships and behavior patterns is important for establishing effective learning objectives, which will serve as the basis for the construction of the tool.

Creating a stock and flow model is a very effective way to identify the relevant relationships operationally. Furthermore, the model building process often leads to insights about the relationships and resulting dynamics. Stock and flow maps and behavior over time graphs are other tools that help identify relationships and behavior patterns. Whatever the means, clearly understood dynamics and relationships will better facilitate the identification of learning objectives.

## Step 3: Define the Learning Process

Defining the learning process implies choosing an approach or combination of approaches that support the objectives. The learning process encompasses the learning activities, as well as the infrastructure or materials that support the activities. As the two are highly interdependent, the learning activities and the infrastructure that supports the activities should be considered simultaneously.

### Learning Activities

The activities space can be framed in terms of two fundamentally different thinking processes: synthesis and analysis. Synthetic processes focus on combining separate parts to form a whole, where analytic processes involve identifying distinct parts from the whole.

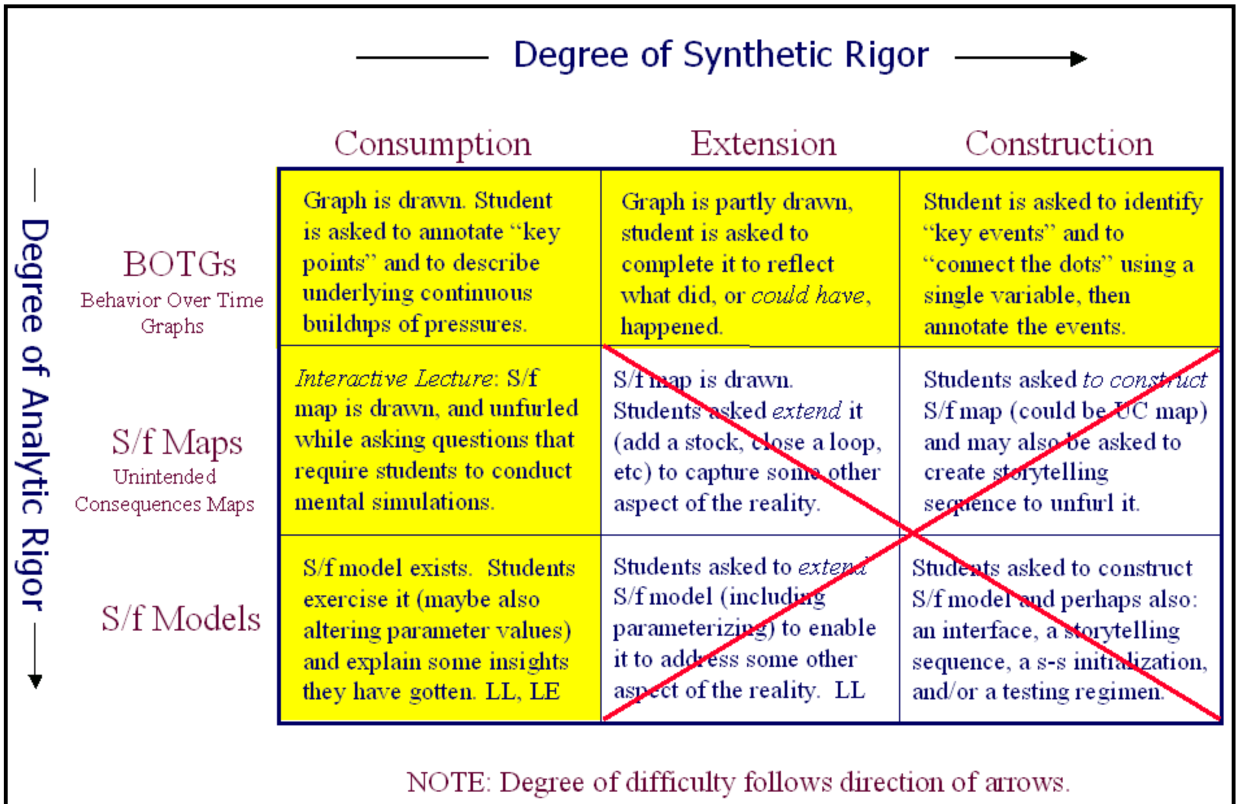


**Figure 1 – The System Dynamics Activities Space** [2]

Figure 1 describes activities along the synthetic continuum based on the amount of intellectual rigor required to complete those types of tasks. Likewise activities along the analytic continuum are organized based on the degree of analytic rigor. Examples of activities that combine these two thought processes are stated inside the matrix.

In terms of difficulty of gaining the skills required to complete tasks, activities in the lower right section of the graph are the most difficult, where activities in the upper left are the least difficult. Furthermore, there is a great deal of difference in difficulty between the two extremes. Activities that would fall into the upper left corner could be completed successfully after one lesson, whereas many lessons would be required to achieve proficiency at activities in the lower right section. This large discrepancy in degree of difficulty has implications for the type of tools that should be constructed. When considering the curricular space, activities that would be appropriate for students who have not had prior experience with system dynamics would fall in the highlighted regions in figure 1.

[2] "The System Dynamics Activities Space" diagram, courtesy of Barry Richmond

Challenge 3 from *Food Chain* serves as a good illustration of a progression of learning activities and how they could be put together in a way that supports the learning objectives (listed earlier) for an audience of students who have not had prior experience with system dynamics. This particular progression involves overview, background, exercises, and evaluation.

