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Assessing the effect of simulation models on systems learning in an introductory environmental science course

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ASSESSING THE EFFECT OF SIMULATION MODELS ON
SYSTEMS LEARNING IN AN INTRODUCTORY
ENVIRONMENTAL SCIENCE COURSE

by

Heather J. Skaza

Bachelor of Science
The Ohio State University
2006

A thesis submitted in partial fulfillment of
the requirements for the

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ABSTRACT

Assessing the Effect of Simulation Models on Systems Learning in an Introductory Environmental Science Course

by

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While there is plenty of anecdotal evidence within the systems dynamics community supporting the use of systems simulations in the classroom to improve student understanding, there is little published, controlled, experimental research. This paper describes the results of a paired experiment testing the effect of using system dynamics simulations to increase systems understanding in an introductory environmental science course. We believed that the students using the systems simulations would demonstrate a greater systemic understanding of environmental issues than those who did not.

We conducted an experiment during the fall semester of 2009, with 304 students enrolled in four sections of Introduction to Environmental Science. Students in the experimental group used systems simulations to complete two homework assignments: one on population dynamics and one on carbon accumulation in the atmosphere. Students in the control group completed the same assignments, using parallel text descriptions, instead of simulations. We

measured general and systemic understanding of environmental issues at the beginning of the course, at the end of the course, and at multiple points throughout the course. Regression analyses results show that there was a significant positive relationship between performance on assessment questions immediately following the first intervention and simulation use. Experimental group students were better able to recognize interconnections, identify stocks and flows and understand how accumulation occurs within the systems they studied. The study led to some questions about the effectiveness of using multiple-choice questions and behavior over time graphs to assess systemic understanding. The study also demonstrated the effectiveness of using methods, besides simulation, in the classroom to increase systemic understanding.

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I would like to thank Carrie Bojda and Abby Beck for their help with data entry, but also for their encouragement when I did not think I would be able to finish, Marco Acosta, for helping me write and revise into the morning hours and Jennifer Krause, for sharing the graduate school experience with me while we lived together. Thanks to Dottie Shank, for all of her hard work and for lending a supportive ear.

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CHAPTER 1

INTRODUCTION

Designing an effective introductory course in environmental science is a challenge. The 'big picture' goal is to get students, many of whom have no experience in the sciences, to think about their relationship with the environment. To serve this larger goal, it is also necessary to develop students' environmental vocabulary and their knowledge of basic environmental processes. Environmental science is a multi-disciplinary field, so even the basic concepts cover a wide range of topics. Environmental issues are complex. Understanding the human relationship with the environment requires a systemic understanding.

Systems Thinking in Education

Educators in the system dynamics community have long supported the notion that systems thinking skills are an essential part of education. According to Forrester (2008), systems-oriented education gives "students a more effective way of interpreting the world around them" (p.2). System dynamicists agree that systems thinking skills are particularly helpful in understanding complex problems (Maani & Maharaj, 2004). This is useful in environmental education, as environmental systems can be complex, with developmental patterns that are difficult to predict. System thinking tools help students conceptualize and evaluate environmental issues, facilitating the recognition of "causal relationships in complex systems that cannot be identified by other methods of problem solving" (Grant, 1998, p.68).

Even though there is support for system dynamics in education, there are few studies that give quantitative evidence of the effectiveness of systems interventions (Doyle, Radzicki & Trees, 1998). In Doyle, Radzicki and Trees' (1998) words, "there is insufficient evidence to convince skeptical, scientifically minded observers, which is crucial if systems thinking ideas and techniques are to become more widely accepted in educational and corporate settings" (p.254). A larger base of empirical evidence is important to understanding how to best use systems tools so that we can develop the most effective interventions.

Hopper and Stave (2008) reported (based on a meta-analysis of systems intervention studies) that very few studies provide data from experimental, controlled studies. Most of the information we have about the effects of systems interventions in the classroom is anecdotal. Many studies that measured student responses to systems interventions did not use a control group (Evagorou, et al., 2007; Fisher, 2003; Hogan, 2000; Kainz & Ossimitz, 2002; Korfiatis, Papatheodorou & Stamou, 1999).

