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EVALUATING THE IMPACT OF SYSTEM DYNAMICS BASED LEARNING ENVIRONMENTS: PRELIMINARY STUDY

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Abstract

This paper reports results of preliminary study for developing a methodology on evaluating impacts of system dynamics based learning environments. Specifically causal loop mapping tool is suggested to determine the impacts of system dynamics learning on dynamic problem understanding. During the preliminary study was developed a tool for testing the understanding of the structure of system underlying a dynamic problem. The pilot experiment determined some means of characterising the complexity of a dynamic system and how the performance of the subjects can be evaluated and compared with the characteristics of the system.

Introduction

A promising technological approach to learning environments involves the use of system dynamics as a methodology since it supports both the modelling of complex, dynamic domains and interaction with learning effectiveness (Sterman, 1994). Many excellent uses of system dynamics to support learning in complex domains exist and are available commercially. Learning environments to support learning about complex, dynamic systems include SimCity™ for helping children learn bout factors influencing the growth of urban area and Beefeater™ for helping adults learn about factors influencing the growth of a particular business, and a host of other such environments which are now frequently used to support various types of learning activities. Such environments are consistent with a great deal of learning research concerning active learning (Bruner, 1985), cognitive apprenticeship (Collins, 1991), cognitive flexibility (Spiro et al., 1987), and situated learning (Lave, 1988). However, there is very little evidence to demonstrate the impact of these environments and their overall learning effectiveness. Moreover, there is no established methodology to determine which design approach might be most likely to lead to desired learning outcomes in various situations. Our long term goal is to develop a methodology which can be used to insure *consistent* success in the effectiveness of system dynamics based learning environments, and to establish reliable measures of effectiveness for such environments. We shall describe an evaluation methodology that can be suited to complex and dynamic domains. We shall then describe how that methodology can be used to evaluate the impact of system dynamics learning.

Background Review

There exists a well-elaborated methodology for analyzing a complex, dynamic domain in terms of system dynamics (Davidsen, 1996; Spector & Davidsen, 1997). That model proceeds on several assumptions. First, the type of complexity involved is characterized by systems which involve nonlinear relationships, delays and internal feedback among several variables, systemic behavior which may change dramatically over time, and systems in which human perceptions and actions based on perception play an active role in determining performance and outcomes. That such systems can be effectively modeled using system dynamics is now quite well established (Forrester, 1961, 1985, 1992; Sterman, 1994). What is not well established is how such models can be optimally used to facilitate learning.

It has been argued that collaboration facilitates learning about new and complex topics (Salomon, 1993; Vygotsky, 1978). This belief in the utility of collaboration in learning, however, has not been demonstrated to be effective in the context of system dynamics based learning environments, although nearly all such environments in some way attempt to integrate collaboration with other learners into various learning activities. Moreover, there is a clear distinction between a model of reality and the process of modeling reality. Many of those who support the use of system dynamics in learning about complex domains generally support the notion of constructivists that learners construct their own models of reality. Likewise, many who construct system dynamics based learning environments believe that active learner engagement with the underlying models is crucial. This implies that learners should be eventually be provided with access to underlyling models and encouraged to modify and reconstruct those models.

Rouwette and colleagues (in press) further argue that group model building actively contributes to learning outcomes. They have produce some preliminary evidence that both the collaborative and the constructivist aspects of such system dynamics based learning environments contribute to improved learning. However, their research is largely based on data gathered from self-reports of participants and is difficult to independently confirm and validate.

From this brief review of design trends and beliefs with regard to system dynamics based learning environments, it should be obvious that learner engagement is generally viewed as critical to the efficacy of a learning improvement, consistent with the general instructional design and learning effectiveness literature. Moreover, the general belief in the system dynamics learning community is that collaboration with other learners enhances learner engagement as does the ability to manipulate existing and create alternative models. While we share these widely held beliefs, it is our intention to establish a methodology which can be used to determine to what extent these beliefs are true.

This paper describes a methodology appropriate for evaluation of learning effectiveness in complex and dynamic domains and reports the use of that methodology in settings involving system dynamics based learning environments which include/exclude opportunities for collaboration, which show/hide the underlying system dynamics model, and which allow/disallow modification of the underlying model. Three quite different problems were selected for this purpose: (1) the spread of infection problem; (2) an environmental policy formulation problem; and, (3) a problem involving yeast reproduction. In each domain, two experts were asked to produce causal loop diagrams on paper representing the concepts, factors, and causal relationships thought to be associated with a short problem description.