*Food Chain* is a software product designed for college and university introductory level courses in Biology and Environmental Science, as well as high school level courses. Students at each level experientially discover ecosystem dynamics through a simulated open water lake ecosystem. Challenge 3 consists of four sections designed to set the context and provide an overview for the challenge, provide background content information about the components of the ecosystem, and allow the students to conduct and analyze experiments.

## Overview

The first section "Understand the Challenge" explains the context. A newspaper article reads that "a lone dissenter on the Lake Mirabile zoning committee has held up a proposal to construct 100 new houses on the shoreline of Lake Mirabile." While the committee realizes that more houses would mean a higher tax base and more spending money for the community, they also realize that there may be potential environmental implications of the construction. The student, an environmental scientist and long-term member of the community, has been called upon to analyze the situation.

## Background

The next section "Lake Mirabile" provides background information on the components (species, carbon dioxide, oxygen, detritus and nutrients) of the ecosystem.


**Figure 2 – Background**

Fact cards, such as the one in Figure 1, are used to provide the background content information the students will need to complete the challenge, as well as develop understanding of the lake ecosystem.

**Exercises**

In the third section "Develop Your Recommendation" students have the opportunity to explore different housing construction scenarios in the simulated ecosystem. This is where the system dynamics specific techniques come into play. System dynamics specific teaching techniques, however, do not exist independently of other teaching techniques. *Food Chain*, for example, uses student directed experiential learning in a way we term "structured discovery," as well as Socratic method techniques. As it is important to incorporate systems dynamics concepts into discipline specific subject matter, it is also important to integrate a systems dynamics approach into other teaching techniques.

The first scenario that students conduct is a base case scenario that shows what would happen if no new houses were constructed. In this scenario, the ecosystem is in a state of equilibrium, so population levels for all species as well as quantities of nutrients, detritus, carbon dioxide and oxygen, remain constant. While on the surface, this is not particularly interesting, the experiment paves the way for a coaching sequence, which highlights the difference between a static and active equilibrium.