The experimental studies that have been conducted have different purposes and assessment techniques. A group of studies have assessed the ability to interpret stock and flow relationships (Booth Sweeney & Sterman, 2007, Ossimitz, 2002). Some have tested student ability to control dynamic systems in a simulation environment (Cavaleri, Rapheal & Filetti, 2002; Jenson & Brehmer, 2003; Moxnes, 2003). In these cases, systemic understanding was measured by the student's success in achieving the best outcome for the system, as defined by the researchers. Others measure students' ability to predict dynamic behavior,

given other variable parameters in textual and/or graphical form (Booth Sweeney & Sterman, 2000; Sterman & Booth Sweeney, 2002). In these studies systemic understanding was measured by the student's identification of the correct dynamic behavior for the given conditions.

A few studies have used controlled experiments. Fisher (2009) conducted an experiment with some students building systems simulations with Vensim software, which allows the user to build and run system dynamics models. Control group students used a more traditional tool, their graphing calculator. She reported a significant increase in understanding for the simulation-builders compared to the control group. Wheat (2008) tested economics students' understanding of macroeconomics principles using systems thinking tools. He reported that students who used systems thinking tools preferred them and they demonstrated an increase in conceptual understanding. Doyle, Radzicki and Trees(1998) and Vennix (1990) both report on studies that tested the relative effectiveness of using systems simulations on undergraduate students' systemic understanding of economic systems. Pala and Vennix (2005) conducted a controlled experiment testing the effect of a systems thinking course on students ability to correctly identify the level of a stock for given flow conditions.

Systems Simulations in Education

There are several reasons why systems simulations have the potential to be very effective at increasing student understanding of complex systems. Simulations allow students to work with a simplified version of the real world

system. A good simulation distills the complex, real-world system to the parts that are crucial to students' understanding of the subject. This is a great benefit for students who have little or no experience with the real-world system that the simulation represents. They do not have the ability to tackle all of the parts and interconnections of the real-world system, so a simulation lets them experiment with only a part so that they can reach an understanding without being overwhelmed by the complex whole.

The simulation environment is useful to student understanding in that it allows the student "to simulate the behavior of systems that are too complex to attack with conventional mathematics, verbal descriptions, or graphical methods" (Forrester, 1993, p.185). Teaching the basic principles of complex systems without a simulation might involve more reading, lecture or mathematics than is necessary when a simulation is used. The simulation reduces the students' cognitive load by relieving them of the responsibility of remembering equations or principles that part the system, but may not be necessary information for them to have to understand the basic principle.

Simulations take the concrete parts of the real world and make them flexible. In a simulation environment, we can change time boundaries and add or take away variables that exist in real life (deJong, 1991). Simulations allow for experimentation in a consequence-free environment. A student can explore any number of 'what if' scenarios.

Learning with simulations is exploration-based (Goodyear et al., 1991). The student's job is to experiment with the simulation and learn about the

underlying system (deJong & VanJooligan, 1998). Systems simulations allow students to 'play' with a system. They can make changes in a hypothetical setting and observe how their changes affect the systems behavior.

Simulations allow the student to ask a question, generate a hypothesis, test their hypothesis and form conclusions in an iterative process. This changes the student's learning from remembering and reproducing information to deeper understanding (deJong, 1991), facilitating the transfer of knowledge to other domains.

Goals for Systems Education and Assessment

Booth Sweeney and Sterman (2000) tested students' understanding of stock and flow dynamics by asking them to draw the behavior of a stock, when given a graph of flow behavior over time. Understanding stock and flow relationships is an important part of thinking systemically. Using a bathtub as an example, the water in the bathtub is the stock in that system. The water coming out of the faucet is the inflow and the water going down the drain is the outflow. Students who understand these variables and how they are related, understand how the inflow and the outflow work together to increase or decrease the level of the water in the bathtub. This understanding is significant when the stock is money in a bank account or carbon in the atmosphere. In Booth Sweeney's study, students completed the task in two contexts: 'water in a bathtub' and 'money in a bank account.' Booth Sweeney and Sterman assigned the same task for systems with delay. They found a low level of understanding for systems

with and without delay. In a subsequent study, Booth Sweeney and Sterman (2002), asked students to demonstrate their understanding of carbon accumulation in the atmosphere using graphical representations of carbon in the atmosphere, carbon emissions and carbon absorption. Again, their results show a general misunderstanding of how emissions and absorption work together to change levels of carbon in the atmosphere.

