AN INVESTIGATION INTO USING A MODEL TO TEACH SYSTEMS THINKING SKILLS

By

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A THESIS PRESENTED TO THE GRADUATE SCHOOL OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE

UNIVERSITY OF FLORIDA

2011
To my dad, who always gives me perspective and encouragement. I love you dearly.
ACKNOWLEDGMENTS

I would like to thank my committee for their guidance and insightful advice. I have learned a great deal from them and this project was a success largely due to their extensive knowledge and collaborative ideas. I would like to extend a special thank you to Dr. Martha Monroe, my committee chair, whose whole-hearted support, counseling, and passion are unparalleled. She inspires her students to achieve greatness and her faith in her students seems to have no boundary. Thanks also to Matthew Cohen for conducting the interventions and sacrificing his time and energy to ensure the project was as successful as it could be.

I thank my family and friends who have never lost sight, even when my direction was unclear. The support of those close to me has allowed me to believe in myself and pursue goals that seemed unattainable.

I am eternally grateful for my graduate student cohort, whose friendship, advice, and knowledge have been vital to this process. I thank them for having the time to support my endeavors with notepads and video cameras in hand. I especially want to thank Geetha Iyer, Lindsey McConnell, Sarah Hicks, Annie Oxarart, Deb Wojcik, and Annelena Porto Delgado, who will always be part of my family.

I want to thank the UF Water Institute and College of Agriculture and Life Sciences for providing funding to pursue a graduate degree that would have never been possible otherwise.

I thank Dina Leibowitz and Anna Cathey for allowing me to use their data. Their model was integral to this project and provided us with rich insights into the usefulness of models. I thank Dina for her friendship, kind words, time, moral support, and conversation.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACKNOWLEDGMENTS</td>
<td>4</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td>7</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>8</td>
</tr>
<tr>
<td>ABSTRACT</td>
<td>9</td>
</tr>
<tr>
<td><strong>CHAPTER</strong></td>
<td></td>
</tr>
<tr>
<td>1 INTRODUCTION</td>
<td>11</td>
</tr>
<tr>
<td>2 METHODS</td>
<td>19</td>
</tr>
<tr>
<td>Study Design</td>
<td>19</td>
</tr>
<tr>
<td>The Intervention</td>
<td>19</td>
</tr>
<tr>
<td>Diagramming the System</td>
<td>21</td>
</tr>
<tr>
<td>Testing the Hypotheses</td>
<td>22</td>
</tr>
<tr>
<td>Data Collection Tools</td>
<td>23</td>
</tr>
<tr>
<td>Focus Groups</td>
<td>24</td>
</tr>
<tr>
<td>Final Exam</td>
<td>24</td>
</tr>
<tr>
<td>Pilot Testing</td>
<td>25</td>
</tr>
<tr>
<td>Analysis</td>
<td>26</td>
</tr>
<tr>
<td>3 RESULTS</td>
<td>29</td>
</tr>
<tr>
<td>Pre and Posttests</td>
<td>29</td>
</tr>
<tr>
<td>Focus Groups</td>
<td>30</td>
</tr>
<tr>
<td>Final Exam Question</td>
<td>35</td>
</tr>
<tr>
<td>Limitations</td>
<td>36</td>
</tr>
<tr>
<td>4 DISCUSSION</td>
<td>41</td>
</tr>
<tr>
<td>Hypothesis 1</td>
<td>41</td>
</tr>
<tr>
<td>Hypothesis 2</td>
<td>41</td>
</tr>
<tr>
<td>Focus Groups</td>
<td>41</td>
</tr>
<tr>
<td>Final Exam</td>
<td>42</td>
</tr>
<tr>
<td>Synthesis</td>
<td>42</td>
</tr>
<tr>
<td>5 CONCLUSION</td>
<td>44</td>
</tr>
<tr>
<td><strong>APPENDIX</strong></td>
<td></td>
</tr>
<tr>
<td>A PRETEST</td>
<td>49</td>
</tr>
</tbody>
</table>
## LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-1</td>
<td>Mean scores for pre and posttest for each treatment</td>
<td>38</td>
</tr>
<tr>
<td>3-2</td>
<td>Paired t-tests for pre and posttest means for each of the treatments</td>
<td>38</td>
</tr>
<tr>
<td>3-3</td>
<td>One-way ANOVA on the posttests of Treatments 2 and 3</td>
<td>38</td>
</tr>
<tr>
<td>3-4</td>
<td>Correlation statistics for student demographics for year in school, prior systems experience and pre/posttest scores</td>
<td>39</td>
</tr>
<tr>
<td>3-5</td>
<td>Correlation statistics for student demographics for course grades, majors, GPA, and pretest scores</td>
<td>39</td>
</tr>
<tr>
<td>3-6</td>
<td>Responses to the final exam question about algae and springs</td>
<td>40</td>
</tr>
</tbody>
</table>
## LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-1</td>
<td>Diagram of the springs system from the presentation/discussion</td>
<td>28</td>
</tr>
</tbody>
</table>
AN INVESTIGATION INTO USING A MODEL TO TEACH SYSTEMS THINKING SKILLS

By

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August 2011

Chair: Martha C. Monroe
Major: Forest Resources and Conservation

There is a need to develop effective means to teach systems thinking to a variety of audiences, some of whom will not have copious amounts of time to invest in systems education. Though there is a large body of research dedicated to teaching systems thinking to students over a period of weeks or months there has been little research on effectively teaching the basic components of systems thinking in a two-hour period.

In this study we developed a short systems thinking intervention for undergraduates. We used multiple and relevant examples, function-centered Structure-Behavior-Function as a framework to develop the intervention, and a computer model to test the effectiveness of that strategy. We used a pre/posttest design with focus groups to measure the use of thinking skills and focused on three specific concepts: feedback, delay, and indirect causality.

The results of the study indicate that a short, well-conceived systems thinking lecture can relay concepts of indirect and delayed causality and feedback mechanisms. After receiving a 50-minute lecture on systems thinking, posttest scores were significantly greater than pretest scores (p<. 001). Two groups of students received an additional systems presentation/discussion, one using a computer model to relay
concepts, the other using static graphs to convey the same information. These students’ posttests were also significantly increased over pretest scores (p< 0.001), but were not significantly different from each other. The results indicate that computer models are not necessary to teach systems thinking concepts in short interventions. Engaging presentations using multiple examples that stress relationships between components are useful strategies to teach these systems thinking concepts. The information obtained in this study can be used to help college and non-formal educators develop interventions to help adult learners understand the complexity of the world around them.
CHAPTER 1
INTRODUCTION

When we try to pick something up by itself, we find it hitched to everything in the universe.

--John Muir, 1869

The world abounds in complexity. The self-organizing patterns of the ridge and slough landscape in the Everglades of south Florida are a prime example of a visible indicator of underlying complexity. This system is characterized by a complex set of feedback mechanisms between the sediments, hydrology, and vegetation that operate in such a way as to create elevated ridges of sawgrass surrounded by deeper open water (Watts et al. 2010). The world hosts many other complex systems, which scientists seek to understand. Socially constructed systems such as public transportation, global financial markets, and generational poverty, along with environmental problems such as groundwater depletion, climate change, and deforestation are complex and therefore are difficult to remedy. Understanding the dynamic and complex nature of systems allows us to approach solutions to environmental and social problems and better understand the world in which we live.

Riess and Mischo (2010 pg.707) describe systems thinking as “the ability to recognize, describe and model (e.g., to structure, to organize) complex aspects of reality as systems.” Systems thinking is a cognitive process that allows a person to identify and understand the interactions occurring within a defined area by constructing a mental or visual model of the system. The world “is increasingly governed by complex systems that are dynamic, self-organizing, and continually adapting” (Assaraf and Orion
therefore having the ability to conceptualize systems is a vital step in the process of understanding them.

While it may be inferred that systems thinking is integral for researchers and problem solvers of complex systems and less important for the general public, such is not the case. The last few decades have seen a wave of support for increasing the public's involvement in decision-making -- an important deviation from the "experts know best" era of generations past (Chittenden 2011; Davies 2009; Rowe and Frewer 2000; Stave 2000). People need to be part of the decision-making process in order to understand and play a role in solving complex environmental problems.

For the public to be effectively involved, they need to be able to make informed decisions about complex issues (Frewer, Howard and Shepherd 1998) and be scientifically literate (Durant, Evans and Thomas 1992; Feinstein 2010; Hawthorne and Alabaster 1999; Stave 2002;). Civic science literacy is believed to be the "cornerstone of informed public policy" (Miller 1998 pg. 204) Systems thinking provides an analytical framework to promote scientific literacy among the public.

Thinking systemically requires that people develop a mental image of a system, yet it is challenging for most people to conceptualize a functioning system with all of its interconnections, due to our general "inability to combine an understanding of the parts into an understanding of the whole" (Johnson 2010 pg.116). While systems thinking may not be intuitive, (Liu and Hmelo-Silver, 2009; Verhoeff, Waarlo and Boersma 2008) once mastered, it can provide a means to simplify a complex world of many different systems.

There is a broad recognition of the need to teach systems thinking to the public (Johnson 2010; Liu and Hmelo-Silver 2009; Verhoeff, Waarlo and Boersma 2008) and
to explore methods of teaching systems thinking, especially in non-formal education forums. Computer models are conventionally used as a means to teach about systems and systems thinking, however they are difficult and time-consuming to master because they are often not intuitive (Deaton 2000 pg.13; Liu and Hmelo-Silver 2009; Thompson and Reimann 2010). Outside of universities and high schools with courses dedicated to exploring systems, however, there is not likely to be much demand for 12-week systems thinking courses. Further, the public tends not to invest major time commitments unless the issue is perceived as threatening (Monroe et al. 2009). If we expect to captivate learners for systems thinking interventions, it will likely be for brief periods of time. Therefore it is important to develop effective strategies for short interventions, exploring both how to enhance understanding and what the essential concepts might be. Simple computer models that allow learners to explore the intricacies of a system without being required to have a deep understanding of how the model was designed might provide a useful tool to teach systems (Thompson and Reimann 2010).

While the nomenclature varies from field to field, the concepts of systems thinking are the same. Every system must have stocks, flows, drivers, causal relationships and feedback loops (Deaton and Winebrake 2000; Meadows 2008). “Stocks are the elements of a system that you can see, feel, count or measure” (Meadows 2008 pg.17) and are “an accumulation of material or information that has built up in a system over time” (Meadows 2008 pg.189). Flows can be described as the movement of stocks in and out of the system (Meadows 2008). A causal relationship is one where one variable or system component has some effect on another within the system (Deaton and Winebrake 2000). Feedback mechanisms are signals that accelerate (reinforcing or positive) or decelerate (balancing or negative) a process within a system (Deaton and
Feedback loops are the “closed chains of causal connections from a stock, through a set of decisions, rules, physical laws, or actions that are dependent on the level of stock and back again through a flow to change the stock” (Meadows 2008 pg.189). Delays or lags are inherent to many systems and can be described as an effect that is not immediately evident within the system due to a delay in the feedback signal on the stock.

A clear understanding of stocks, flows, causal relationships, feedback mechanisms, and lag or delay is vital to developing a systems perspective (Deaton and Winebrake 2000; Hmelo, Holton and Kolodner 2000; Jacobson and Wilensky 2006; Meadows 2008; Reiss and Mischo 2010), as these are fundamental to a variety of complex systems. “Being able to recognize and distinguish between [positive and negative feedback loops] in a real-life environmental system can lead to significant understandings of how the system works” (Deaton and Winebrake 2000 pg.16). Being able to recognize and identify these functions enables people to think in systems. Some of these concepts, however, should be familiar to undergraduate students if they have some initial understanding of the system, such as stocks and flows in an ecosystem.