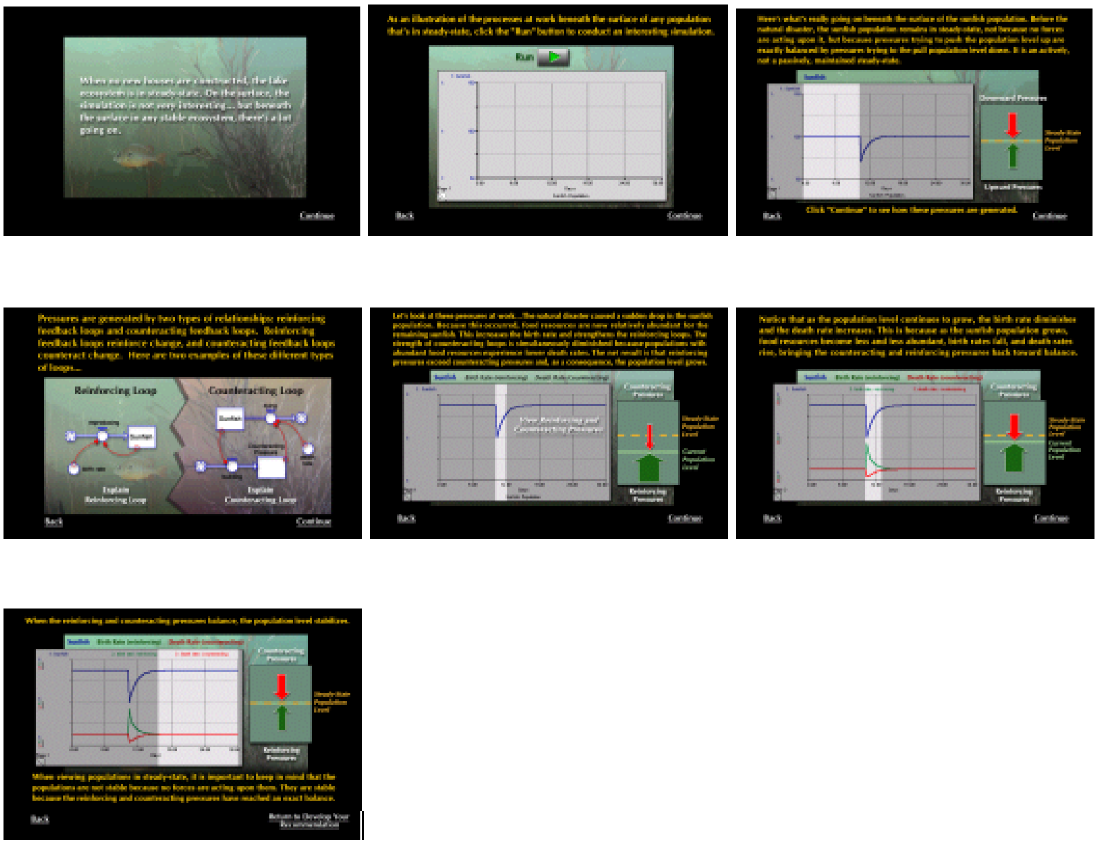

**Figure 3 – Coaching Sequence**

Coaching is a technique where a message or series of messages is displayed based on simulation results or a decision a student has made. Some uses of coaching include…

1. highlighting or drawing attention to a specific simulation result that is important to the understanding of the substance or dynamics of the lesson
2. explaining dynamics that have occurred in a simulation
3. inferring students' mental models based on the decisions they have made and capitalizing on "teachable moments" to broaden that mental model.
4. posing a pregnant question in an effort to guide the student in their thought process

This particular coaching sequence illustrates that any population experiences constant reinforcing pressures, trying to push the population up, as well as constant counteracting pressures, trying to pull population levels down. Furthermore, the strengths of these pressures can shift due to changes in the ecosystem. The reason that the populations remain constant when the ecosystem is in equilibrium is not because there are no pressures acting on the population. It is because the reinforcing pressures are exactly balanced by the counteracting pressures.

The dynamic concepts of reinforcing and counteracting loops are also introduced, not just in broad terms of upward and downward pressures (though this is still useful), but also using stock and flow examples.

