System Dynamics as a Strategy for Learning to Learn

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Learning for the 21st Century Conference
Andersen Worldwide Center for Professional Education
St. Charles, Illinois
April 15 - 17, 1998

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Abstract

Following their formal education students face processes and organizations which are too varied, complex and dynamic to be designed and managed with solutions provided in school. To be successful students must learn independently and apply new knowledge throughout their careers. How do students learn how to learn? How can students develop the ability to learn about complex systems and challenges without the aid of experts? Our Master of Philosophy in System Dynamics program trains students from an wide variety of cultural and educational backgrounds how to independently learn about complex systems. Our goal is not to provide solutions but to develop the ability to build new solutions. This paper describes how the implementation of a simple experiential learning model with a combination of techniques including apprenticeship, reality-based cases and experimentation develops skills for independent learning. Barriers to learning to learn provide the basis for strategy improvement.

Introduction

The intellectual challenges which students face following graduation are growing as the systems in which they must operate and manage become increasingly complex. These systems have many different types of components which interact through structural feedback, circular causality in which the impacts of an agent's actions return to affect that agent. These relationships are characterized by delays and nonlinearities which make understanding how the system behaves and why difficult and therefore difficult to manage (Richardson, 1990). Consider a program to reduce illegal drug use as an example. The system includes (at a minimum) drug suppliers and sellers, users (casual and addicted), drug prices and supplies, law enforcement and judicial organizations and their actions, penal systems and the victims of drug-related crime. Each of these components is related to several others in ways which vary with the current and expected conditions and actions of others. For example law enforcement agencies can respond to an increase in recreational drug use by increasing arrests and thereby the risk of detention for drug users. The increased risk can reduce drug use after a delay in recognizing the increased risk and adjustment of drug use behavior by recreational users. These systems are difficult to understand (Sterman, 1994) and manage (Homer, 1993) and can generate well intended but counterproductive such as increased crime due to increased arrest rates (Friedman, 1976).

To address challenges such as these students need the ability to develop knowledge about specific complex systems that can then be applied to find solutions. This learning may occur individually or

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as a part of a team of domain and methodology experts who are collectively seeking a solution. However due to the complexity or novelty of the system (or both) this learning must often occur without an a priori source of understanding about the system in the form of a system expert. We call the development of such independent learning skills "learning to learn".

One objective of our educational systems is to prepare our students to successfully address such complex issues by developing the knowledge which is necessary to find solutions but may be unavailable until the student addresses the problem. To do this students must have the ability to learn about the complex systems they seek to manage. Since knowing how to learn about complex systems is not natural students must be taught how to learn without the assistance of an expert. An important challenge for educators in the next century will be how to help students learn to learn. The development and testing of strategies for this purpose is a critical step in effectively reaching this goal.

Our Master's of Philosophy in System Dynamics program at the University of Bergen trains students to use the system dynamics methodology to understand and improve complex systems. A primary goal of our program is to develop independent learning skills in our students - the ability to learn. This paper describes our program as an example of a strategy for training students how to learn independently. I describe the challenges of learning to learn. A simple experiential model of learning focuses teaching on tools for specific learning cations and managing the learning process, which we apply twice with each set of students. Barriers to learning to learn and measn used to address them are described as the basis for future research and improvement.

Challenges of Learning to Learn

Learning can be described broadly with the development of three types of cognitive skill. A fundamental form of learning focuses on acquiring and remembering facts (broadly defined). In this form exact and specific answers are known and available. No methods or procedures must be applied to obtain solutions beyond memorization. The range of problems which can be addressed is limited to those with solutions which are known and stored. Examples include learning the alphabet, addition tables or the names of the seven continents.

A second cognitive skill focuses on the application of procedures. In this form exact and specific solutions are not directly available but procedures for finding solutions are. Clear measures of solution value are also available for judging the quality of the application of the procedures. For example when an engineer determines the size of a steel beam for an office building he or she follows a specific procedure and produces a specific beam size. While every beam size for every possible office building condition is not available the procedure provides an exact means of finding solutions. The relative value of beam sizes can be assessed with known and clear criteria (e.g. saftey factor, weight or cost). Other examples include word problems, games such as chess and design operations such as optimization.