Booth Sweeney and Sterman's studies (2000, 2002) tested students' systemic understanding by asking them to graph a trend or identify the correct conditions for a given a trend over time. If a student is unable to graph the behavior of a stock or flow, does that mean that she does not understand the relationship between the two or does it mean that they cannot represent their understanding graphically? What do we really want students to be able to do as systems thinkers?

In response to Booth Sweeney and Sterman's studies, Stave and Hopper (2007) asked the question, "What constitutes systems thinking?" They proposed a Taxonomy of Systems Thinking Characteristics, modeled after Bloom et al.'s *Taxonomy of Educational Objectives*. The taxonomy was a hierarchical set of characteristics to be used in designing interventions and "evaluate the effect of our efforts to facilitate systems thinking" (Stave & Hopper, 2007, p.2). It was the result of a literature search, as well as feedback from systems educators. The taxonomy categorized common themes in goals and assessments within System Dynamics/Systems Thinking education. It is shown in Figure 1.

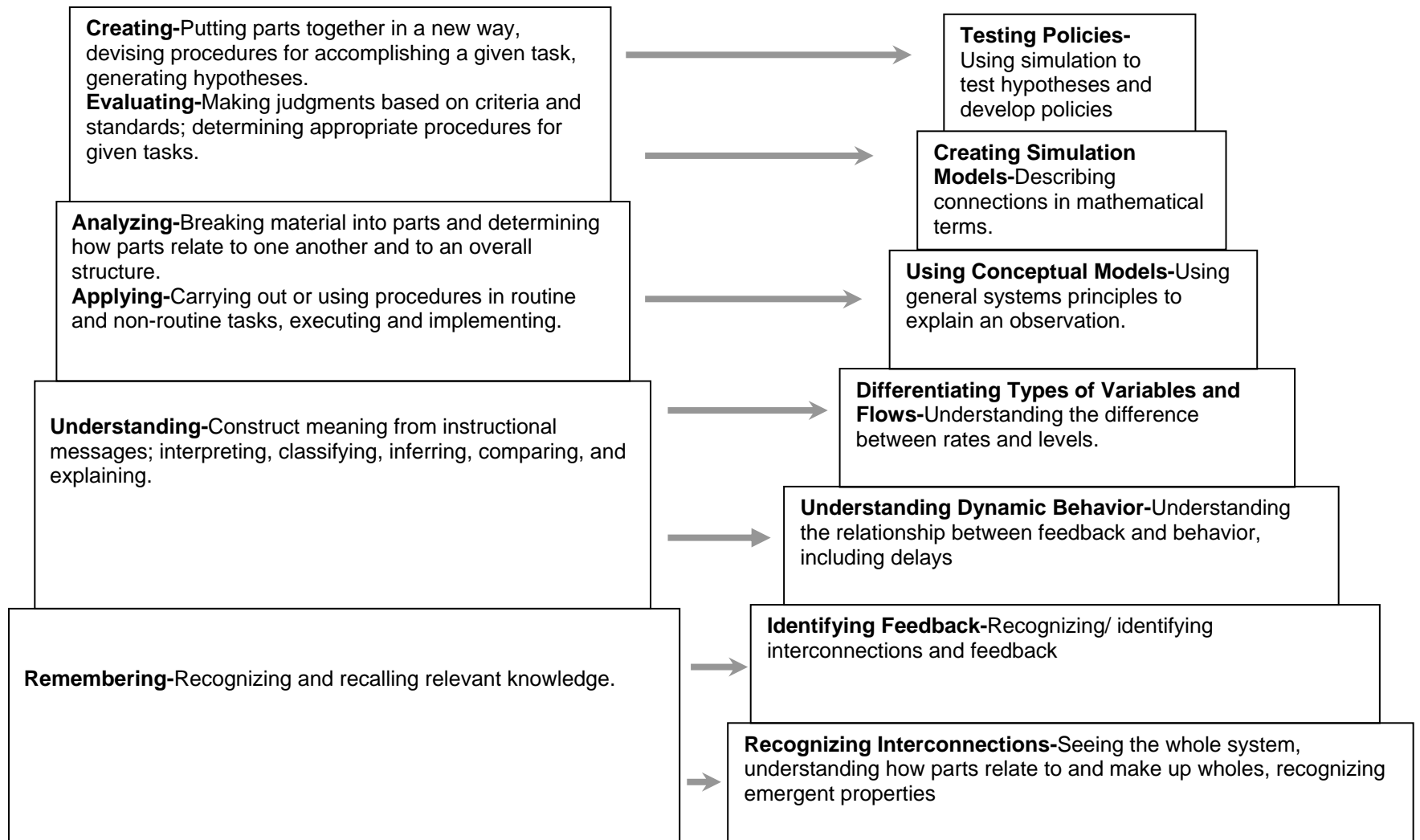


Figure 1. Bloom's Taxonomy and Systems Thinking Taxonomy

Hopper and Stave (2008) used the Taxonomy of Systems Thinking Characteristics to evaluate fourteen experimental studies that tested the effect of systems thinking interventions on increasing students' systemic understanding. They noted that, while the studies had the common goal of improving systems thinking ability, they defined success differently and had different ways of assessing whether or not those goals had been met. The three findings from their evaluation were 1) there is strong support for higher order skills being built upon lower level skills, 2) most of the studies tested intermediate systems thinking skills and 3) half of the studies used the assessment techniques created by Booth Serman and Sweeney (2000). Hopper and Stave concluded that new and more rigorous ways of testing systems thinking abilities were need. They also found the need to assessing the lower and higher level systems thinking skills.

The current study builds on previous work on how to develop the best systems thinking interventions and how to assess their effectiveness in increasing systemic understanding. Assessing the effect of systems interventions on systemic understanding is challenging. Some of the challenges include clearly defining learning objectives, designing systems interventions targeted to specific systems thinking skills, specifying performance objectives, and designing rigorous and repeatable ways to assess their effects. The current study continues Stave and Hopper's work by using the taxonomy as a framework for addressing these challenges.

CHAPTER 2

DESCRIPTION OF THE STUDY

Approach

Pilot Study

The current study tests the relative effectiveness of using systems simulations to increase students' systemic understanding of environmental issues in an introductory environmental science course. The study started in the summer of 2008, when we began designing the undergraduate environmental studies course for the fall semester of 2008. We developed several systems simulation interventions and assessment methods. We used the fall semester, 2008 and spring semester 2009 to test these interventions and assessments with the student populations in the Introduction to Environmental Studies classes. Skaza and Stave (2009) reported on a pilot study conducted in the spring of 2009.