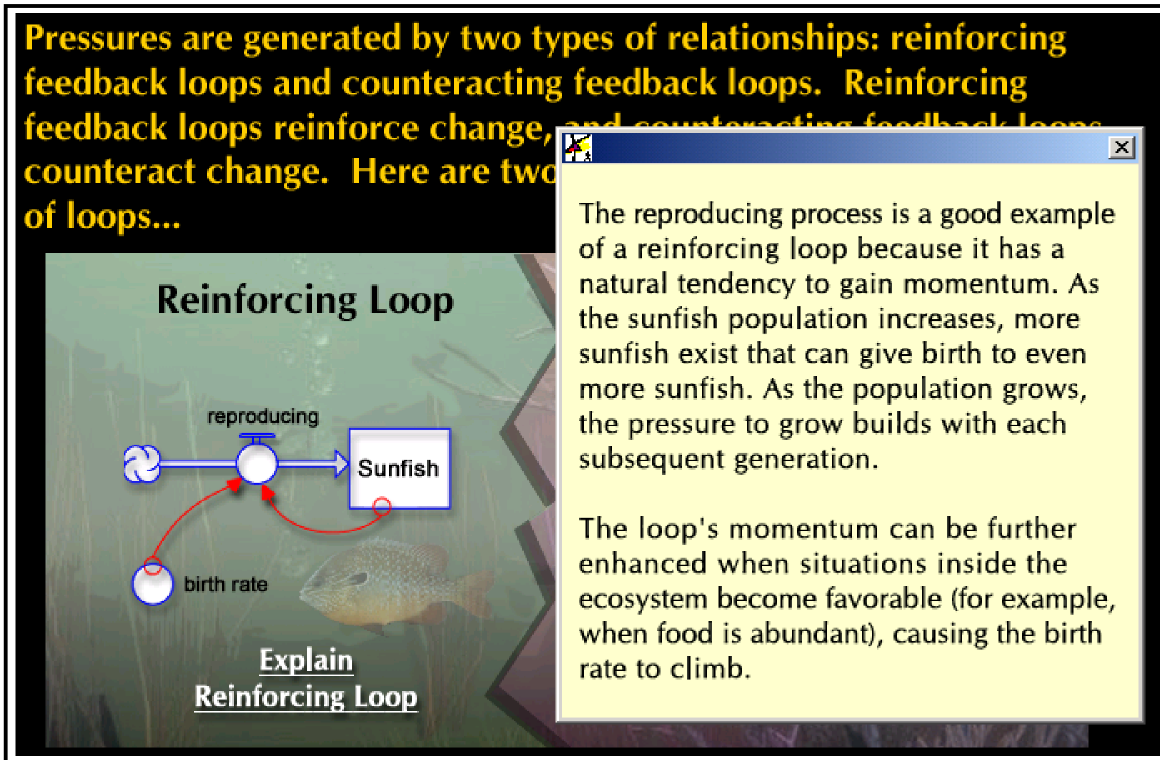


**Figure 4 – Reinforcing Loop Stock/Flow Example**

At this point, students should probably not be subjected to the details of the mathematical, statistical, or operational relationships between things like Sunfish, birth rate, and reproducing. A focus on these details would likely obscure the understanding of biology that the lesson should achieve. There is value, however, in building a high level understanding of the language, structural relationships, and dynamic concepts. Students will be able to apply these high level concepts to build understanding. Furthermore, when they come across stock and flow diagrams in the future (and they will in this tool!), the language will be less foreign and easier to digest.

Students also explore a scenario that represents the opposite extreme from no new construction: the construction of all 100 new houses. While this scenario also contains coaching that is similar to the "no new houses" scenario, from the student's perspective, more focus must be placed on the analysis of behavior over time graphs to help determine causality in a sequence of events. These events begin when nutrients from fertilizer and septic systems runoff into the lake. Excess nutrients cause algae to bloom and overshoot the carrying capacity of the ecosystem, ultimately resulting in the collapse of the algae population. This collapse of the primary producer population, which is at the bottom of the food chain, sets off a series of events that is highly disruptive to the ecosystem.