Despite their wide range of applications the preceding two forms of learning are inadequate for many complex systems. In these circumstances previously developed solutions are not available and no fixed procedure can be applied to directly develop alternative solutions. Additionally, the basis for judging solutions can be both unclear. Even the questions to be answered may be ambiguous, uncertain or multifaceted. A third type of learning develops new knowledge for use in developing solutions for these systems. This form of learning focuses on strategies for using tools and methods to build useful knowledge. Consider the challenge of developing a policy to control the size of a deer population on an isolated plateau over many years. Several objectives may contribute to the goal of such as policy. Should a manager of this ecosystem seek a smaller healthier deer population or a larger weaker population which facilitates hunting? How is deer health effectively measured and judged to be acceptable? In a simple model the deer population changes dynamically in response to the grass which the deer eat and the wolves which eat the deer. By setting annual deer and wolf hunting levels and the amount of grass to plant each spring a manager can influence the deer population. However due to the nonlinear and delayed reactions of the wolf, deer and grass populations to each other the impacts of any given policy are not static or easily determined. Furthermore, no useful algorithms are available which can provide solutions. How can a manager select hunting and seeding levels which form an effective policy? Knowledge concerning how each of the three policy levers impacts each of the three populations over time must be developed before an effective policy can be developed. How can students develop the skills to build this kind of knowledge?

Learning approaches based on the transmission of known solutions or explicit means of finding solutions from teachers to students cannot prepare students to address complex problems in complex systems. The unique needs of independent learning cause it to be difficult to develop competence due to several factors:

- Because learning to learn is a process it is more abstract than learning known specific facts and procedures. This requires students to generalize and apply perspectives with multiple levels of aggregation.
- Learning to learn can require a change in the student's mental model of learning from a more structured and rigid knowledge base or set of steps to be applied once to a more flexible iterative process (Doyle and Ford, 1998).
- Verifying that independent learning has occurred is difficult because the proper use a flexible set of procedures is less recognizable than many other learning indicators.
- Learning to learn is heavily dependent supporting on conditions which are difficult to provide, assess and facilitate such as safe learning spaces for experimentation.

• Learning to learn often includes questioning and adjusting objectives and measures of those objectives.

Despite these difficulties the challenges of independent learning are not obvious. In fact many complex systems appear deceptively easy to manage (Sterman, 1992). Convincing students of their need for effective independent learning skills is a first step in learning to learn. Therefore effectively demonstrating the challenges inherent in designing and managing complex systems and the need for independent learning skills is critical. The first course in our progrm begins with a participatory exercise in managing a simulated business environment, In "The Beer Distribution Game"[2] (Figure 1) participants fill orders for beer from their customer on their left and place orders for beer with their supplier on their right with the goal of controlling the size of their inventory. The supply chain includes the structural feedback, delays and nonlinear relationships characteristic of complex systems while remaining completely exposed to the participants. Orders are filled and placed and inventory levels and orders recorded for a simulated 35 - 40 weeks in response to a single stream of customer orders placed with the manager of the retail inventory.