The Evaluation Methodology

It is possible to view learning from a number of alternative perspectives. The preferred learning perspective largely determines the appropriate learning effectiveness methodology. Sfard (1998) identifies a participation metaphor and contrasts it with an acquisition metaphor. She argues that both metaphors should be taken into account when considering learning from a larger and longer-term perspective. We agree with this argument. The implications for evaluation are twofold. When learning is viewed as acquisition of expertise, it makes sense to evaluate learning in terms of how learners are performing and thinking in comparison with experts. When learning is viewed as participation in a community of practitioners, it makes sense to evaluate how activities of learners are changing in various learning and working situations. When the domains are dynamic and complex, evaluation is more challenging since experts are likely to exhibit a wider ranges of performances and since activities are much more open-ended than is the case with simpler domains. Nevertheless, a scientific attitude with regard to the design of environments to support learning about complex domains implies the need to collect measures of outcomes in a variety of settings in order to determine what works best, when, and why.

In this paper we focus on the learning as acquisition of expertise perspective (Ericsson & Smith, 1991). With simpler domains, it has been demonstrated that experts do in fact exhibit similarities in their thinking, and, consequently, it is possible to capture initial learner thinking patterns in the form of concept maps, to see how those maps differ from concept maps of experts, and then track changes over time and after instruction and experience performing a variety of tasks (Schvaneveldt et al., 1985). The type of concept maps which have been used to capture learner and expert thinking range from association nets to semantic networks. Surprisingly, simple association nets have proven to be excellent predictors of performance in a variety of domains, including aircraft maintenance as well as formation flying (Schvaneveldt et al., 1985). These domains, however, are not complex and dynamic in the sense described earlier, so we still regard these domains as simple when compared with the domains modeled and supported with system dynamics (e.g., predicting the spread of an epidemic, macro-economic planning, environmental policy formation, etc.).

The type of concept mapping methodology which appears to be the most appropriate for the kinds of complex, dynamic domains which are well supported by system dynamics modeling and simulation techniques is causal loop diagramming. Causal loops are visual representations of the dynamic influences and interrelationships that exist among a collection of variables. Our general hypothesis is that within the context of a problem area in a complex, dynamic system experts will construct similar causal loop diagrams. Furthermore, these diagrams will be noticeably different from those constructed by less experienced persons. As a consequence, the level of fit between a learner's causal loop diagram and that of an expert's will be a reasonable predictor of level of expertise in that problem domain. This particular methodology is partly quantitative and partly qualitative in nature. A measure of fit between a learner's causal loop diagram and an expert's is derived based on similarities in the set of key concepts identified for a particular problem domain, and the types and directions of links. Additionally, subjects are asked to insert open-ended comments about links and key components. Protocol analysis is used to determine whether a subject's comments reflect an expert level of understanding of that problem domain.

Pilot Experiment

The first step in developing the causal loop mapping tool was to produce and validate with experts causal loop diagrams for particular problem domains. Three quite different problems were selected for this purpose: (1) spread of an infection; (2) yeast reproduction; and, (3) a deer population problem. In each domain, two experts were asked to produce causal loop diagrams on paper representing the concepts, factors, and causal relationships thought to be associated with a short problem description. The suggested test tool includes a dynamic description of a problem and a questionnaire (see appendixes) in which subjects are asked to identify the concepts, relationships and effects between the concepts that describe the dynamic problem. The test experiment was conducted using three cases of dynamic problem. These cases include the following: (1) Deer population on the Kaibab Plateau, (2) Spread of an Infection, (3) Yeast Reproduction.

The questionnaires were handed out randomly between the students taking IT Strategy course. None of them have had previous experience with system dynamics or system thinking. On the first day students filled in the questionnaires where they were asked to:

- list the concepts or variables that are related to the described problem;
- indicate relationships between concepts (positive or negative)
- informally they were asked to draw out a diagram of relationships
-

After the first day there was an introductory lecture on System Dynamics. The lecture covered basic concepts of feedback (positive and negative), description of casual relationships and casual loop diagramming, also shortly were introduced concepts of stocks and flows. At the end of the second day students were asked to fill in the questionnaires again, only they were asked to pick up a different problem than they had on the previous day.

The data collected from the questionnaire was used to identify how subjects:

- understand dynamic problem description,
- how they understand what they are asked to do,
- what concepts they perceive as important and take into account, and
- how they relate them between each other.