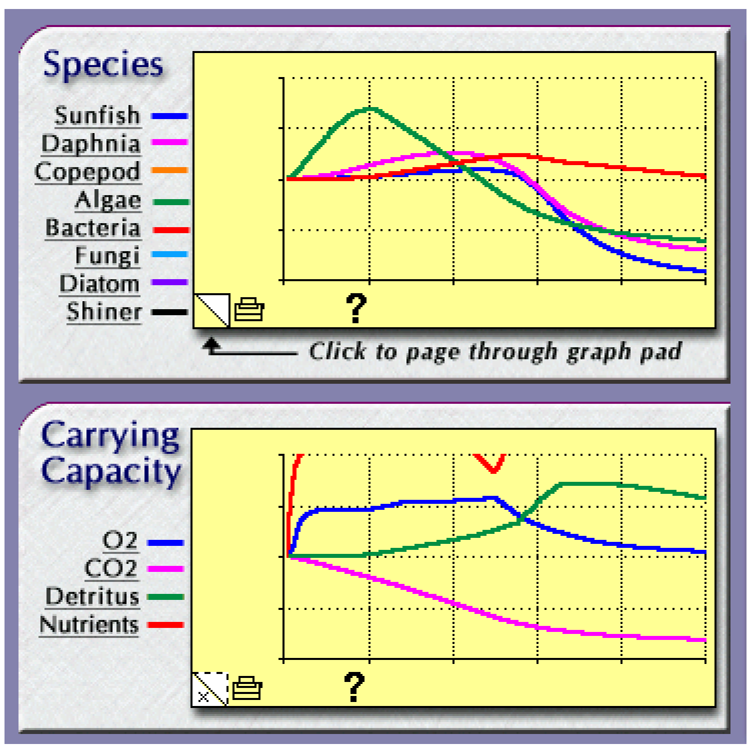


**Figure 5 – Behavior Over Time Graphs**

An important system dynamics skill is the ability to move beyond simple immediate cause and effect relationships and think in terms of behavior over time.

Thinking in terms of behavior over time is important because delays between cause and effect often make effects difficult to intuit. Considering only the immediate consequences of an initiative like the decision to construct houses on the shoreline of a lake often means inadvertently engendering long-term losses with short-term gains. In the case of the nutrient runoff and subsequent algae bloom, the species populations actually thrive shortly after the bloom. If the zoning committee fails to consider the inevitable collapse of the algae population, their decision would likely bring long term consequences for the ecosystem and community. Relying on behavior over time graphs and asking students to explain behavior over time is a good way to build these skills. By using behavior over time graphs to extend a boundary out in time, teaching tools can help students develop a richer understanding of an open water lake ecosystem in the process of building important system dynamics skills.

Another tool students can use to build understanding is a simplified stock and flow diagram. This type of diagram uses stocks and flows as a language to better understand the structural relationships that give rise to the behavior over time (figure 6).