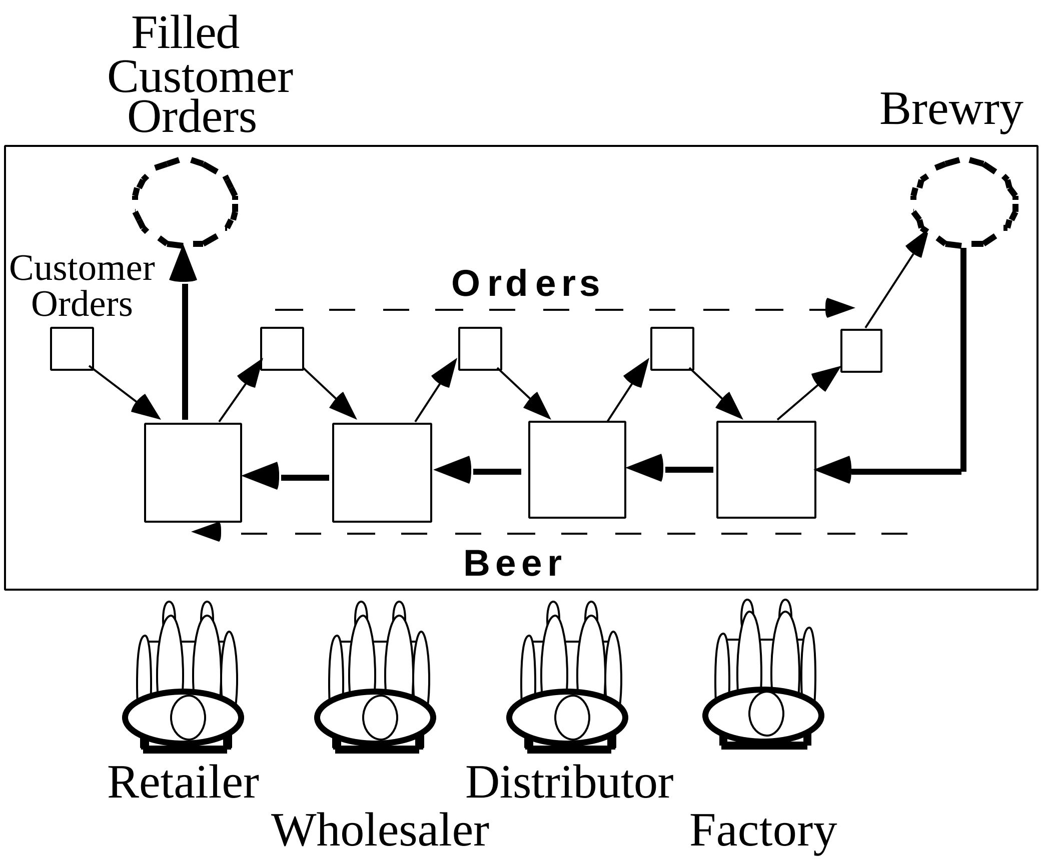

Figure 1: The Beer Distribution Game

[2] When the Beer Distribution Game is used with students under the legal drinking age for alcohol the exercise becomes The Apple Juice Game and functions in exactly the same manner.

Participants find it extremely difficult to perform well in the Beer Distribution Game (Sterman, 1989). Typical performance is ten *times* worse than optimal. Orders and inventories oscillate with increasing amplitude despite a static stream of orders from customers. An interactive debriefing session after the game identifies the challenges of managing systems and the need for an ability to learn about them as a part of finding solutions to problems such as inventory management. Students learn from the Beer Distribution Game that even apparently simple systems can generate very complex and problematic behavior.

A Model of Learning to Learn

Our strategy is based on a relatively simple model of experiential learning (Figure 2) called the OADI learning cycle. The model has its roots in the Plan-Do-Check-Act model of the continuous improvement methodology developed by Deming (1982), adapted to learning by Koffman (Kim, 1993) and applied to individual and organizational learning (Roth and Senge, 1995). In the OADI learning cycle each letter represents a fundamental learning action: observe, assess, design or implement. Observation includes perceiving and describing the system of interest, its processes and agents, their characteristics and objectives. Assessment compares the condition of the system to the goal and evaluates the impacts and consequences of any differences. During design possible solutions to the mismatch between the system and the goal are generated. These designs are applied through implementation. Learning is continuous in this model, with implementation being followed by observation of the effects on the system.

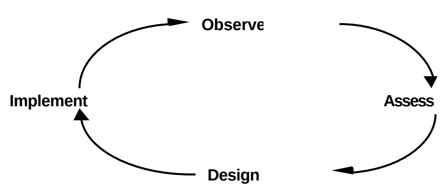

Figure 2: The OADI Learning Cycle

A simple example of describing learning with the OADI learning cycle is a project manager attempting to keep his or her project on schedule and in budget. The managers *observes* that the project budget and estimated costs are equal but that the deadline is four months away while the estimated time required to complete the project is eight months. The manager then *assesses* that he or she will lose their job if the project is late, *designs* a solution of increasing the labor on the project by hiring more people, *implements* the design by doubling the project staff, *observes* that the new hiring have reduced the time required to four months but that the estimated costs now exceed the budget. The manager *assesses* that he or she will lose their job if the project is over budget, *designs* a solution to lay off half the newly hired staff, *implements* the new design, and the learning continues.

Although the OADI learning cycle is a useful conceptual model learning in practice is not nearly as simple as the process depicted in Figure 2 or as easy as implied by the preceding example. Several characteristics of learning about complex systems make actual learning more difficult:

- The four fundamental learning actions can be difficult and time consuming. An example is implementing a design to improve a nation's economy by changing the work ethic of it's citizens.
- Moving from one action to another may incur delays and changes which impede the effectively taking the next learning action. For example the delay between implementing a new education program and observing the impacts on students may make observation more difficult and less accurate.
- More than one iterative one path through the four actions are possible and required for effective learning. For example repeated observation and assessment may be required to obtain a useful understanding of the system and its relations to the objectives before progressing to design.
- Which sequence of learning actions is effective is not obvious or easily identified

To incorporate these challenges into our strategy the concept of independent learning is operationalized by defining it as purposefully and effectively using the OADI learning cycle. From this perspective learning to learn is developing the skills required to use the OADI learning cycle. Our program separates the training of our students for this goal into two parts: developing skills in the four learning actions for complex systems and managing the iterations among the four actions.