Conveying the concept of indirect causality is important because many causal relationships are not directly related to the outcome and cannot be explained in terms of linear causality. In addition, linear causality is intuitive and most frequently emphasized in traditional education systems, (Hmelo, Holton and Kolodner 2000; Hmelo-Silver, Marathe and Liu 2007). For example, for a person to comprehend the numerous causes of climate change they must understand that burning fossil fuels is not the sole perpetrator, but instead, there are a number of seemingly unrelated factors that also play a role.
Feedback mechanisms are also important to understand because most causal relationships in the world are dynamic and loop-like instead of linear and chain-like. Lags and delays or delayed causality are important to understand because often the effects of some causes do not become evident immediately. For example, the effects of DDT on bird populations could not be predicted until long after it was used as a pesticide. Many systems experts suggest that these concepts are among the most basic and most important for the public to better understand (Deaton and Winebrake 2000; Hmelo, Holton and Kolodner 2000; Jacobson and Wilensky 2006; Meadows 2008; Reiss and Mischo 2010).

To help educators develop the skills needed to enable students to understand systems, the ‘Structure-Behavior-Function’ (S-B-F) theory of complex systems was developed as a way to teach systems thinking (Prabhakar and Goel 1998). The fundamental approach of S-B-F is that students begin by learning the structure or systems components and their respective relationships (Hmelo, Holton and Kolodner 2000; Liu and Hmelo-Silver 2009). They then learn about the behavior or mechanism of the structures and finally the function or role each structure has within the system (Liu and Hmelo-Silver 2009).

Encouraging learners to conceptualize beyond isolated structures is necessary for understanding the system. This can be accomplished by focusing on the function (Function-centered S-B-F [fS-B-F]) and behavior of the structures and this is an easier task if the learners are already familiar with the structures. An fS-B-F approach provides learners with a context for understanding how the structures interact, which allows them to build on their knowledge, connect concepts and then apply them (Hmelo, Holton and Kolodner 2000; Liu and Hmelo-Silver 2009; Meadows 2008).
A few studies have explored the use of short interventions using computer models and S-B-F to convey systems thinking skills. (Assaraf and Orion 2005, 2010; Ossimitz 2000). In one noteworthy example, Liu and Hmelo-Silver (2009) developed two-hour computer modules on the respiratory system for pre-service teachers and middle school students to teach systems concepts. Students viewed the same information organized in two different modules; some looked at structures of the respiratory system first and others were introduced to the functional aspects of those structures first. The pre-service teachers’ posttests revealed that participants who received the function-centered module were able to explain the system’s structures (p<.001), behaviors (p<.05), and functions (p<.05) at the non-salient or micro level, which included concepts such as gas exchange and transport. The middle school students posttests indicated that students who received the function-centered module were able to identify more behaviors (p<.05), trended toward being able to identify more functions (p<.05), and had no difference in ability to identify structures.

Another demonstration of the useful difference between traditional S-B-F and fS-B-F can be seen in the degree to which experts and novices hold a systems perspective (Jacobson and Wilensky 2006; Liu and Hmelo-Silver 2009). When experts talk about systems, they describe the function and behavior, where novices, whose understanding is often confined to structure, do not (Hmelo, Holton and Kolodner 2000; Liu and Hmelo-Silver 2009). For example, a non-expert might describe an Intensive Care Unit (ICU) by focusing on the patients, doctors, nurses, medical equipment, and medicines—parts of the details, elements, and structures of an ICU. An expert is more likely to explain patient life support and critical care. These are functions of the unit, which require the same structural elements, but the focus is on how those structures operate as a unit.
rather than merely defining them as separate entities. An expert would also include complex, emergent behaviors that arise within an ICU; such as how the types of patients in the unit, such as intoxicated drivers who have killed someone or drug dealers who have been shot, can have negative impacts on the staff morale and attitudes. The intricate processes and emergent behaviors become more noticeable as a person’s understanding of the system is heightened.

To effectively teach systems thinking skills in a shorter period of time, a number of strategies may be useful. The most effective methods of teaching complex concepts and skills include multiple examples and engaging learners in physically or mentally working with concepts (DeYoung and Monroe 1996; Eysink et al. 2009; Krajcik and Sutherland 2010). Engaging learners while teaching, instead of relying solely on passive instruction, has been shown to increase cognitive involvement, which also factors into a person’s ability to apply knowledge to new situations (DeYoung and Monroe 1996; Dunleavy and Milton 2008; Lepper and Malone 1987). Simplified systems diagrams are also tools that can be employed to convey systems thinking concepts.

For this project, I will measure the effectiveness of conveying the concepts of indirect causality, feedback mechanisms, and delays to the learners using multiple examples and function-centered S-B-F (fS-B-F), an effective strategy to teach complex systemic behavior in a two-hour unit. I will also explore whether seeing a computer model of a system enables students to understand indirect causality and feedback mechanisms.

I hypothesize that 1) a short lecture that provides examples of indirect causality, feedback loops, and delays using function-centered S-B-F explanations and multiple, concrete examples can effectively convey systems to learners and 2) technology, as
represented by a computer model, coupled with a discussion and presentation will be a more useful component to help learners understand indirect causality, feedback mechanisms, and delay than the discussion and presentation alone.
CHAPTER 2
METHODS

This chapter will describe the study, three data collection tools, pilot testing of the intervention and tools, sample population, and types of analyses used for this project.

Study Design

An experimental pre/post design was developed to test the two hypotheses. Prior to the intervention, 50 undergraduate students registered for the course Society and Natural Resources in the spring of 2011 were given a pretest. One week after the pretest, all students received a 50-minute lecture on systems thinking using multiple examples of systems to explain concepts. The class was then divided into three groups based on their course section. The first group received the post-test shortly after the lecture (Treatment 1). This group of students then received a presentation/discussion without a computer model. The second group received the lecture, followed by the presentation/discussion without a computer model and finally the posttest (Treatment 2). The third group received the lecture, then a presentation/discussion that included computer model, and then a posttest (Treatment 3). Follow-up focus groups helped explore how students remembered the exercise and discussion. One question on the students’ final exam provided insight into long-term memory. The data gathered from students in Treatment 1 were grouped with the data from Treatment 2 for the focus groups and final exam question because they received the educational strategy.

The Intervention

All of the material for this intervention was prepared by a faculty member who is an expert in systems ecology. The first part of the intervention was a 50-minute lecture, which detailed five systems, including a home rat infestation, an arctic fox and island
seabird interaction, and overfishing in the Philippines. Students read the article, Environmental Tipping Points: A New Slant on Strategic Environmentalism (Marten, Brooks and Suutari 2005), which details three case studies with a focus on indirect causality, feedback mechanisms and delays. Information from this article was used to reinforce these concepts. The examples referenced components as part of a larger system where behaviors emerged as a result of the interactions and feedback mechanisms within the system. The presentation and reading included multiple examples that described the functional aspects of these system components.

The next phase of the intervention were 50-minute presentation/discussions, which conveyed nearly identical concepts, but differed in the delivery. This presentation used one local example--freshwater springs--and was based on data collected by PhD students at the University of Florida. The treatments were designed to give learners a context for evaluating the drivers and feedback mechanisms that might be responsible for nuisance algae growth in this system. The beginning of both presentations were identical and provided students with information on the springs ecosystem, including the functions of the system elements: nutrients, snails, dissolved oxygen, flow rate, and vegetation (i.e., an fS-B-F strategy). Students were shown a systems diagram (Figure 2-1) of the relationships between the components and asked to evaluate what might be causing the algae to grow to nuisance levels. Treatments 1 and 2 used static graphs to illustrate the relationships between snails, aquatic vegetation, dissolved oxygen, and algae, while Treatment 3 used a computer model generated in Microsoft® Excel to convey the relationships between the same organisms.

FS-B-F provided a framework for the systems presentation and treatments. As such, functional components and their relationships within the systems were the primary
focus of the information presented. Because most students were from wildlife, forestry, and natural resources, we assumed they were somewhat familiar with the structural components of ecosystems (i.e. foxes, rats, cats, dogs, shore birds, algae, snails, and nutrients) as well as their functions in the scenarios used in the lecture and treatments.

**Diagramming the System**

Diagramming systems can be a useful tool to visualize conceptual ideas (Luckie 2011). Further, engaging learners is preferable to passive transmission of information because it increases cognitive involvement, which aids in the learning process (DeYoung and Monroe 1996). Using conceptual mapping exercises to help teach systems thinking concepts allows learners to grasp the relationships between components. This enables learners to construct a conceptual image and reveal the complexity of the system (Luckie 2011).

During the treatment, students were presented with a skeleton diagram that consisted of words related to the springs ecosystem printed across the page: algae, nitrates, recreation, grazers, water flow, aquatic vegetation, manatees, human population and dissolved oxygen. Before receiving information about the springs, they were asked to draw arrows between components they believed to be related. They were also asked to write positive and negative signs to explain the types of interactions that occur between components. The students were reminded that a plus sign would indicate a positive relationship and a negative sign would indicate an inverse relationship. For example, if they believed that more manatees would cause algae to decrease, then they would draw an arrow pointing from “manatees” to “algae” and would write a negative sign at the arrow’s point. The students were asked to continue adding to the diagram as they listened to the information on springs. Diagramming was
used as a method to engage learners, and ensured that students were listening to lecture, as each handed in a completed diagram.

**Testing the Hypotheses**

H1: A short presentation that provides examples of indirect causality, feedback loops, and delays using fS-B-F explanations and multiple, concrete examples can effectively convey systems concepts to learners.

Treatment 1: These students took a pretest, received the systems lecture, took a posttest and then received Treatment 2, the non-model discussion. This group was used to determine if systems thinking concepts can be taught in a one-hour lecture. This group is also used as the control group for H2.

H2: Technology, as represented by a computer model, coupled with a discussion and presentation will be a more useful component to help learners understand indirect causality, feedback mechanisms, and delays and is more effective than the discussion and presentation alone.

Treatment 2: These students took a pretest, received the systems lecture, received a presentation/discussion on freshwater springs health that stressed the relationships between components and drivers in the springs ecosystem, then took a posttest. This group was presented with a static graph that showed little or no correlation between algae and nitrate concentration.

Treatment 3: This group took a pretest, received the systems lecture, received a similar presentation/discussion on springs but instead of graphs viewed a model created in Microsoft® Excel of the springs ecosystem, then took a posttest. The instructor made manipulations to the model and ran it while students observed. The manipulations included increasing nitrate concentration, reducing populations of organisms that graze
upon algae and decreasing concentration of submerged aquatic vegetation to show their individual effects on algae growth. Each of these changes to the model produced a graphical output.

**Data Collection Tools**

A pretest of 18 open-ended questions and 6 demographic questions (Appendix A) was designed to measure familiarity with systems concepts. The same instrument was used for the posttest without demographic questions (Appendix B). These tools measured students’ ability to describe the function of system components in the context of feedback loops, indirect causality, and delays, which literature (Deaton and Winebrake 2000; Hmelo, Holton and Kolodner 2000; Jacobson and Wilensky 2006; Meadows 2008; Reiss and Mischo 2010) suggests are paramount to understanding systems. The pretest demographic questions included items about years at the university, GPA, name, and major, as well as questions to determine prior systems knowledge. Questions about systems concepts were conveyed through seven scenarios. The scenario questions asked participants to read a short paragraph (Appendix A) and then provide an explanation of the behavior. The scenarios were followed by open-ended questions that asked participants to describe another scenario where the same phenomenon occurred.