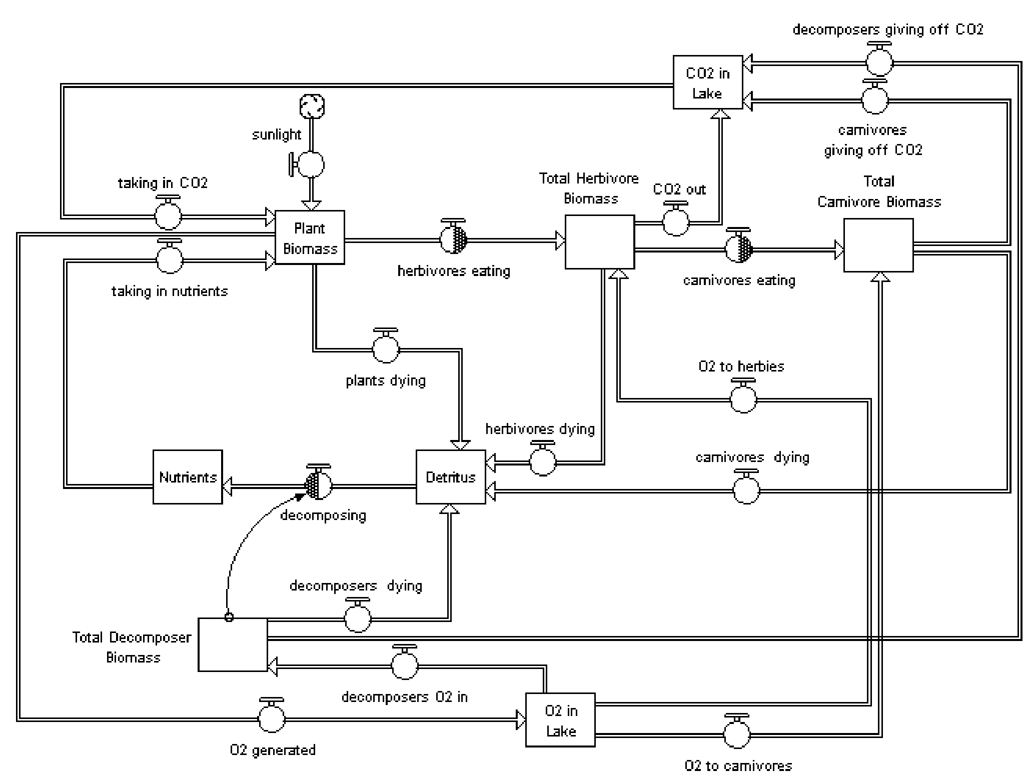


**Figure 6 – Simplified Stock/Flow Diagram**

The diagram is simplified (in this case presented without converters and connectors) because overloading the diagram with the less important elements of the language would render it ineffective as a communication tool, especially when the audience is not yet proficient with the language. In order to communicate effectively, isolate enough of the essential components of the structure to represent the relevant relationships. Including more than "just enough" is counter-productive.

While "what" you choose to present is important, "how" you present it is equally important. One approach *Food Chain* uses is to begin with a blank screen and progressively unfurl different segments of the diagram until the entire diagram is displayed. It is easier to digest the diagram in pieces than try to swallow it whole. Furthermore, each unfurled piece is accompanied by a text annotation that describes the piece and its relationship to the rest of the system. Though the differences between stocks and flows can also be described explicitly, this approach communicates the differences between stocks and flows implicitly. Whether defined implicitly or explicitly, system dynamics is used as a language to communicate relationships and achieve the discipline specific learning objectives, as opposed to being the primary objective of the lesson.

### Evaluation

Tools should support the "evaluation" objectives of a lesson. One way to do this is through the approach used in *Food Chain*: to require students to write down and hand in their responses to questions about the exercises.

## Infrastructure

All of these learning activities rely on a materials infrastructure. In the case of this specific tool, activities occur within the context of a software application architecture. For software application based lessons, an architecture should be created that supports the progression of activities. Applications consist of different "spaces" or screens. Each screen allows access to other screens. The architecture, typically communicated in the form of a diagram, shows what the screens are and how they connect.

The *Food Chain* architecture is based on a combination of a menu and navigation bar system. A full discussion of architecture design and the decisions leading to choices for the *Food Chain* architecture is beyond the scope of this paper. Figure 8 is an example of an architecture that should be useful for most small (lesson-sized) applications.