Describing the Level of Dynamic Complexity in the System

The three problems that have been considered as a test tools can be graded according to the level of dynamic complexity that they include. Each problem had a proposed "solution set" in the form of a feedback loop diagram, which of course is not the only one, but at least includes the minimum structural complexity necessary to describe the dynamics of a system.

The level of complexity in the system can be described by the number of:

- concepts or variables,
- interrelationships or links between concepts,
- the effect of the independent concepts on dependent ones or polarities of the links
- feedback loops.
-

Note that the links and effects are separated since a person can identify that some concepts are related but can identify wrongly the effect.

The two problems of Spread of an Infection and the Yeast Regeneration are more or less equal in complexity. Both of them include three major feedback loops and the number of concepts and links are as follows:

Spread of an Infection			Yeast Regeneration		
# Concepts	# Links	Effects (+/-)	# Concepts	# Links	Effects (+/-)
6	8	8	8	11	11

The Dear Population problem, however, is more complex, compared to the above problems. First of all, this problem involves several subsystems, which are:

- predator population (including importation and hunting)
- deer population and grass available for deer as food
-

A necessary comment: the problem description of the deer population, as it was historically on the Keibab Plateau, did not cover the extinction of the predators (see the problem description for Deer Population questionnaire in appendixes), but said that the hunting on deer was stopped. Hence, that could lead to the inability to identify the necessary concepts related to the predators. The complexity of the deer population problem includes the following (see also the feedback loop diagram in appendixes):

	Deer related	Predator related
Concepts	8	9
Links	12	12
Effects	12	12

The total number of loops in the deer population problem is 8 (see appendixes).
Based on the above description of the level of complexity in the system the evaluation of system understanding by a subject can be done according to the number of concepts, links and effects that subject can identify based on the dynamic problem description.

Results and Evaluation of the Pilot Experiment

As was already mentioned the Deer Population problem was not described appropriately (i.e. without mentioning predators extinction) therefore most of the people were able to identify concepts related to the deer population, but very few did mentioned concepts related to the predators population. Also, many tended to pay attention to such concepts as pollution, acid rain etc., which can be due to the bulk of the information regarding this matter in the media. This fact also indicates novices inability to generalise and abstract to the level of complexity that is enough to describe the problem. In some cases people used description of the same concept as "less" or "more food", for example, which is a description of a state of a concept but not definition of a concept. So may be it is worth asking to determine the concepts with nouns.

The problem of spread of an infection was relatively easy interpreted and most of the people identified most of the concepts related to the populations (infected and non infected). However, not all were able to identify the effect of density and connectivity on the infection rate. Probably people were misled or confused by the concepts (descriptions) of rate of infection, rate of contacts (which is probably better to call frequency of contacts) and red contacts. In some cases people did not see that the total population is not changing and also how the density of a certain fraction of population is defined. None of the subjects indicated such concept or parameter (which can be assumed constant) as the probability of infection if there is a red contact.

In the yeast regeneration problem people seemed to identify most of the concepts and some of them were able to identify the relationships and effects. However, they also tended to introduce the concepts which are not included in the suggested solution (though, they may be relevant), such as temperature for example. Having identified such concepts they were not able to relate them to those that were described since they did not have knowledge or description of how they are related (formally or informally), for example, there was no description in the handout of how the change of the temperature would influence the budding. Also it seems like the picture of the "budding" does not support the understanding but disturbs the attention to such concepts as mature cells food particles and so on.

The overall results demonstrate how novice subjects perceive the dynamic problem and map the concepts. They tend to use too few concepts or look for concepts outside the problem description. The impact of system dynamics learning is difficult to evaluate. However, on the second day there was an attempt to draw casual loop diagrams, but due to the incomplete identification of all concepts they were inadequate, and also the lack of practice in casual loop diagramming had its effect. Hence, the introduction of the system dynamics learning has to be more deep.

Conclusions and Future Work

The initial study, design of the test tool and pilot test suggest partly qualitative and also quantitative description and evaluation of the understanding of a dynamic problems. The further work includes the improvement of the test tool and introduction of a more comprehensive system dynamics learning procedure as a treatment in the experiment. The system dynamics learning can be design in the form of a computer learning environment or as series of lectures. The performance can be measured by the account of the structural components that were identified by the subjects relative to the number of components in a suggested solution set. That would show to what extent subjects are able to reproduce the structural components and relationships based on the dynamic description of a problem. The learning effect then can be measured based on the performance before and after the learning by comparing the performance of subjects.