A rubric was developed (Appendix C) to score all responses to the pre and posttest questions. Answers were scored between 0-3, depending on the depth of the explanation provided. A response of “I don’t know” or no response received a score of 0, a response that indicated little understanding of the concept received a 1, a score of 2 was given to responses that revealed some understanding of the concept, but lacked
mention of the process, and a score of 3 was given to answers that adequately or better described the process. All scores were summed to give a final score for each student.

**Focus Groups**

Focus groups were organized 3 months after the initial interventions to determine if information from the presentation and treatments had a lasting effect on students’ understanding of systems and what students remembered about the systems intervention. Information from the focus groups was also used to explain the results from the students’ perspectives. Students who had the most improvement from pre to posttest as well as those who scored high on both tests were invited to participate in a focus group. These students were chosen because they understood the concepts and would be likely to provide the most relevant information about what was most helpful to their learning the concepts. Four focus groups were held with a total of 12 students in April 2011. Students who participated in the focus groups were from each of the treatments.

A series of questions (Appendix D) were asked of students to determine if the presentations affected the way they look at complex systems, both related and unrelated to springs health. These focus groups were audio recorded, transcribed in full, and analyzed. All of the participants signed consent forms (IRB Protocol # 2010-U-0763, Appendix E).

**Final Exam**

At the end of the semester, after incorporating systems thinking and simplified systems diagrams into four case studies covered in lecture, we asked students a question on the final exam to determine if they retained a systemic perspective in terms
of freshwater springs. The question was based on information presented to the students during the presentation/discussion.

**Pilot Testing**

The lecture, presentation/discussion, model, and pre/posttest were pilot tested with 71 students from another undergraduate course, “Facets of Sustainability” in September 2010 and significant improvements were made to the treatments and tests. The pilot pre and posttests were identical and largely multiple-choice questions asking students to identify the type of systems concept exhibited in each scenario. The students were randomly assigned to one of two groups: Treatment 2 (n=33) and another received Treatment 3 (n=38). Observers were present and the treatments were video recorded.

Several flaws were identified and remedied from the pilot version of this project. The issues that would have a substantive impact on the study were the delivery of the treatments, the survey tool, and the model. The treatments during the pilot study were given to the participants by different instructors whose teaching styles were undoubtedly different. One instructor provided all of the material in the final execution of this project. The pilot study used multiple-choice questions, which essentially tested students’ knowledge of terminology rather than knowledge of the concepts. The pre and posttests were changed to open-ended questions where students were provided with scenarios and asked to explain the processes involved. This allowed an assessment of their systems knowledge or ability to think in systems notwithstanding any prior formal instruction in systems. The original computer model contained several errors that required the model to be recalibrated before using it in the final version of the project.
The improved version of the pre and posttest was pilot tested on another group of undergraduates registered for a Fire Ecology course in the spring 2011. None of these students were enrolled in Society and Natural Resources. Several additional changes were made based on the information gathered. Some questions were eliminated for the sake of time and others were re-worded for clarity.

**Analysis**

The data were analyzed using both quantitative and qualitative methodologies. The quantitative analysis was performed using IBM® SPSS® Statistics version 19. A one-way ANOVA was performed to determine if there were significant differences between the groups based on pretest scores. Paired t-tests were conducted to determine if the differences between the means of the pre and posttest scores were statistically significant. A one-way ANOVA was used to determine if differences between the posttest scores minus the pretest scores from Treatments 2 and 3 were statistically significant. Calculations were performed to determine if there were correlations between demographic information and scores.

Qualitative analyses of the data included rubric creation, coding, and use of the Constant Comparison Method (Dye et al. 2000). A rubric (Appendix C) was developed to score the pre and posttest questions and to ensure internal validity, an unaffiliated individual scored the tests in addition to the Principle Investigator. The scoring was consistent between scorers.

The content of the focus group interviews was also analyzed qualitatively. The recordings were transcribed and then coded to establish themes. The Constant Comparison Method was used to develop 10 codes (Appendix G). The transcriptions were read numerous times and codes were continuously revised to accurately reflect
the theme revealed within the data. Themes emerged out of the codes and related ideas were grouped (Glesne 2006 pg.147-172).

The answers to the final exam question were scored 0-3 (Appendix C).
Figure 2-1. Diagram of the springs system from the presentation/discussion
CHAPTER 3
RESULTS

Fifty undergraduate students received the initial systems lecture, but ten students were removed from the sample population. One student spoke English as a second language and was unable to comprehend the questions. The others were absent from the presentation/discussion or did not return their posttest. The sample size of the entire population was 40 students, with 9 students receiving Treatment 1, 18 students receiving Treatment 2, and 13 receiving Treatment 3. These students were a fairly diverse group of undergraduates though most were majoring in Forestry/Natural Resource Conservation (n=12), Wildlife Ecology (n=14), with the remaining students majoring in Marketing, Environmental Sciences, Biology, Agricultural Education, and Religion. Nearly all were either juniors (n=18) or seniors (n=19). The students’ self-reported GPAs ranged from 2.02 to 4.0. There were 22 females and 18 males. All students gave their informed consent to allow us to use their data (approved IRB Protocol # 2010-U-0763, Appendix F).

When asked an open-ended question about their prior experience with systems (Appendix C), about a third (n=13) reported to have heard of systems briefly either on television, from someone, in a course/courses, or in journals, but the majority (n=26) had never heard of systems. Only one student reported to have taken a course dedicated to systems.

Pre and Posttests

The one-way ANOVA of the pretest differences between groups was not significant, suggesting the groups were similar at the beginning of the intervention. All of the mean scores improved from pre and posttest (Table 3-1) and a paired t-test of the
A one-way ANOVA was performed to determine if there were significant differences between posttest score improvement by concept. There were no significant differences, which indicates that students’ learned about all of the concepts. These findings suggest that systems thinking can be taught in a one-hour presentation to undergraduate students conveying the concepts of indirect causality, feedback mechanisms, and delay.

A one-way ANOVA was performed on the posttest minus pretest scores of Treatments 2 and 3 (Table 3-3) and there are not significant differences between scores (p> .05). This suggests that immediately after the presentation/discussion students who received the model treatment were no more knowledgeable in systems thinking concepts than those who received the static graphs,

Correlation analyses were performed on students’ demographic information (Tables 3-4 and 3-5). The analysis revealed significantly positive correlations between student classification (i.e. freshman, sophomore, junior, senior) and pretest scores (p< .01). This indicates that students who had more years in school had higher scores. This did not impact the study, however, because upper-class students were evenly distributed across treatment groups. There were also significant correlations between scores on the pretest and scores on the posttest (p< .001), which is not unexpected. There were not significant correlations between other demographic information such as final course grade and posttest scores.

**Focus Groups**

The focus group interviews were conducted with 12 students, representing each of the treatment groups. There were two students from Treatment 1 and five each from Treatments 2 and 3. The information from the students who were in Treatments 1 was
combined into Treatment 2 (non-model treatment) for the purpose of discussing the use of the model and learning about nutrients and algae. The interviews yielded 10 useful themes and well as provided rich data that helped to explain what factors helped these students perform well on the pre and posttests. Their responses revealed some of what was confusing and easy to learn, what they already believed, and what notions were hard to change in this short intervention. They explained the concept of delay was well-understood and retained, multiple and relevant examples helped them understand the material, and systems thinking had been useful after the presentation and treatments. An analysis of which students provided comments on the causes of algae in the springs ecosystem suggested notable differences in their perceptions.

It appears that delay was one of the easier concepts for these students to comprehend. There was an example from the pre and posttests as well as the lecture that used sunburn as a means to describe the concept of delay. Students referenced this example more than any other when asked to recall systems thinking principles from the pre and posttests:

Participant 1.3.3:  (1/1/6) There was the delay one--the sunburn [example].
Participant 1.4.3:  (1/2/1) The sunburn one was delay.
Participant 2.3.3:  (2/1/15-17) The sunscreen one was time lag, the time differences between two variables.

The sunburn example was easy for students to relate to the concept of delayed causality, which may be due to most people’s familiarity with sunburn.

The use of multiple relevant, real-world examples made systems thinking less abstract for the students who participated in the focus groups:
Participant 1.3.3: (1/5/28) I think the biggest help was all the examples of everything.

Participant 1.2.2: (1/7/2) The examples were really helpful.

(1/6/1-2) Like the cats and dogs, there were all these terms and then you give the reasons and examples it made perfect sense.

Participant 2.3.3: (2/14/7-9) I think the real world examples and the simplicity of it initially helped to understand the general concepts. It just made it easier to understand.

Students indicated that the many examples of systems they were familiar with helped them to understand the common dimensions of systems we were conveying.

Students also commented on the usefulness of the diagramming exercise and system diagrams used in the lecture and presentation/discussion:

Participant 3.3.1: (3/22/11-15) I liked the discussion period, I thought it was fun, because we had…paper and we were following along, trying to draw our lines. I wanted to keep drawing my lines and try to figure out how everything had a connection.

(3/23/15-26) You don’t necessarily think of everything when you are looking at it. But then to have all of the different factors written out, you think, “how can you connect them?” But seeing the web and how you could draw everything together helped me to visually understand it.

Participant 4.3.2: (4/32/8-9) I learned that you could diagram it and have it manifested on paper to talk to people about it.

According to the respondents, diagramming exercises and simplified systems diagrams can help learners develop a conceptual mental image of the connections.
Some of the students reported visualizing other scenarios through a systems perspective as well as using it as a framework to think about the interconnectedness of situations in general:

Participant 1.4.3: (1/4/27) It helped us see how it applied to everything.

Participant 1.3.3: (1/10/1-5) So I think having this really opened it up so I could broaden it to more things than just what we talked about in those classes.

Participant 2.2.3: (2/15-16/39-4) So it’s like a positive feedback system where as the number of trees increase the reflective surface from the snow and the sunlight is reflected back up but if there are trees not as much gets reflected so it gets warmer, so more trees grow and it’s this big cycle.

Students applied the concepts they learned in the treatments to think about a variety of other situations both in their courses and in their everyday lives.

The students were asked the question, “Thinking about north central Florida springs for a moment, I would like to know from each of you- to what degree do you think an abundance of nutrients is causing excessive algal growth, on a scale of 0-10.” They were asked to explain their answers. The answers ranged from 5-10. Students from Treatment 2 tended to give higher scores indicating they were more certain that nutrients cause algae and less certain of other possible causes.

Participant 1.2.2: (1/3/32-34) I’d say 10 because if they’re noticing the algae coming in after they’re bringing nutrients then obviously the input is creating an output.
Participant 2.5.2: (2/12/16-22) I think it’s an unequivocal link beyond just what we learned there. I’ve seen other studies and personal research that links them heavily and beyond that, what else is there that we were really provided with that could show algal blooms.

Participant 2.4.2: (2/12/23-24) I think it (nitrates) is a primary cause but then I think that there are other causes that I’m not educated on.

Students from Treatment 3 responded with lower scores and indicated they were open to alternative causes of algae.

Participant 1.3.3: (1/4/1-5) I’d have to go one step lower and be like a 6 or 7 because there’s other human impact, like erosion of the natural grasses... provides more opportunity for the eutrophication stuff to happen.

Participant 1.4.3: (1/4/9-10) the amount of oxygen, the nutrients that we were talking about.

Participant 2.2.3: (2/12/25-28) I’ll say a 5 because I think to a certain extent that the nutrients are going to cause algal blooms but there’s going to be other limiting factors that once it reaches that threshold it can’t really grow anymore if something else limiting it.