Tools for Learning to Learn

Once students are convinced of the need to learn how to learn independently about complex systems our strategy for learning to learn turns to training in the four basic learning actions. An apprenticeship model (demonstration, mimic with feedback and repetition, slowly adding complexity and withdrawing assistance) is used to develop student skills in multiple tools for each action (Figure 3). Tools of increasing complexity and capability are gradually introduced as students develop competence. Students are trained to initially focus their observations of complex systems by having describing the nature of systems and problems and graphically depicting dynamic behavior in ways that suggest relationships among system components. Basic assessment skills are developed by writing focusing questions which capture problems in concise forms such as "What ordering policies minimize inventories in the Beer Distribution Game?" System mapping at the conceptual level with methods such as causal loop diagramming (Goodman, 1988; Richardson and Pugh, 1981) help students assess systems and design possible solutions. Beginners also learn how to design by expanding their modes of thinking. For example the concept of behavior being driven by structural feedback instead of exogenous influences is often a fundamentally new and different perspective.

The implications for complex systems (e.g. policy resistance and counterintuitive behavior) alter how students see problems and potential solutions. Developing the practice of making assumptions explicit and clear is critical at this stage. Beginners implement potential solutions by applying their dynamic reasoning to conceptual models.

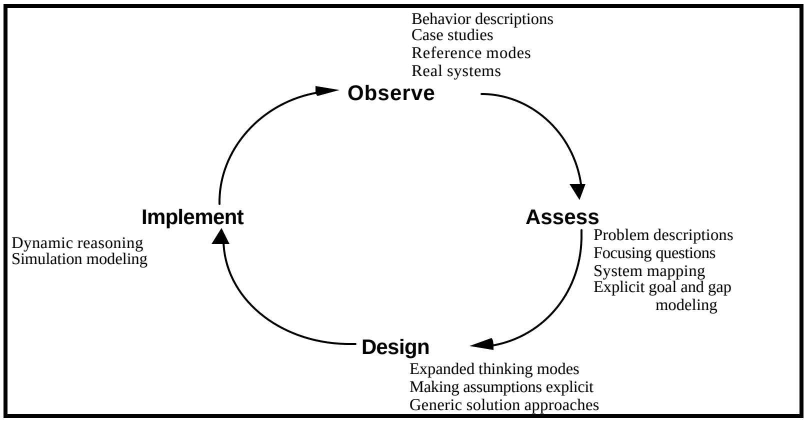

Figure 3: Tools for Developing Basic Learning Actions

More advanced tools are added ss students develop compentence in fundamental system dynamics tools. For example to further develop observation skills we use professionally prepared business cases and mathematical descriptions of behavior such as describing oscillating behavior with amplitude, frequency and phase shift. More advanced assessment tools include the explicit modeling of gaps between system conditions and objectives and the specification of performance as transient or steady state. Design approaches for more advanced students include generic solution approaches (e.g. system archetypes and controller designs) and advanced technology such as computers to reduce delays and improve information transfer. Advanced implementation includes learning to build and validate simulation models of complex systems which can be used to test designs.

Managing Iteration in Learning

The second critical component of our strategy for learning to learn is the management of iteration through the OADI learning cycle. Students need to be able to manage the learning process as well as competently perform the individual activities. This aspect of our strategy is as important as developing the ability to use individual tools but receives inadequate focus and training by educators. To train students in the management of the OADI learning cycle the apprenticeship approach is used again with three significant differences:

- **Separate development of tool and process skills:** Training in the learning process is separate and distinct from training in the use of individual tools. Students in our program can develop skills in the use of a tool or the management of the use of several tools in which they possess competence but not both simultaneously.

- **Simple familiar content:** Examples and exercises in managing the learning process are simple and familiar enough for students to allow them to focus on the iterative learning process and not the content of the problem.
- **Explicit iteration demonstration:** The iterative nature of the learning process is demonstrated explicitly. Processes are typically presented as occurring once perfectly to produce the completed final product. While potentially impressive this hides the actual iterative process used and (more importantly) fails to demonstrate what students should expect and practice in the independent learning process.