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Appendixes: Dynamic problem descriptions, suggested solution set and questionnaire form.

The Questionnaire Form:

a. List the variables or concepts you think are related to the deer population behaviour over the period of time. (Please note that you can list as many variables that you can think of that may have caused the observed behaviour. Use the back of the sheet if you need more space)

Example: Suppose you identify a concept P and you assume that P has some effect on the observed behaviour. Then on the **"What is the name of the concept"** column you will write "P". On the **"Explain the meaning of the concept"** column you will write "Age of deer" if that's the meaning of "P".

What is the name of the concept?	**Explain the meaning of the concept**
P	Age of Deer

b. From the concepts you have listed above indicate the relationship between each of them.
Example: Let us assume you have identified two concepts above as "P" and "Q". We shall also assume that you think that "P" has a **positive** influence on "Q" i.e. An **increase** in "P" leads to an **increase** in "Q". Below you will write underneath **concept 1**: "P" and underneath **concept 2**: "Q" and on the second column you will write a positive sign indicating the effect of "P" on "Q". Had it been a negative effect i.e. when there is an increase in P this leads to a decrease in Q, you will write a negative sign instead of a positive sign.
Now go on a fill the blank spaces.

Concept 1	**Concept 2**	**Effect of Concept 1 on Concept 2 : Positive(+) or Negative(-). Note: (Not Both)**
P	Q	+

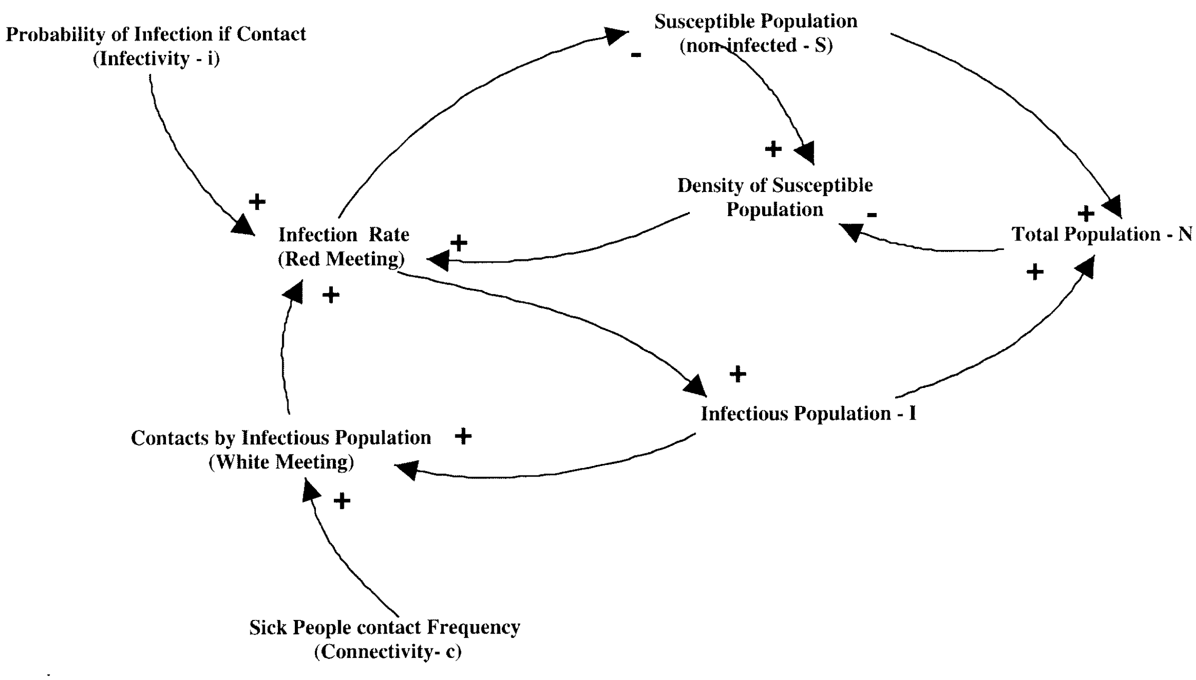
Problem 1

The spread of an Infection

Read the passage below:
The total population of Tech, a town in Brazil, consists of two sub-populations, the susceptible population and the infectious population. The susceptible (non – infected) population is drained by infection spreading in the population at a particular rate. At the same time, the infectious population is increased by the infection spreading at the current rate. The infection rate (the rate at which the infection is spreading) changes over time. It depends on the rate of contacts between members of the infectious population and members of the uninfected population, called red contacts, leading to the transmission of decrease. The rate of red contacts is determined by the rate of contacts between members of the infectious population and any other member of the population as well as the probability that the person contacted is actually non-infected. This probability is closely related to the density of susceptible in the population in total. The rate of contacts between members of the infectious population and any other member of the population is determined by the size of the infectious population and the rate at which each of them meet with other members of the population.