(2/12/30-34) In the lecture it was like a feedback loop where the algae was blooming a lot and taking a lot of the oxygen out of the water which was killing the snails or making the snails not eat as much which made the algae bloom more, so it wasn’t necessarily just all the nutrients.

(2/12-13/35-5) I think initially I would’ve said like a 9 or 10 but after the lecture I feel really surprised that when we did that modeling thing I thought that it seemed to have a lot less of a direct effect. I would probably say maybe like a 4 to a 6. It seemed like we moved the amt of nutrients up a lot and it barely had any effect and I think it had more having to do with sunlight exposure. I think it definitely has an effect but not as much as I
thought before. Because its dependent on a lot of different variables as well.

The students who received Treatment 3 still attributed nutrients as the primary cause of nuisance algae growth, but were more noticeably more open to other less direct causes. This may be an indication that the presentation of the model was more effective at relaying the concept of indirect causality

**Final Exam Question**

A question was asked on the final exam to determine if students had retained information they learned in the treatments. The question was:

According to Matt Cohen’s discussion section on springs in Florida, what is the best response to the question of excess algae in springs?

a. Increased nutrients have been proven to be the cause
b. Increased nutrients are the most likely cause
c. Increased nutrients may be one cause
d. There is little evidence that increased nutrients are the cause

Four of the students from the initial study were not included in this data set--two students dropped the course and two others left the answer blank on their final exams, the sample size of this population was 36.

The responses to this question indicated that perhaps most students were at least able to question the importance of nutrients in the springs systems (Table 3-6). Out of the students who participated in the study, half (n=23) indicated that nutrients may be only one cause and three students indicated that there was little evidence that nutrients cause increased algae, a point that was made in all discussion sections. This was remarkable, since on the pretests, only three from the entire population of students listed any causes other than nutrients as being responsible for excess algae.
A number of Treatment 2 students (n=9) responded that nutrients were most likely the cause, compared to one from Treatment 3 who gave this response. Although all students received information that should have caused them to consider additional factors, a large minority failed to remember them.

**Limitations**

As with any research study, there are limitations. For this project the small sample size, non-random assignment of treatment groups, timing of discussion periods, length of pre/posttests compared to time allotted to take them, and quality of instrument were some of the potential limitations.

The population was small and determined by the number of students who registered for the course. The uneven distribution of participants in the treatment groups was determined by the timing of the discussion sections. Having a larger sample population, with an equal number of participants in each treatment would have given the results greater statistical power and made them more generalizable to the population of undergraduate students.

The students were assigned to the treatment groups based on the course section in which they were registered. This did not allow for non-random assignment, which can adversely impact the external validity of the results. Each of the treatments did, however, contain a relatively diverse mixture of students based on the number of majors, student classification, and self-reported GPAs. Therefore the potential effects of the validity of the study should have been minimized.

Another limitation was the timing of the discussion sections; the Treatment 2 group received the treatment directly after the systems thinking presentation, while the other two groups received treatments one day after later. This may have impacted the
results, as the subjects in Treatment 3 had slightly higher posttest scores (mean score= 30.92) than the Treatment 2 (mean score= 29.28). Treatment 3 participants may have benefited from the additional time between presentation and treatment, as it may have served to allow them to absorb and then apply the information.

Another limitation was the length of the pre and posttests and the amount of time allotted to take them. The pretests were administered at the beginning of lecture a week prior to the intervention. Students were allowed 20 minutes to finish the test, but several were given extra time. All students completed the pretests within the lecture period. However, the posttests were given after the interventions, which took up most of the discussion period. In order to prevent students from being late to other classes, they were given the option to take the post-tests home and return them the following day during lecture. The open-ended nature of the responses made it possible to allow students to complete the post-test at home; there were no outside resources that could have assisted them. Students were also assured that there were no wrong answers, in an attempt to mitigate any desire the students had to work together to get perfect scores on the test. The fact that the data collection tool was lengthy and students had a limited amount of time could have impacted the quality of the answers they provided, but shortening the tool would have removed potentially helpful questions. However, the short period of time provided the opportunity to capture their initial thinking, which was more useful than providing lengthy answers that students were less sure of.

Another potential limitation is the quality of the instrument used to test the effectiveness of the teaching strategies. Although expert review helped increase content validity, it is possible that the questions could have been improved to better ascertain knowledge of systems.
Table 3-1. Mean scores for pre and posttest for each treatment

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Mean Pre</th>
<th>N</th>
<th>Std. Deviation</th>
<th>Std. Error Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment 1</td>
<td>20.22</td>
<td>9</td>
<td>8.614</td>
<td>2.871</td>
</tr>
<tr>
<td>Treatment 1</td>
<td>27.89</td>
<td>9</td>
<td>10.517</td>
<td>3.506</td>
</tr>
<tr>
<td>Treatment 2</td>
<td>21.06</td>
<td>18</td>
<td>4.556</td>
<td>1.074</td>
</tr>
<tr>
<td>Treatment 2</td>
<td>29.28</td>
<td>18</td>
<td>4.944</td>
<td>1.165</td>
</tr>
<tr>
<td>Treatment 3</td>
<td>20.92</td>
<td>13</td>
<td>5.299</td>
<td>1.470</td>
</tr>
<tr>
<td>Treatment 3</td>
<td>30.92</td>
<td>13</td>
<td>7.522</td>
<td>2.086</td>
</tr>
</tbody>
</table>

Table 3-2. Paired t-tests for pre and posttest means for each of the treatments

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Mean Difference</th>
<th>Std. Deviation</th>
<th>Std. Error Mean</th>
<th>Sig. (2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment 1</td>
<td>-7.667</td>
<td>3.808</td>
<td>1.269</td>
<td>8</td>
</tr>
<tr>
<td>Treatment 1 Post</td>
<td>-10.594</td>
<td>5.128</td>
<td>1.209</td>
<td>17</td>
</tr>
<tr>
<td>Treatment 2</td>
<td>-8.222</td>
<td>6.683</td>
<td>1.854</td>
<td>12</td>
</tr>
<tr>
<td>Treatment 3</td>
<td>-10.000</td>
<td>14.039</td>
<td>3.050</td>
<td>10</td>
</tr>
</tbody>
</table>

Table 3-3. One-way ANOVA on the posttests of Treatments 2 and 3

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>20.434</td>
<td>1</td>
<td>20.434</td>
<td>.541</td>
<td>.468</td>
</tr>
<tr>
<td>Within Groups</td>
<td>1094.534</td>
<td>29</td>
<td>37.743</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>1114.968</td>
<td>30</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 3-4. Correlation statistics for student demographics for year in school, prior systems experience and pre/posttest scores

<table>
<thead>
<tr>
<th>Classification</th>
<th>Prior ST exp</th>
<th>Total Pre</th>
<th>Total Post</th>
<th>Final exam</th>
</tr>
</thead>
<tbody>
<tr>
<td>Classification</td>
<td>Pearson</td>
<td>-.116</td>
<td>.439**</td>
<td>.035</td>
</tr>
<tr>
<td>Correlation</td>
<td>Pearson</td>
<td>.483</td>
<td>.005</td>
<td>.833</td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td>N</td>
<td>39</td>
<td>39</td>
<td>39</td>
</tr>
<tr>
<td>Prior ST exp</td>
<td>Pearson</td>
<td>1</td>
<td>.007</td>
<td>.113</td>
</tr>
<tr>
<td>Correlation</td>
<td>Pearson</td>
<td>.968</td>
<td>.486</td>
<td>1.000</td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td>N</td>
<td>40</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>Total Pre</td>
<td>Pearson</td>
<td>.007</td>
<td>1</td>
<td>.675**</td>
</tr>
<tr>
<td>Correlation</td>
<td>Pearson</td>
<td>.968</td>
<td>.000</td>
<td>.754</td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td>N</td>
<td>40</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>Total Post</td>
<td>Pearson</td>
<td>.113</td>
<td>.675**</td>
<td>1</td>
</tr>
<tr>
<td>Correlation</td>
<td>Pearson</td>
<td>.486</td>
<td>.000</td>
<td>.901</td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td>N</td>
<td>40</td>
<td>40</td>
<td>40</td>
</tr>
</tbody>
</table>

Table 3-5. Correlation statistics for student demographics for course grades, majors, GPA, and pretest scores

<table>
<thead>
<tr>
<th>Class Grade</th>
<th>Class Classification</th>
<th>Major</th>
<th>GPA</th>
<th>Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class Grade</td>
<td>Pearson</td>
<td>.343'</td>
<td>.242</td>
<td>.158</td>
</tr>
<tr>
<td>Correlation</td>
<td>Sig. (2-tailed)</td>
<td>.035</td>
<td>.161</td>
<td>.351</td>
</tr>
<tr>
<td>N</td>
<td>38</td>
<td>38</td>
<td>35</td>
<td>37</td>
</tr>
<tr>
<td>Major</td>
<td>Pearson</td>
<td>.343'</td>
<td>-.080</td>
<td>-.125</td>
</tr>
<tr>
<td>Correlation</td>
<td>Sig. (2-tailed)</td>
<td>.035</td>
<td>.636</td>
<td>.449</td>
</tr>
<tr>
<td>N</td>
<td>38</td>
<td>40</td>
<td>37</td>
<td>39</td>
</tr>
<tr>
<td>GPA</td>
<td>Pearson</td>
<td>.242</td>
<td>-.080</td>
<td>1</td>
</tr>
<tr>
<td>Correlation</td>
<td>Sig. (2-tailed)</td>
<td>.161</td>
<td>.636</td>
<td>.025</td>
</tr>
<tr>
<td>N</td>
<td>35</td>
<td>37</td>
<td>37</td>
<td>36</td>
</tr>
<tr>
<td>Total Pre</td>
<td>Pearson</td>
<td>-.242</td>
<td>-.181</td>
<td>-.183</td>
</tr>
<tr>
<td>Correlation</td>
<td>Sig. (2-tailed)</td>
<td>.142</td>
<td>.265</td>
<td>.279</td>
</tr>
<tr>
<td>N</td>
<td>38</td>
<td>40</td>
<td>37</td>
<td>39</td>
</tr>
</tbody>
</table>
Table 3-6. Responses to the final exam question about algae and springs

<table>
<thead>
<tr>
<th>Group</th>
<th>Nutrients are the cause</th>
<th>Nutrients are most likely the cause</th>
<th>Nutrients may be one cause</th>
<th>There is little evidence that nutrients are the cause</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment 2</td>
<td>5% (n=2)</td>
<td>19% (n=7)</td>
<td>36% (n=13)</td>
<td>5% (n=2)</td>
</tr>
<tr>
<td>Treatment 3</td>
<td>0</td>
<td>5% (n=1)</td>
<td>27% (n=10)</td>
<td>3% (n=1)</td>
</tr>
</tbody>
</table>

More students who received Treatment 2 were less open to additional factors
CHAPTER 4
DISCUSSION

Hypothesis 1

The data clearly suggest that key systems thinking concepts can be taught in a one-hour lecture. By using multiple and relevant examples and focusing on an fS-B-F format, undergraduate students were able to apply these concepts to different scenarios. Treatment 1 posttest scores were significantly higher than the pretests, so we must reject null hypothesis that a short presentation using examples of indirect causality, feedback loops, and delays using function-centered S-B-F explanations and multiple, concrete examples will not effectively convey systems concepts to learners.