The pilot study was a paired experiment that used systems simulations to teach students in an undergraduate environmental science course about several environmental issues. The control groups did not use the simulation, but had an equivalent text description of the environmental issue presented in the intervention. Since the study's subjects were undergraduate students who we assumed had no previous experience in environmental science and/or system dynamics, we evaluated students' systemic understanding of these concepts using the lower levels of the systems thinking taxonomy developed by Stave and

Hopper (2007): recognizing interconnections, identifying feedback and differentiating types of variables and flows.

The pilot study informed the current study in four ways:

- 1) We were able to determine from assessment results and student evaluation at the end of the semester which simulations students were able to understand and which ones were too complex. We chose the simulations for the current study's interventions from this information.
- 2) Assessment results showed that students' systemic understanding did not develop in the order described by Stave and Hopper (2007). Pilot study results showed that students recognized interconnections and then began to develop an understanding of stock and flow variables and how the flows work together to increase or decrease the stock. We used this information to change the way we evaluated student answers for the current study.
- 3) Student responses in the pilot study were often vague, and therefore difficult to evaluate. We were able to revise assessment questions for the current study to illicit student responses that were more specific.
- 4) Based on student response in the pilot study we were able to be more specific about how we thought the simulations would change student understanding and what we expected to see. This enabled us to be more specific in our problem statement and hypotheses for the current study.

Research Question

This study addressed two questions. First, does the use of systems simulations in an introductory environmental science course increase students' systemic understanding of environmental issues?

Determining whether or not simulations increase student understanding requires a rigorous approach to measuring systemic understanding. Consequently, a second question developed: How do we best assess a change in systemic understanding?

Hypotheses

We believed that we would see a greater systemic understanding of environmental issues for the group of students using the systems simulations than for the students who did not. This general hypothesis was broken down in to several subhypotheses.

- 1) Simulation users would perform better on assessments that tested a gain in their general knowledge of environmental issues by the end of the course.
- 2) Simulation users would perform better on assessments that evaluated a gain in their systems knowledge by the end of the course.
- 3) At the end of the course, simulation users would demonstrate a greater systemic understanding of the environmental issues addressed by the systems simulations.