The spread of an Infection

Possible Solution Set



Problem 2

The growth and decline of a yeast population

Read the passage below:

Yeast is a yellowish sediment that develops in sugar solutions such as fruit juices. It consists largely of simple cells of a minute fungus and is useful particularly as an agent for fermentation in the making of bread, alcoholic beverages such as wine and bear, and other foods. During fermentation, yeast lives by breaking sugar molecules into alcohol and carbon dioxide. In fact, alcohol is one of the oldest methods known for preserving juice and food. Yeast cells reproduce by building, as shown in Figure 1.0.

During the process of budding, small bud forms on the membrane of a mature cell. As the bud grows, it breaks away from its "mother" and forms a new plant. When put in a favourable sugar environment, yeast cells keep budding and tend to continue to develop until the sugar on which they feed reaches a critical point. At this point, available sugar is low and the yeast's growth medium has been filled with alcohol and carbon dioxide. Since yeast cannot survive in a medium of alcohol and carbon dioxide, individual yeast cells eventually die.

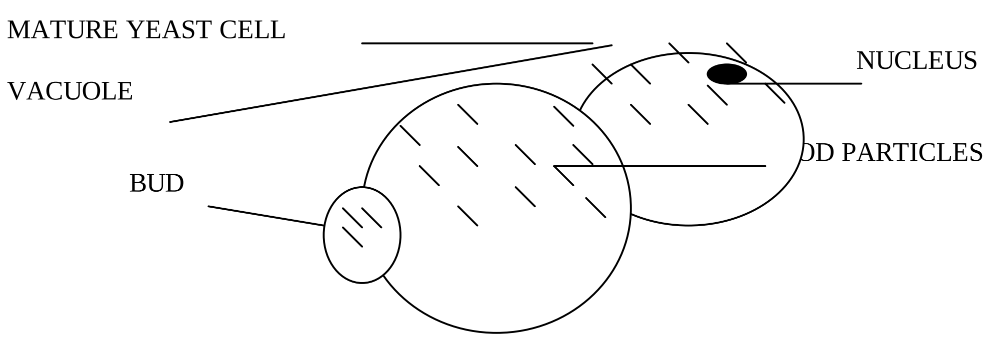
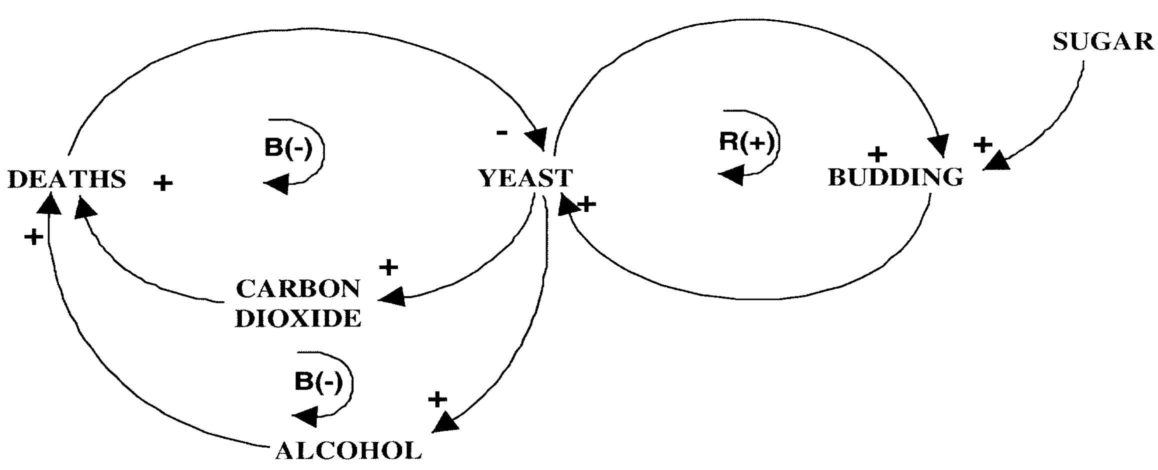