Hypothesis 2

Using the computer model did not yield any significant difference in posttest scores between Treatments 2 and 3, however the mean posttest scores for these treatments were increased (p>.05) (see Table 3-2). So we cannot reject the null hypothesis. A computer model, coupled with a presentation/discussion was not a more useful component to help learners understand indirect causality, feedback mechanisms, and delay than the discussion and presentation alone.

Focus Groups

The information gathered in the focus groups helped to provide insight into what students believe are the most effective strategies to help them understand the systems concepts we emphasized in this intervention. Many of the students commented on the helpfulness of seeing multiple examples of systems that they could relate to and were familiar with. They also said the diagramming exercise helped them to visualize the
connections and to see how the components interacted within the system. Only one student mentioned that the computer model was useful.

**Final Exam**

The data from the final exam question reveal 19% of students from Treatment 2 believe that nutrients are most likely the cause of excessive algae compared 5% from Treatment 3. Students received identical information related to this topic, except that Treatment 3 saw a computer model to show the complexity of the springs system. Assuming the students in the two groups are similar and the presentation/discussion was effective, either the students from Treatment 2 were not paying attention, rejected the new information, or did not believe the new information because they did not see it presented in the form of the computer model.

**Synthesis**

There is literature to suggest that using computer models to teach about systems can be quite successful in terms of participant learning and retention (Jacobson and Wilensky 2006; Liu and Hmelo-Silver 2009; Reiss and Mischo, 2010), however, most of those studies were conducted over a period of several weeks to a semester and students manipulated the model themselves. There is a lengthy time commitment associated with learning how models operate. The intention of this study was to determine if using the model as a visual aid could help learners conceptualize the processes of this complex system. The focus groups and final exam question indicate that the model was more useful in helping learners have a more holistic perception of springs health and causes of excessive algae, though the posttest scores do not corroborate that finding. Follow-up focus groups with all of the students from the study
and a direct question about the computer model might have enabled us to better understand the usefulness of the model.

Systems thinking concepts can be taught in short interventions if characteristics of the intervention include multiple, familiar, relevant examples, as well as exercises that engage learners, such as diagramming exercises. The information gathered during the focus groups indicate the students considered those factors to be integral to their understanding of systems thinking concepts.

This information can be used to develop effective interventions to teach systems thinking concepts to a variety of audiences, from college classrooms to non-formal education settings. This study shed some light on the characteristics that a successful systems thinking intervention could contain: relevant and multiple examples and a diagramming exercise. These results could be useful to educators, systems thinking experts or not, who can develop units or lectures to convey systems thinking skills to their students.
CHAPTER 5
CONCLUSION

Much of the world can be described in terms of complex and dynamic systems consisting of feedback mechanisms and non-linear causal relationships. A systems thinking framework can help people understand complex interactions. It is becoming increasingly more necessary for the public to understand concepts such as indirect causality, feedback mechanisms and delayed causality, especially as environmental degradation, water scarcity, and threats of a changing climate promise to affect humans on a global scale. The public needs to be involved in resolving science-based issues that affect socio-ecologic systems (Stave 2002). In order for citizens to be involved in the decision-making process, they must be present and have a presence among scientists. In order for this to occur, the public needs to have a working knowledge of systems and have the ability to apply systems thinking to a variety of situations. Therefore it is important that systems thinking be developed as a thinking paradigm for all.

Understanding what the audience knows about a topic is integral to developing successful interventions. An audience assessment would be ideal, as it can reveal what the intended audience knows, what they do not and whether or not they hold any misconceptions about the information at hand (Jacobson, McDuff and Monroe 2007). In this project, students’ prior knowledge probably hindered their ability to consider alternate explanations about the causes of excessive algae. Several focus group participants exposed their firmly embedded notions about the causal relationships between nitrates and algae and had a difficult time considering other possibilities. This is not surprising, as literature states that when people are provided with information that
is counter to their mental model, they disregard the new, unfamiliar information (Festinger 1957; Kearney and Kaplan 1997).

Despite presenting information that would cause attentive students to recognize some level of cognitive dissonance and learn new information, many students did not. The focus group data suggest that prior knowledge about nutrients, eutrophication, and algae are part of the students’ mental models. Only one student expressed the impact of the surprising revelation of the computer model and this student was a very high achiever throughout the course. It would likely require more than one presentation for most students to call prior knowledge into question. Even though the students were provided with information that should have caused them to consider things other than nitrates and fertilizers as culprits in promoting excessive algae growth, less than half (n=12) of the 31 students in the Treatments 2 and 3 included additional factors in their posttest answers. This is after the students received a presentation on the topic and diagrammed many of the possible causes of increased algae. During the focus groups, respondents from Treatment 2 stated there was a strong connection between algae and nitrates, while Treatment 3 students were less certain. Interestingly, on the final exam, most (n=26) of the 36 students from the Treatments 2 and 3 considered things other than nitrates as causing nuisance algae. This could be a result of the multiple iterations of systems throughout the course or perhaps students learned that most systems often surprise us and therefore were not willing to provide a response that indicated certainty.

Systems thinking skills can be taught in a variety of contexts to a diverse array of audiences. The results of this study suggest that lengthy courses dedicated to systems thinking are not the only way to convey systems concepts. Undergraduate students
could benefit from presentations introducing systems concepts in a variety of courses. Brief units that teach systems thinking concepts can be useful tools to aid educators in relaying concepts of delay, feedback, and indirect causality to students and increasing science literacy. Undergraduate students in a variety of majors can use these concepts to explain market fluctuations, ecosystem function, and international negotiations.

These undergraduates may be similar to other audiences, as well. The types of adults who are likely to be interested in working on a local issue and voicing their ideas about solutions may be similar to the undergraduates who took this course as an elective. If so, then interested adults could probably learn about systems concepts in a short lecture and gain enough understanding to apply this information to the issue of interest.

There are particular contexts in which these adults gather that may be most conducive to learning about systems. Groups where participants meet repeatedly and could understand that having a background in systems as a worthy investment could apply systems thinking to problems they want to solve. Participatory processes, such as community forums, focus groups, working groups, faith-based study circles, and citizen advisory boards, especially those that seek to make sense of complex environmental problems, could benefit from teaching strategies such as these. However, if prior knowledge and common perceptions interfere with understanding the relationships between elements, more effort might be needed to help learners assimilate the new information.

This study demonstrates that it is possible to teach systems thinking skills using short interventions. Students in this study gained a different understanding of how to
view ecological problems. Using multiple examples (DeYoung and Monroe 1996; Eysink et al. 2009) with scenarios that were relevant and familiar, enabled students to direct their cognitive attention toward learning the skills associated with systems thinking. Because systems can be confusing, non-intuitive, and difficult for even highly educated individuals to understand (Sweeney and Sterman 2007), it is important that learners involved in systems thinking programs are not overloaded by attempting to learn new information as well as a new way of thinking. Using familiar content could allow presentations to be developed using function-centered S-B-F as the framework.

While computer models have proved to be an important tool to teach systems thinking skills to learners (Deaton and Winebrake 2000 pg.13; Liu and Hmelo-Silver 2009; Thompson and Reimann 2010), in this context, and at least in the short-term, the model was not significantly more helpful than no model. Students improved scores in both treatments, with and without the computer model. Perhaps this implies that systems thinking presentations can be effectively simplified and that purveyors of systems thinking interventions should not be intimidated by believing that a computer model is requisite for relaying the concepts. However, the differences in the focus group data and final exam question do indicate that the model may have been useful in allowing students to consider the roles of the system components, if the treatment groups were sufficiently equivalent which they appear to be. These differences may also be attributed to the continued reinforcement of the concepts throughout the course that somehow amplified the minor differences between treatment groups.

Relaying the concepts of indirect and delayed causality and feedback mechanisms to learners is foundational to developing a systems perspective. Having an
understanding of these skills enables a person to make sense of myriad systems. Fostering a systems perspective in learners can provide them with a valuable framework for thinking as well as enhancing science literacy. In response to the need to promote science literacy among the public, a National Science Foundation panel concluded, “One of the most compelling challenges of our time is to enhance the public’s access to and understanding of complex environmental information” (Pfirman et al. 2003 pg.41).

Developing strategies for effectively teaching systems thinking concepts in short interventions deserves further exploration. This study elucidated some important characteristics of successful methods to teach systems thinking skills. However, more work could be done determining the best methods for teaching each concept and how the concepts are best mastered. Further research is also needed to understand long-term effects of learning systems thinking skills, how often these skills should be reinforced, and how easily these concepts are transferred from one type of system to others.
APPENDIX A
PRETEST

What is your Major?
__________________________

What is your Minor, if you have one?
__________________________

What is your GPA?
______________

According to the number of credits you have earned, are you classified as a:
A. Freshman
B. Sophomore
C. Junior
D. Senior
E. Graduate student

How long have you been a student at UF?
A. Less than a year
B. 1-2 years
C. 2-3 years
D. 3-4 years
E. More than 4 years

If you have heard of systems or systems thinking, such as Systems Ecology, Mechanical Systems, etc. before today, where did you hear about it?

Circle the answer that best describes your understanding of systems thinking.
A. Not at all
B. A little understanding
C. Moderate understanding
D. Pretty good understanding
E. Understand it very well

Please answer each question with a specific sentence or two at most. Please print if you have handwriting that may be challenging to decipher. Please write "I don't know" if that is most appropriate.

1. An older woman broke her left wrist as a child. It healed, but not perfectly, and she shied away from using it throughout life. She recently developed a pain in her right wrist, but doesn’t recall ever injuring it. She visits her doctor, who asks a few questions and is
not surprised about pain in the right wrist. What is the best explanation why the right wrist is bothering the woman?

1a. Can you give another example from your own experiences where this sort of phenomenon occurs?

2. Kelp forests are found in marine environments and are formed by a variety of giant algae that is anchored to the ocean floor. One of the main herbivores of kelp are sea urchins, who damage the kelp “forest” by grazing where the algae are anchored, allowing the kelp to float away. Sea otters eat urchins. Historical hunting of otters altered the entire ecosystem. How would hunting otters affect the kelp?

2a. Can you think of another example where altering one part of the system unexpectedly affected some other part?

3. What are some ways that reduced snowfall affects the economy?

4. There is a device that measures the soil moisture content of lawns and controls when sprinklers come on. The purpose is to save water by eliminating unnecessary watering. Please explain process that occurs for this technology to conserve water.

4a. Can you give another example from your own experiences where this sort of phenomenon occurs?

5. Imagine two people sharing a bed in Minnesota with a dual electric blanket that has two controls, one for each half of the blanket. When one person becomes chilly, she turns the dial to heat up her half of the blanket. The controls on this particular blanket were installed incorrectly, so unbeknownst to them Person A has control of Person B’s side of the blanket and vice versa. Can you explain what happens?

5a. Can you give another example from your own experiences where this sort of phenomenon occurs?

6. Pine forests are fire adapted in that pine needles burn easily and pine bark is highly protective of the tree. Frequent fire (say every 2-3 years) reduces competition from other trees that could grow faster and taller than pines when fire is absent, but are likely to die when fire is present. Moreover, these competitors have leaves that burn much less easily, so as they outcompete pines, fire also becomes much less likely. What do you think the effect would be of a decade or more of fire-exclusion?

6a. Can you think of another example from your own experience where a small change was self-perpetuating?

7. Growing up, you were taught to apply waterproof sunscreen throughout the day to prevent sunburn. On a trip to the beach, you diligently check your skin for signs of pink and reapply consistently. When you get home, however, you find that you are sunburnt. Why?
7a. Can you give another example from your own experiences where this sort of phenomenon occurs?