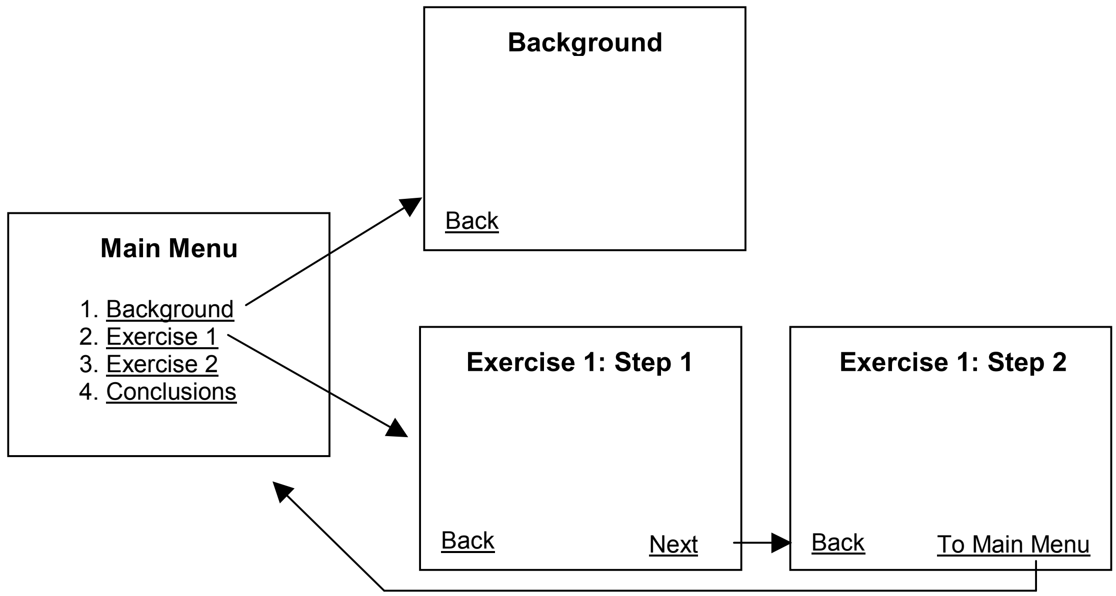


**Figure 7 – Sample Architecture Diagram**

This sample architecture is organized around a main menu, which divides the application into sections. Using a main menu screen provides an outline students can keep in their mind's eye while progressing through the application. This "outline" turns out to be important because it gives students a framework for organizing their thoughts about what they are doing in any section and how that fits into the overall activity. Students can access a section by clicking on a button or link on the main menu screen that navigates them to the first screen in the corresponding section. Within each section, they can then use a "next-back" navigation scheme (where each screen has a "next" button and a "back" button) to advance through a linear progression of screens. The last screen within the section should have a link back to the main menu. While the "next-back" navigation scheme does not provide the big picture outline of a section as the main menu navigation scheme does, it very clearly indicates what to do when a task is complete: click "next." This clarity works well when you want students to concentrate on the lesson's material and not on "where they are" or want to do next. This approach outlines a clear chronology through the application as it helps students understand the overall progression, as well as where they are within that progression.

### Step 4: Evaluation and Feedback

An important part of any tool development process is testing the teaching tool to determine its effectiveness. Software developers beta test their software before making final fixes and releasing it. Good teachers test out their lessons in class or seek feedback from colleagues, so that they can refine their methods. In an environment where few tools exist and the road map for producing quality tools is still unclear, this step becomes even more important.

## Conclusion

A set of tools that use system dynamics concepts to communicate discipline specific subject matter and build critical thinking skills would likely be adopted by the mainstream education system at a faster rate than system dynamics concepts are currently being adopted. This paper focuses on presenting process and techniques that can be used for building a software application, designed to communicate system dynamics concepts and substantive knowledge. While examples are from a specific tool, occupying a fraction of the activities space, the process and techniques used should be transferable to the development of other types of activities in other areas of the space. While the universe of activities and effective design principles is only partially explored, the approach and principles that have been identified seem to effectively communicate the substantive and critical thinking lessons. Further exploration and successful implementation means increasing the use of system dynamics within the mainstream education system and consequently empowering the world to think and act more systemically.

Back to the Top