4) Simulation users would show a greater systemic understanding of the environmental issues addressed by the simulations on assessments following the interventions.

The Current Study

The study subjects were 304 students enrolled in four sections of Introduction to Environmental Studies at the University of Nevada-Las Vegas during the fall semester of 2009. Table 1 shows meeting days and times and class sizes. One small class and one large class were randomly selected to be the experimental groups. The other two sections were the control groups. The two large sections met in a lecture hall, while the smaller classes met in smaller classrooms.

Course Design

The class had five educational components: assigned text book readings, in class lecture, six assessments, an activity that encouraged students to tie course concepts to their day to day experiences, and five assignments based on the readings and lecture. We used the same text, conducted the same lectures and assessments and expected students to complete the same activities for all sections. The only difference between the classes was that the experimental sections used systems simulations to complete three of five assignments. The control sections completed the same assignments, but with only a text description of the environmental issue the assignment focused on. Figure 2 is a timeline of assignment and quiz completion. Appendix A is the course syllabus.

Table 1. *Class Information for Introduction to Environmental Science Classes*

Section number	Group	N	Meeting Day	Meeting Time
001	Control	50	Mon., Wed.	10:00-11:15AM
002	Control	105	Mon., Wed.	11:30 AM-12:45 PM
003	Experimental	56	Tues., Thurs.	10:00 -11:15AM
004	Experimental	93	Tues., Thurs.	11:30 AM-12:45 PM

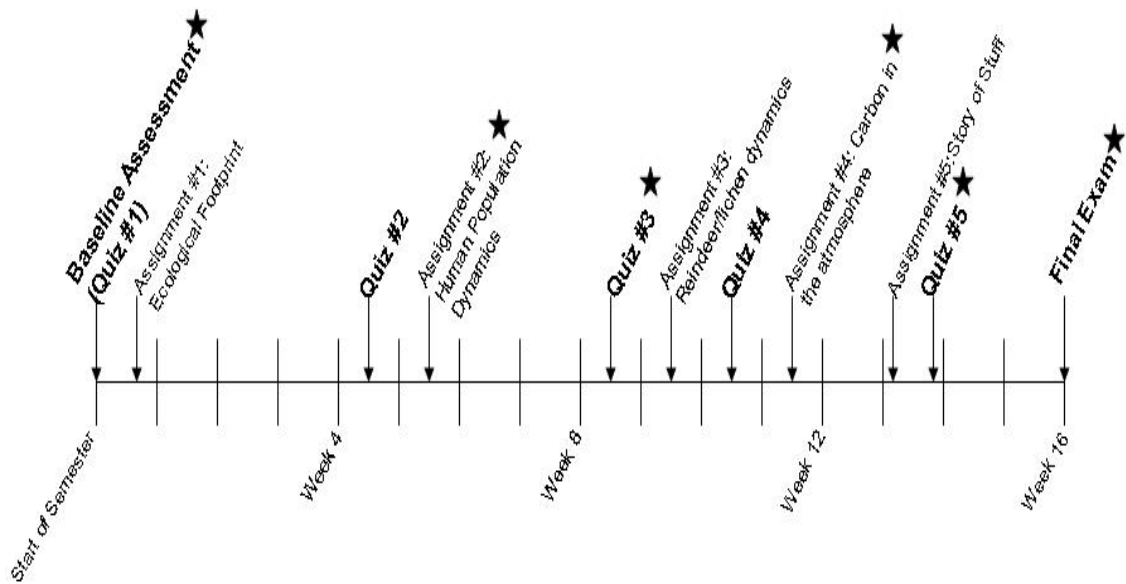


Figure 2. Timeline of assignments and assessments.

CHAPTER 3

METHOD

Description of Interventions

We used the course assignments to administer systems simulation interventions. Five assignments guided students to examine causal relationships in the environmental issues presented in class. Three of these included a systems simulation for the experimental sections. We gave the control sections an equivalent text description of the system the simulations were based on. All students answered questions in an online assessment with their assignment. The assessment questions asked students about the system they studied in their homework assignment, whether it was through simulation use or text description. Students completed assignments individually and on line. All assignments were completed at home and on-line. There was no live guidance from an instructor. Table 2 describes the five assignments.