8. Imagine it’s Christmas and you are buying lots of presents for your family. You call to check your balance each time you make a purchase to be sure you have enough money. A week after Christmas you receive 7 bounced transaction notices in the mail. Why were you not aware that this was going to happen?

8a. Can you give another example from your own experiences where this sort of phenomenon occurs?

9. Have you been to any of the springs in north Florida?

9a. How familiar are you with the causes of increased algae in Florida Springs ecosystem?
   A. Not at all
   B. Slightly familiar
   C. Somewhat familiar
   D. Fairly familiar
   E. Very familiar

9b. Can you explain what might be the causes of the algae in the springs and spring runs?
APPENDIX B
POSTTEST

Circle the answer that best describes your understanding of systems thinking.
A. Not at all
B. A little understanding
C. Moderate understanding
D. Pretty good understanding
E. Understand it very well

Please answer each question with a specific sentence or two at most. Please print if you have handwriting that may be challenging to decipher. Please write “I don’t know” if that is most appropriate.

1. An older woman broke her left wrist as a child. It healed, but not perfectly, and she shied away from using it throughout life. She recently developed a pain in her right wrist, but doesn’t recall ever injuring it. She visits her doctor, who asks a few questions and is not surprised about pain in the right wrist. What is the best explanation why the right wrist is bothering the woman?

1a. Can you give another example from your own experiences where this sort of phenomenon occurs?

2. Kelp forests are found in marine environments and are formed by a variety of giant algae that is anchored to the ocean floor. One of the main herbivores of kelp are sea urchins, who damage the kelp “forest” by grazing where the algae are anchored, allowing the kelp to float away. Sea otters eat urchins. Historical hunting of otters altered the entire ecosystem. How would hunting otters affect the kelp?

2a. Can you think of another example where altering one part of the system unexpectedly affected some other part?

3. What are some ways that reduced snowfall affects the economy?

4. There is a device that measures the soil moisture content of lawns and controls when sprinklers come on. The purpose is to save water by eliminating unnecessary watering. Please explain process that occurs for this technology to conserve water.

4a. Can you give another example from your own experiences where this sort of phenomenon occurs?

5. Imagine two people sharing a bed in Minnesota with a dual electric blanket that has two controls, one for each half of the blanket. When one person becomes chilly, she turns the dial to heat up her half of the blanket. The controls on this particular blanket were installed incorrectly, so unbeknownst to them Person A has control of Person B’s side of the blanket and vice versa. Can you explain what happens?

5a. Can you give another example from your own experiences where this sort of phenomenon occurs?
6. Pine forests are fire adapted in that pine needles burn easily and pine bark is highly protective of the tree. Frequent fire (say every 2-3 years) reduces competition from other trees that could grow faster and taller than pines when fire is absent, but are likely to die when fire is present. Moreover, these competitors have leaves that burn much less easily, so as they outcompete pines, fire also becomes much less likely. What do you think the effect would be of a decade or more of fire-exclusion?

6a. Can you think of another example from your own experience where a small change was self-perpetuating?

7. Growing up, you were taught to apply waterproof sunscreen throughout the day to prevent sunburn. On a trip to the beach, you diligently check your skin for signs of pink and reapply consistently. When you get home, however, you find that you are sunburnt. Why?

7a. Can you give another example from your own experiences where this sort of phenomenon occurs?

8. Imagine it’s Christmas and you are buying lots of presents for your family. You call to check your balance each time you make a purchase to be sure you have enough money. A week after Christmas you receive 7 bounced transaction notices in the mail. Why were you not aware that this was going to happen?

8a. Can you give another example from your own experiences where this sort of phenomenon occurs?

9. Have you been to any of the springs in north Florida? [Yes] [No]

9a. How familiar are you with the causes of increased algae in Florida Springs ecosystem?
   A. Not at all
   B. Slightly familiar
   C. Somewhat familiar
   D. Fairly familiar
   E. Very familiar

9b. Can you explain what might be the causes of the algae in the springs and spring runs?
APPENDIX C
SCORING RUBRIC

Prior systems experience
0=Not heard of systems
1= Heard of it briefly (mentioned, TV, etc)
2= Heard it in course/courses or read about it in journals
3= Took at least one class related to systems

Systems Understanding
1=A
2=B
3=C
4=D
5=E

1. Wrist-Indirect causality
0 = “I don’t know” or no answer
1= No understanding of indirect causality or incorrect/incomplete explanation
2= Overuse due to neglect of Left wrist
3= Great explanation of indirect causality

1a. Indirect causality
0= “I don’t know”
1= No understanding of indirect causality or incorrect/incomplete explanation
2= Adequate explanation of indirect causality
3= Great example of indirect causality

2. Kelp forests-indirect causality
0=“I don’t know” or no answer
1= No understanding of indirect causality or incorrect /incomplete explanation
2= Fewer otters to eat urchins leads to increased grazing
3= Great explanation of indirect causality

2a. Indirect causality
0= “I don’t know”
1= No understanding of indirect causality or incorrect/incomplete explanation
2= Adequate explanation of indirect causality
3= Great example of indirect causality

3. Sprinklers-Balancing feedback
0=“I don’t know” or no answer
1= No understanding of balancing feedback or incorrect /incomplete explanation
2= The sprinklers come on when the soil is dry, thus conserving water
3= When the soil becomes dry, the sprinklers turn on and stay on until the soil reaches a certain wetness, then they turn off
3a. Balancing feedback
0= "I don’t know"
1= No understanding of balancing feedback or incorrect/incomplete explanation
2= Adequate explanation of balancing feedback
3= Great example of balancing feedback

4. Heating blanket-Reinforcing feedback
0= "I don’t know"
1= No understanding of reinforcing feedback or incorrect/incomplete explanation
2= Adequate explanation of reinforcing feedback-One gets hot and turns down the dial
3= Great example of reinforcing feedback – As one gets colder they turn up the dial, heating up the other, who turns down the dial. One continually gets hotter, as the other gets colder

4a. Reinforcing feedback
0= "I don’t know"
1= No understanding of reinforcing feedback or incorrect/incomplete explanation
2= Adequate explanation of reinforcing feedback-
3= Great example of reinforcing feedback

5. Fire exclusion-Reinforcing feedback
0= "I don’t know"
1= No understanding of reinforcing feedback or incorrect/incomplete explanation
2= Explanation of the process- Pines would be replaced by hardwoods
3= Adequate explanation of reinforcing feedback – Pines would be replaced by hardwoods, which would then exclude fire, allowing hardwood succession to continue

5a. Reinforcing feedback
0= "I don’t know"
1= No understanding of reinforcing feedback or incorrect/incomplete explanation
2= Explanation of process without connection of the cycle
3= Adequate explanation of reinforcing feedback

6. Sunburn-Delay or lag
0= "I don’t know"
1= No understanding of delays/lags or incorrect/incomplete explanation
2= Adequate explanation of delay/lag
3= Great example of delay/lag

6a. Delay or lag
0= "I don’t know"
1= No understanding of delays/lags or incorrect/incomplete explanation
2= Adequate explanation of delay/lag
3= Great example of delay/lag
7. Bounced transactions-Delay or lag
0= "I don't know"
1= No understanding of delays/lags or incorrect/incomplete explanation
2= Adequate explanation of delay/lag
3= Great example of delay/lag

7a. Delay or lag
0= "I don't know"
1= No understanding of delays/lags or incorrect/incomplete explanation
2= Adequate explanation of delay/lag
3= Great example of delay/lag

8. Snowfall affects on economy
0= "I don't know"
1= Businesses don’t suffer because they are able to remain open or businesses that rely on snow suffer (snow plows, ski resorts, salt companies)
2= Lower heating bills, leaving people with more money
3= Additional indirect effects mentioned-snowmelt, river flows, albedo and climate, affects on crops

9. Visited springs
0= No
1= Yes

9a. Familiar with causes of algae
0= Not at all
1= Slightly familiar
2= Somewhat familiar
3= Fairly familiar
4= Very familiar

9b. Explain causes of algae
0= “I don't know” or no response
1= “Nitrates” “phosphorus” or “runoff” chemicals
2= Fewer than 3- reduced grazers, DO, recreation, invasives, flow, nitrates, reduced consumption of algae
3= 3 or more- reduced grazers, DO, recreation, invasives, flow, nitrates, and reduced consumption of algae

Final Exam Question
0=Increased nutrients have been proven to be the cause
1=Increased nutrients are the most likely cause
2=Increased nutrients may be one cause
3=There is little evidence that increased nutrients are the cause
APPENDIX D
FOCUS GROUP QUESTIONS

1. Do you remember any of the scenarios from the quizzes at the beginning of the semester?
   a. What was the principle involved in the scenario?

2. Since the systems thinking lecture, have you seen that principle in other situations?
   a. Have you said to yourself, “Oh, that is indirect causality or reinforcing feedback”?

3. Thinking about north central Florida springs for a moment, I would like to know from each of you, to what degree do you think an abundance of nutrients is causing excessive algal growth. On a scale of 0-10.
   a. Can you explain why you feel that way?

4. Let’s take a minute to review the main concepts from Matt Cohen’s lecture and the springs example.

5. How interested were you in Matt’s lectures?
   a. Did they cause you to think about other systems?

6. Have you thought about systems in your day to day life since Matt’s lecture?
   a. Can you think of examples of systems you have seen?
   b. Have you consciously realized, “Oh, this looks like a system”?

7. Can you think of some different examples of systems that demonstrate basic features that we were explaining?

8. You were selected because you had great improvement from the pre to posttest. What do you think helped you to understand systems?
   a. And what about those things were most useful?

9. Can you think of anything that we could have done or explained differently that would have been more helpful?

10. For those of you who heard of ST in course, which course was it?
    a. What kinds of things did they say about systems?
    b. What was the context that they used to talk about systems?
    c. Did you find yourself thinking about systems differently after learning about systems?
APPENDIX E
IRB FOR PRE AND POSTTEST DATA

Informed Consent

Protocol Title: The effects of systems thinking interventions on undergraduate students

Please read this consent document carefully before you decide to participate in this study.

Purpose of the research study:

Next week you will listen to a lecture on systems and participate in a discussion as a part of your regular class. Each discussion group will participate in a slightly different strategy of covering the same material. As a part of my master’s thesis research, I would like to measure any potential difference between the two discussion treatments. I would like your permission to access your quiz data. If you are willing to participate in the study, please sign the following form. Doing so tells me that you voluntarily agree to have your quiz information become part of my Masters thesis research on strategies for teaching systems thinking.

You do need to answer all the questions on the form to receive your participation grade for today’s class. If you decline to allow me to use your answers they will be eliminated from my data set. Additionally, your instructor will not know who has provided consent to participate in the study.

What you will be asked to do in the study:

You will be asked to answer a few questions before we begin. These answers will help us understand what type of knowledge you have on the topic as well as provide us with a little information about you that does not identify you in any way (i.e. What is your major?). You will be asked to answer questions about systems thinking before and after the lecture and discussion.

Time required:

This exercise will last for the duration of the lecture and discussion periods. The pre and post test will take less than ten minutes.

Risks and Benefits:

There are no risks or benefits for allowing me to access your answers

Compensation:

There will be no compensation for allowing me to access your answers

Confidentiality:

Your identity will be kept confidential to the extent provided by law. Your answers will be associated with a number but not your name. Your name will not be used in any report.

Voluntary participation:
Your participation in this study is completely voluntary. There is no penalty for not participating.

Right to withdraw from the study:

You have the right to withdraw from the study at anytime without consequence.