Addressing Barriers to Learning to Learn

The important barriers to learning to learn are a subset of the barriers to learning in general. The most important barriers to students in our program are caused by the unique challenges of learning to learn, including:

- **Risk adverse students:** We have found that risk-averse students have more difficulty in learning independent learning because of their discomfort with experimentation which may "fail" in the sense of not give a correct and final solution immediately. Independent learning requires taking initiatives which develop knowledge but not solutions, becoming comfortable with failure and adept at how to use failure to improve. Our porogram provides students with safe places for experimentation with privacy in the form of personal computer accounts and facilities and individual assignments, opportunities for fast and relatively easy iteration and freedom from forced public demonstration of skills. We encourage students to learn experientially by emphasizing the role of assignments[3] and assigning projects which require experimentation ("deep water" assignments).
- **Discomfort with uncertainty and ambiguity:** Learning is more difficult when conditions, systems and outputs are not constant, when there is no one answer (uncertainty) or when these components are unclear (ambiguity). In response we focus on learning processes more than the products of those processes in evaluating our students work, valuing processes as "better" or "worse" instead of "right" or "wrong" and to respond to student questions with questions to provoke thought and processing instead of providing answers. The tools and learning process model of our strategy assist in providing a framework for ambiguous problems and systems.
- **Lack of interest in topic:** Uninteresting topics and unrealistic contexts can lead to a lack of commitment to find solutions. We use reports from newspapers and magazines on topics of natural interest to our students (e.g. current events, drugs and love), manual and computer-based management flight simulators and professionally developed business case studies to lure students into the learning space and maintain their interest. For example one system dynamics model attempts to explain the fate of Romeo and Juliet (Radzicki, 19??).
- **Passive learning model:** Some students prefer a passive learning role in which the instructor or reading material provide the lessons to be mastered or the exact set of steps and tools to apply to get the one right answer. This approach can be efficient for some

[3] For example in the first lecture the author informs his students, "You can't learn system dynamics from my lectures. You can only learn system dynamics by **doing** system dynamics."

types of learning and this mode of learning may be the only approach which students have experienced in their formal education. However independent learning requires an active constructivist approach to learning by both the student and instructor. These students need gentle introduction and guidance to a constructivist approach to learning.

- **Difficulty in reflecting on experience and observation:** Thoughtful reflection and objective self evaluation is essential to independent learning. These skills are difficult to develop and require a degree of confidence which is often incompletely developed in students.

Our Not-So-Hidden Agenda

The strategy described here has been developed and chosen for a particular reason. Our ultimate goal for our students is to develop their research skills. Research is a process of developing knowledge by testing potential answers with data (Frankfort-Nachmias and Nachamias, 1992). The ability to learn independently is the basis for learning formal research skills, whether directed toward "pure" research as practiced by academics and corporate research and development departments or "applied" research as practiced by consultants and practitioners. Products of the four learning activities of the OADI learning cycle generate research project products. For example the observation activity generates a context description and the existing theories concerning an issue and the design activity generates hypotheses. This is because the OADI learning cycle is a model of learning by testing (i.e. research). Training students to think and learn like researchers is consistent with the independent learning skills needed to address complex problems.

Our strategy for learning to learn is applied twice with each set of students. Our strategy is first applied in the first three courses of our program in the relatively narrow context of teaching students about complex systems using the system dynamics methodology. From the student's perspective this portion of their course work is "about system dynamics". Our strategy is applied again in the final course of our program and during thesis work in a more general context to teach our students formal research tools and methods which extend those shown in Figure 3 and described above. From the student's perspective this portion of the program is largely "about research". Although the focus of the two applications are different both implement the two basic components of our strategy; the development of skills in basic learning activities and the management of the independent learning process.

Conclusions

Our strategy for training students to learn independently uses separate apprenticeship-based training in fundamental learning activities and the management of an iterative learning process. Based on several years of experience the strategy appears to be effective with the majority of our students. These successes support the continued use and development of this strategy. However a few students have not responded well to our approach. These limited successes point to characteristics of the objective of learning to learn and the strategy itself which facilitate improvement. We are currently evaluating the impacts of our strategy on our students to identify areas of effetiveness and improvement. Preliminary results indicate that progress in learning to learn (versus learning system dynamics) has been constrained by limits on the ability of students to reflect, generalize, self-evaluate and develop a constructivist learning model. Although educational culture and history play a large role in creating these limits improvement of our strategy can help reduce them. By doing so our strategy for learning to learn can be applied to a broader spectrum of students adn thereby prepare them for success in the twentey-first century.

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