Figure 1.0 Budding of a yeast cell

The growth and decline of a yeast population
Possible Solution Set

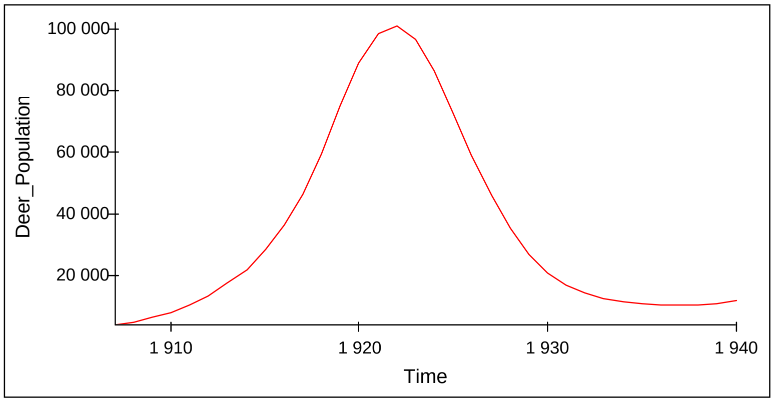


Problem 3

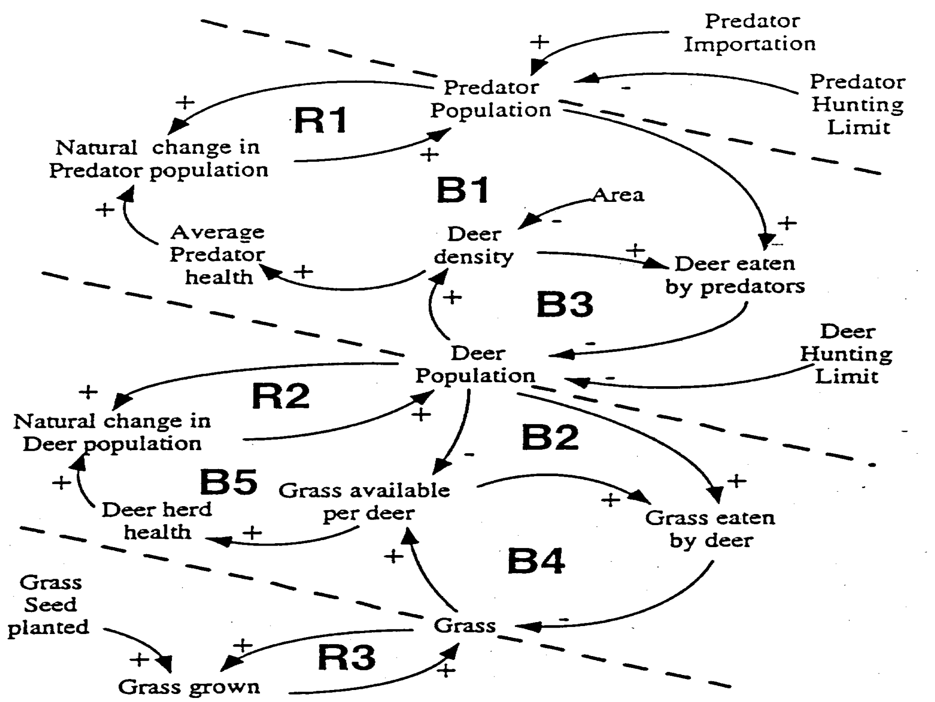
Historical account of Deer Irruption on the Kaibab Plateau:

Read the story below:
Prior to 1907, the deer herd on the Kaibab Plateau, which consists of some 727,000 acres and is on the north side of the Grand Canyon in Arizona, numbered about 4,000. In 1907, a law was passed banning all hunting of deer from the area. By 1918 the deer population increased tenfold, and by 1924 the herd had reached 100,000. Then it started to decrease and by 1936 to 1940 it was around 10,000.

Graphical representation of the deer population over time (years)



Appendix 1: Simplified Causal Loop Diagram of Kaibab Plateau System Model



Feedback Loops

B1 - Predators eat deer loop
B2 - Deer eat grass loop
B3 - Deer density controls deer eaten loop
B4 - Grass availability controls grass eaten loop
B5 - Deer control grass availability & deer health loop

R1 - Predator population growth loop
R2 - Deer population growth loop
R3 - Grass growth loop