Whom to contact if you have questions about the study:

Lara Colley 352-466-1023 veganfrk@ufl.edu

Dr. Martha Monroe: mcmorone@ufl.edu

Whom to contact about your rights as a research participant in the study:

IRB02 Office, Box 112250, University of Florida, Gainesville, FL 32611-2250; phone 392-0433

Agreement:

I have read the procedure described above. I voluntarily agree to participate in the procedure and I have received a copy of this description.

Participant: __________________________ Date: ________________

Principal Investigator: __________________ Date: ________________
APPENDIX F
IRB FOR FOCUS GROUPS

Informed Consent -- Focus Group

Protocol Title: The effects of systems thinking interventions on undergraduate students

Please read this consent document carefully before you decide to participate in this study.

Purpose of the research study:

To understand any impacts the systems thinking lecture and discussion had on the way you think about the everyday world.

What you will be asked to do in the study:

If you agree to participate, you will be asked to join a focus group. As a part of the group, you will be asked to answer a few questions related to the lecture and exercise you took part in last month. You will be able to respond to other students’ answers and discuss your experiences together. Pizza will be provided.

Time required:

The focus group will take less than one hour.

Risks and Benefits:

There are no risks or benefits

Compensation:

There will be no compensation, other than the pizza that will be provided

Confidentiality:

Your identity will be kept confidential to the extent provided by law. Your answers will be associated with a number but not your name. Your name will not be used in any report.

Voluntary participation:

Your participation in this study is completely voluntary. There is no penalty for not participating.

Right to withdraw from the study:

You have the right to withdraw from the study at anytime without consequence.

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Dr. Martha Monroe mcmorroe@ufl.edu
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Agreement:

I have read the procedure described above. I voluntarily agree to participate in the procedure and I have received a copy of this description.

Participant: ___________________________ Date: ___________________________

Principal Investigator: __________________ Date: __________________________

Approved by
University of Florida
Institutional Review Board 02
Protocol # 2010-U-0763
For Use Through 08-31-2011
Code Definition: Students were able to recall the correct systems thinking concept and as it related to the example used in the lecture

<table>
<thead>
<tr>
<th>Protocol Code:</th>
<th>Answers Recorded in Protocol</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Protocol #/page #/line #)</td>
<td></td>
</tr>
<tr>
<td>1/1/6</td>
<td>There was the delay one- the sunburn</td>
</tr>
<tr>
<td>1/2/1</td>
<td>The sunburn one was delay.</td>
</tr>
<tr>
<td>2/1/15-17</td>
<td>The sunscreen one was like time lag, the time differences between two variables and I think that was also about the checking acct.</td>
</tr>
<tr>
<td>3/20-21/31-2</td>
<td>I guess indirect causality is obvious. 1: Do you remember which scenario that was related to? 2: I guess otters and algae and kelp.</td>
</tr>
<tr>
<td>3/23/27-28</td>
<td>I remember the foxes and rabbits with the different time cycles. I guess the slow and fast effects.</td>
</tr>
<tr>
<td>4/25/13-15</td>
<td>Time lags and delays, there was an example about going out in the sun. Wait is this systems thinking? Yeah, the sunburn doesn’t show up until later.</td>
</tr>
</tbody>
</table>
**Coder:** Lara Colley  
**Gerund:** Applying systems thinking to other contexts

**Protocol Belongs to:** Lara Colley  
**Systems Thinking Focus Group**

**Code Definition:** Students gave examples describing instances where they have used systems thinking other than on pre and posttest

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>1/2/18-20</td>
<td>…if I’m asked to think about something and how it occurred I’ll remember systems thinking and stuff like that</td>
</tr>
<tr>
<td>1/4/27</td>
<td>It helped us see how it applied to everything</td>
</tr>
<tr>
<td>1/10/1-5</td>
<td>After this lecture I was made aware that I have had ST examples in previous classes, but it wasn’t “systems”, it just flows. So I think having this really opened it up so I could broaden it to more things than just what we talked about in those classes.</td>
</tr>
<tr>
<td>2/15/10-13</td>
<td>I actually noticed I could apply it to one of my other classes where I had to make a site plan for a development in an urban planning class and just seeing the impacts on the environment and the effects and I applied the principles like mentally.</td>
</tr>
<tr>
<td>2/15-16/39-4</td>
<td>So it’s like a positive feedback system where as the number of trees increase the reflective surface from the snow and the sunlight is reflected back up but if there are trees not as much gets reflected so its absorbed so it gets warmer, so more trees grow and its this big cycle.</td>
</tr>
<tr>
<td>2/16/18-25</td>
<td>I’m going to the Cayman Islands for a week cause my dad teaches a coral reef ecology class there, so I don’t have that much experience with that but I would imagine that coral reefs is a huge system so I think all the things we’re putting in the environment and the pollution and it effecting the global climate change and the heat which is effecting the acidity in the water, which is effecting the reef, which is effecting the reef so you could apply it to that.</td>
</tr>
<tr>
<td>Date</td>
<td>Text</td>
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<td>----------------------------------------------------------------------</td>
</tr>
<tr>
<td>2/16/5-11</td>
<td>Kind of off the general theme of ecology in one of my classes its kind of agricultural theory and different ideas about how to communicate in agriculture and politically speaking I think systems thinking could be tied in to that what everyone's doing on a local scale in their own communities is effecting who's elected and the way they're interacting, the farm bureau and things along those lines.</td>
</tr>
<tr>
<td>2/16/20-25</td>
<td>that but I would imagine that coral reefs is a huge system so I think all the things we're putting in the environment and the pollution and it effecting the global climate change and the heat which is effecting the acidity in the water, which is effecting the reef, which is effecting the reef so you could apply it to that.</td>
</tr>
<tr>
<td>2/19/1-3</td>
<td>and it was so focused and only related to that marshland ecosystem and just the fiddler crab that it was difficult to apply it to greater things but I thought back to that because he chose intricate food webs that went on for pages and pages went on for pages and pages but it tied back into ST cause he was able to relate the model with sound science</td>
</tr>
<tr>
<td>2/19/6-7</td>
<td>I agree in a biology standpoint just in the human body with the feedback loops, like with the brain, like with homeostasis.</td>
</tr>
<tr>
<td>2/19/21-22</td>
<td>When they provided it as thinking methodology that could be applied to a wider variety of things, I think it was really helpful.</td>
</tr>
<tr>
<td>4/26/30-31</td>
<td>delay in the fact that they are eating an insane amount of baby birds and they are finally starting to quantify that.</td>
</tr>
<tr>
<td>4/27/1-3</td>
<td>In my research I kind of hinted on that (Lags). There are immediate impacts and there are long-term impacts of climate change. The immediate impacts are on leaf chemistry and long term on biomass.</td>
</tr>
<tr>
<td>4/30/28-30</td>
<td>There will be delay (in decreasing traffic), just because you give free bus service, doesn't mean everyone will ride.</td>
</tr>
<tr>
<td>4/31/1-2</td>
<td>How there are different drivers for things you see in nature. It has to do with lots of factors, not just temp. its precipitation, interactions with other species, other organisms. My head is in ecological systems.</td>
</tr>
</tbody>
</table>
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(Protocol #/page #/line #)  

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<tr>
<td>1/3/9/12</td>
<td>As for putting terms on things cause it was always there but after the lecture, like I said, it was like OHHHH. Kinda helped me out with the class kinda helped me do better on the test.</td>
</tr>
<tr>
<td>1/5/3-35</td>
<td>yea that and it helped you realize that you could almost think of anything and it would become a system if you associated it with something else.</td>
</tr>
<tr>
<td>1/7/3-6</td>
<td>and you just never had a way to define it and now you have something definite not just something in your head that you just made up. Something that actually happened.</td>
</tr>
<tr>
<td>1/9/30-33</td>
<td>Yea its really useful. It opens your mind up to see what’s going on, like how something becomes something. For criminology and psychology and showing what causes a person to be a certain way. I think its useful.</td>
</tr>
<tr>
<td>1/9/34-35</td>
<td>I agree it can be taught and applied to anything. It just doesn’t have to be in nature.</td>
</tr>
<tr>
<td>2/12/1-4</td>
<td>Same with me in some of my other classes where we’re starting to talk about system thinking and having that exposure kind of helped me understand what systems thinking was and then apply it to the problems and already have a jump start</td>
</tr>
<tr>
<td>2/15/5-9</td>
<td>I think it helped me a lot just seeing systems when I’m out thinking on my own, but like I mentioned earlier, in my classes we’ll be doing things that involve systems and my professor won’t necessarily say this is systems thinking but that how I see it and it helps me work out the problems.</td>
</tr>
</tbody>
</table>
2/15/14-22
I think one of the reasons I liked it so much is because sometimes there’s a big disparity between what you do in a classroom and then how you can actually apply that to real life and I feel like for systems thinking its not really like that. I feel like it’s a just way to think, so I think I have been able to apply it to my daily routine but I don’t think just because I’ve changed the way I think about things but I don’t think I would necessarily being doing whatever and just think this is systems thinking, is just the way you think about it.

2/16/28-3
I think is provides an analytical framework to look at things and prior to that you just analyze on there own and its just the thinking allows you analyze things as a whole and I think its beneficial beyond, I think it’s the most beneficial thing I’ve taken in a class. What’s the likelihood that you’re going to use the knowledge of a biomass plant in Gainesville? To be honest when you get into the real world or when you get into whatever industry you might be pursuing what’s the likelihood that you’re going to use a rainforest example in Guatemala, but its much more likely that you’re going to use the system thinking, its almost guaranteed at this point because we’ve all use it in our lives thus far.

2/17/1-5
I definitely think you can turn everything into a system so I feel like I’m almost struggling trying to come up with specific examples cause I think you could almost say think about this and talk about it as a system so it just depends on what you want to talk about.

2/19/10-15
I had exposed to it but not the term systems thinking. I understood like feedback loops and cycles but never really the term systems but I never thought to apply that ST in other terms. I think having the term ST really changes things cause you realize it’s a form of thinking and you can apply it anywhere rather than just saying this is A system.

2/19/19-22
I always associated it with just ecological interactions on a biological level. When they provided it as thinking methodology that could be applied to a wider variety of things, I think it was really helpful
<table>
<thead>
<tr>
<th>Date</th>
<th>Text</th>
</tr>
</thead>
<tbody>
<tr>
<td>4/32/10-13</td>
<td>That it could be applied outside of an ecosystem, I hadn’t thought about that before. It kind of clicked. It made more sense in terms of an ecosystem, because we have been learning about that for so long.</td>
</tr>
<tr>
<td>4/32/14-21</td>
<td>You can use systems thinking to describe any policy or decision. People always ask me what do you want to do this or that and if you know the whole system, you can give them an answer. People don’t think their actions affects on other people, and climate change is a big one where you are trying to connect everything. . I think Systems is the only way you can connect in terms of climate change. People have to learn about it.</td>
</tr>
</tbody>
</table>

**Coder: Lara Colley**  
**Gerund: Diagramming useful**  
**Protocol Belongs to: Lara Colley**  
**Systems Thinking Focus Group**

**Code Definition:** Students indicate that the diagramming exercise was a useful tool

**Protocol Code:**  
(Protocol #/page #/line #)  
Answers Recorded in Protocol

<table>
<thead>
<tr>
<th>Date</th>
<th>Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/6-7/34-2</td>
<td>I am a visual learner, so the hands on stuff helps. The before and after pictures and the loops always helped me just so I could see it. Better than just words. Showing this has a negative impact and then seeing where the arrows go from there. The examples were really helpful.</td>
</tr>
<tr>
<td>3/22/11-15</td>
<td>I liked the discussion period, I thought it was fun, because we had that paper and we were following along and trying to draw our lines. But I also was a little confused on the concepts. But I wanted to keep drawing my lines and try to figure out how everything had a connection. I did find it interesting, it was a little confusing as well.</td>
</tr>
<tr>
<td>Date</td>
<td>Comment</td>
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<td>------------</td>
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</tr>
<tr>
<td>3/23/15-26</td>
<td>I feel like seeing it visually was helpful. Because especially with the algae example, you don't necessarily think of everything when you are looking at it. But then to have all of the different factors written out, you think How can you connect them? I think the exercise really helped me, Wow so the manatees and this. I think seeing that...the pluses and minuses still get me. But seeing the web and how you could draw everything together helped me to visually understand it. Just hearing about it and seeing one arrow between one thing is an example, but seeing an ecosystem sized model and that's not even all of the factors you could add in, but it was a large number. I didn't think about how boats might affect algae or whatever was on there.</td>
</tr>
<tr>
<td>4/31/24-28</td>
<td>Do you think more instruction on the diagramming part would have been helpful? Like is that a useful tool to helping you understand systems? Yeah, the visual element is very useful.</td>
</tr>
<tr>
<td>4/31/24-28</td>
<td>Do you think more instruction on the diagramming part would have been helpful? Like is that a useful tool to helping you understand systems? Yeah, diagramming is useful</td>
</tr>
</tbody>
</table>

Coder: Lara Colley
Gerund: Seeing diagrams was helpful
Protocol Belongs to: Lara Colley
Systems Thinking Focus Group

Code Definition: Students indicate that seeing the systems diagrams during the lecture and treatments were helpful

<table>
<thead>
<tr>
<th>Protocol Code: (Protocol #/page #/line #)</th>
<th>Answers Recorded in Protocol</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/8/16-20</td>
<td>the reindeer one was the one I remember the most. You could see how the reindeer were effecting this which in turned affected the nesting bird leaving then led to a big deal with fish and wildlife service. the graph with the arrows helped cause otherwise it would be like a paragraph.</td>
</tr>
<tr>
<td>1/8/29-31</td>
<td>I agree that having it right in front of you helped and being able to pick out one thing to look out and can see how it effects others.</td>
</tr>
</tbody>
</table>
a good way to explore all the different inputs and outputs cause its not just one thing that's going to cause something to change you can visually see what's going on. (Diagramming)

I think that if I read a paper about the springs and it had a graph that showed all of those things that we diagrammed in class, I think that would be the thing I would focus on, instead trying to read through the discussion and results, and kind of gather from that. If I found the diagram interesting and wanted to learn more about a certain input, then I would go back through the paper to find out about it. The diagram would peak my interest and then cause me to go back and read about that complex issue. It would help me understand it instead of trying to read through a paper.

I learned that you could diagram it and have it manifested on paper to talk to people about it

<table>
<thead>
<tr>
<th>Coder: Lara Colley</th>
<th>Gerund: Learning from relevant examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protocol Belongs to: Lara Colley</td>
<td>Systems Thinking Focus Group</td>
</tr>
<tr>
<td>Code Definition: The use of relevant examples made salient the abstractness of systems thinking</td>
<td></td>
</tr>
</tbody>
</table>

Like the cats and dogs, there were all these terms and then you give the reasons and examples it made perfect sense

Those are real examples, that's like a real issue in some things. Just because it wasn't something personal that happened in his life or probably won't happen to us because we don't own a spring but it's still something that's happening that you can relate and imagine.

The graphical representation helps; I think that's just the nature of the whole system. The fact that he boiled it down to examples like cats and rats everyone was able to first grasp it on that level and then move to an environmental level.

I agree with that. I think the real world examples and the simplicity of it initially
<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>3/22/16-19</td>
<td>I enjoyed the original lecture. I like when he explained it with the system of the dogs and cats and neighborhood. I thought that helped explain the concepts in a simple way and then he expanded it with bigger examples and more subtle interactions.</td>
</tr>
<tr>
<td>4/29/11-16</td>
<td>I thought it was interesting, we did it in another class but it was all very abstract with examples that we couldn’t really relate to. He was talking about cats, dogs, and rats, I know what those are, I know what happens in that kind of scenario. It cleared a lot of things up, it was interesting to finally learn about it.</td>
</tr>
</tbody>
</table>

Coder: Lara Colley

Gerund: Learning from multiple examples

Protocol Belongs to: Lara Colley

Systems Thinking Focus Group

Code Definition: The use of multiple examples helped students understand concepts

<table>
<thead>
<tr>
<th>Protocol Code: (Protocol #/page #/line #)</th>
<th>Answers Recorded in Protocol</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/5/28</td>
<td>I think the biggest help was all the examples of everything.</td>
</tr>
<tr>
<td>1/5/36</td>
<td>The examples are the most effective</td>
</tr>
<tr>
<td>1/7/2</td>
<td>The examples were really helpful.</td>
</tr>
<tr>
<td>3/23/14</td>
<td>Having multiple examples</td>
</tr>
</tbody>
</table>
**Coder: Lara Colley**

**Gerund: Remembering terms was difficult**

**Protocol Belongs to: Lara Colley**

**Systems Thinking Focus Group**

**Code Definition:** The students had difficulty remembering the correct terminology

<table>
<thead>
<tr>
<th>Protocol Code: (Protocol #/page #/line #)</th>
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</tr>
</thead>
<tbody>
<tr>
<td>1/2/13</td>
<td>not in the specific terms.</td>
</tr>
<tr>
<td>1/8/9-11</td>
<td>The reinforcing thing, I didn’t remember that until you said it, but I would be able to recognize that when this keeps happening, this will happen more—that sort of thing.</td>
</tr>
<tr>
<td>2/21/15</td>
<td>I can’t remember the terms.</td>
</tr>
<tr>
<td>4/25/27-28</td>
<td>Positive feedback? Because if you didn’t have it you didn’t get warmth from it.</td>
</tr>
</tbody>
</table>

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**Coder: Lara Colley**

**Gerund: Using signs appropriately is confusing**

**Protocol Belongs to: Lara Colley**

**Systems Thinking Focus Group**

**Code Definition:** Using positive and negative symbols were challenging

<table>
<thead>
<tr>
<th>Protocol Code: (Protocol #/page #/line #)</th>
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</tr>
</thead>
<tbody>
<tr>
<td>1/9/8-10</td>
<td>The plus signs and minus signs got confusing. I knew what I wanted to say but the way I put it, well that is not really what you saying.</td>
</tr>
<tr>
<td>1/9/24-26</td>
<td>the plus signs and minus signs are not intuitive and confusing. You think a positive sign means something increases and that is confusing</td>
</tr>
<tr>
<td>3/23/20</td>
<td>the pluses and minuses still get me</td>
</tr>
<tr>
<td>Protocol Code:</td>
<td>Answers Recorded in Protocol</td>
</tr>
<tr>
<td>----------------</td>
<td>-----------------------------</td>
</tr>
<tr>
<td>(Protocol #/page #/line #)</td>
<td></td>
</tr>
<tr>
<td>1/3/32-34</td>
<td>I’d say 10 because if they’re noticing the algae coming in after they’re bringing nutrients then obviously the input is creating an output</td>
</tr>
<tr>
<td>1/3/35-37</td>
<td>I’d say an 8 because it does affect it but not as directly as they assumed. After they did all they did all the charts and graphs in the class it was that but it was thru other sources.</td>
</tr>
<tr>
<td>1/4/1-5</td>
<td>I’d have to go one step lower and be like a 6 or 7 because there’s other human impact, like erosion of the natural grasses is gonna have a impact on that too and that kinda provides more opportunity for the eutrophication stuff to happen.</td>
</tr>
<tr>
<td>1/4/9-10</td>
<td>the amount of oxygen, the nutrients that we were talking about</td>
</tr>
<tr>
<td>1/4/11</td>
<td>there was something about manatees</td>
</tr>
<tr>
<td>1/4/12-14</td>
<td>I remember there was never just one thing, it was everything coming together. More people, more nutrients and everything all at once</td>
</tr>
<tr>
<td>2/11/16-22</td>
<td>I think 10, I think it’s an unequivocal link between the two more than just the cursory link beyond just what we learned there. I’ve seen other studies and personal research that links them heavily and beyond that, what else is there that we were really provided with that could show algal blooms besides I guess even interaction but its all interrelated back to the systems thinking methodology.</td>
</tr>
<tr>
<td>2/12/23-24</td>
<td>I think it (nitrates) is a primary cause but then I think that there are other causes that I’m not educated on</td>
</tr>
<tr>
<td>2/12/25-28</td>
<td>I’ll say a 5 because I think to a certain extent that the nutrients are going to cause algal blooms but there’s going to be other limiting factors that once it reaches that threshold it can’t really grow anymore if something else limiting it.</td>
</tr>
<tr>
<td>2/12/30-34</td>
<td>In the lecture it was like a feedback loop</td>
</tr>
</tbody>
</table>
where the algae was blooming a lot and taking a lot of the oxygen out of the water which was killing the snails or making the snails not eat as much which made the algae bloom more, so it wasn’t necessarily just all the nutrients.

<table>
<thead>
<tr>
<th>Date</th>
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</tr>
</thead>
<tbody>
<tr>
<td>2/12-13/35-5</td>
<td>I think initially I would've said like a 9 or 10 but after the lecture I feel really surprised that when we did that modeling thing I thought that it seemed to have a lot less of a direct effect. I would probably say maybe like a 4 to a 6. It seemed like we moved the amt of nutrients up a lot and it barely had any effect and I think it had more having to do with sunlight exposure. I think it definitely has an effect but not as much as I thought before. Because its dependant on a lot of different variables as well.</td>
</tr>
<tr>
<td>2/21/25-29</td>
<td>8, I think a lot of fertilizer-run off and stuff is a major cause of algae blooms in water. It may not be the only cause, but to grow out of control its either that or sunlight, its not physical things.</td>
</tr>
<tr>
<td>3/21/30-34</td>
<td>I would probably say 6, because I remember as well, so I am not as confident. It brought back memories, I can kind of remember there being other factors involved, I just cant remember.</td>
</tr>
<tr>
<td>4/27/21-25</td>
<td>8 or a 9. I think its really high. I have only been here for a few years and going to Ichetucknee then and now, there is a definite correlation. On top of that, if you drive around the area, you can see that Ag operations are way up in the area. Even people who work there will tell you that the farmers runoff is causing algae</td>
</tr>
<tr>
<td>4/27/26-27</td>
<td>10. That is just something I learned early on in school. Some Env. Class in elementary or middle school</td>
</tr>
<tr>
<td>4/27/28-32</td>
<td>At the spring head, its probably an interaction between human or structural damage to eelgrass and then the algae being able to take over. But its probably mostly driven by runoff. 7 or 8 maybe.</td>
</tr>
</tbody>
</table>
LIST OF REFERENCES


BIOGRAPHICAL SKETCH

Lara Colley is a 4th generation Floridian. She was born in Leesburg, Florida where she attended public schools. Lara has been a passionate environmentalist since the age of 11, which caused her to stand out among her peers. She took some time off after high school and worked various jobs, but after becoming a Unit Clerk at Shands in Gainesville in 2002, she decided to return to college and pursue a degree in Environmental Education. Lara received her Bachelor’s degree from the University of Florida in the School of Forest Resources and Conservation in 2009 and Master of Science from the School of Forest Resources and Conservation in 2011. She plans to teach middle school science, where she first developed a passion for protecting the environment. She plans to integrate the knowledge she gained from this study to instill the same passion she has for the environment into her students.