For this study, we used systems simulations to address three environmental issues: human population dynamics, reindeer and lichen population dynamics (Tabacaru et al., 2009) and carbon accumulation in the atmosphere. We did not analyze the data gathered from the reindeer/lichen exercise. We analyzed data related to the human population dynamics and the carbon accumulation in the atmosphere simulation. These assignments are described below.

Table 2. Homework Assignments and Descriptions

Assignment	Description
1: Ecological Footprint	SIMULATION: Global Footprint Network ecological footprint calculator Students used an ecological footprint calculator to calculate their ecological footprints. They answered questions about their eco-footprint and how it might compare to someone living in a developing country.
2: Human Population Dynamics	SYSTEMS SIMULATION: Original model with total population as the stock, birth rate as the inflow and death rate as the outflow. Students were asked to describe the effect on total population when the number of births and number of deaths in a population are increased or decreased.
3: Reindeer/lichen relationships	SYSTEMS SIMULATION: Model of reindeer herd/lichen dynamics (Tabacaru et al., 2009) gives student a tutorial on how to manage the reindeer herd and instructs them to decide on herd size every year for fifteen years to maintain lichen growth at an optimum for their survival. Students were asked to manage a herd of reindeer so that the lichen that is their primary food source is not overgrazed.
4: Carbon in the atmosphere	SYSTEMS SIMULATION: Sterman's (2006) bathtub model allows students to increase and decrease carbon dioxide emissions. Students were asked to test out carbon emissions levels and note the effect on CO ₂ in the atmosphere. Assessment questions asked them to relate the stock and flows in the system.
5: The Story of Stuff	No simulation, but the students watch an online video to explain the way that the "stuff" we use moves around Earth's system. They answered questions asking them to reflect on their role in the consumer cycle.

Assignment #2: Human Population Dynamics

Assignment #2: Human Population Dynamics was the first assignment in which students used a systems simulation to help students understand an environmental problem. The reading material and simulation for this assignment described global population change as the difference between the number of births and the number of deaths. It was a very simple, one-stock, two-flow system. We broke the assignment into three parts, though the control group only completed the first part.

For Part 1 of the assignment students read a chapter in their text book on human population change. The book describes world population change as the net difference between the number of births and the number of deaths. All students answered the same question set after reading the book. Assessment questions asked students to describe 1) how global population changes when either birth rate or death rate change and all other variables stay the same or 2) how global population changes when birth rate and death rate are equal, 3) how the birth rate and death rate are related to total population change. The variables were never explicitly described in terms of stocks and flows. Pretest questions are shown in Figure 3.

For Part 2 of the assignment, students in the experimental sections used a systems simulation created using Stella software (2010) and made available on the internet by the isee NetSim server. There were two slider bars and two buttons on the simulation's interface. The total population output graph on the interface had a time horizon of three hundred years and was modeled after the total population change graph used in the course text book. Under baseline conditions, the graph showed population growing exponentially until it reached about 10 billion people around the year 2050. Students could manipulate birth rate and death rate using two slider bars. Two actions buttons allowed students to run the simulation by clicking "GO" and restart the simulation by clicking "CLEAR." We kept the simulation structure and interface as simple as possible. We assumed that students in the introductory course had no experience with

population dynamics or a simulation environment. The model interface is shown in Figure 4.

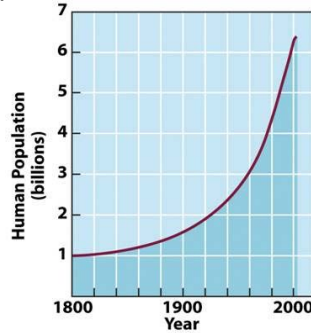
We gave the students a set of instructions for using the simulation. The instructions directed them to investigate the population dynamics they were asked to describe in Part 1 of the assignment. We instructed them to:

- 1) Run the simulation with current birth rate and death rate to note exponential growth pattern. The trend the simulation produced was identical to the one in their text book.
- 2) Decrease the number of births by about one quarter using the slider bar on the interface. Birth rate was still greater than death rate, so population grew exponentially, but at a slower rate.
- 3) After returning to the initial condition, increase death rate by about one quarter. Again, birth rate remained above death rate and population grew at a slower rate than in the initial condition.
- 4) Make the number of births and number of deaths equal. Population stayed the same for the duration of the time horizon.

Assignment #2-Human Population Dynamics

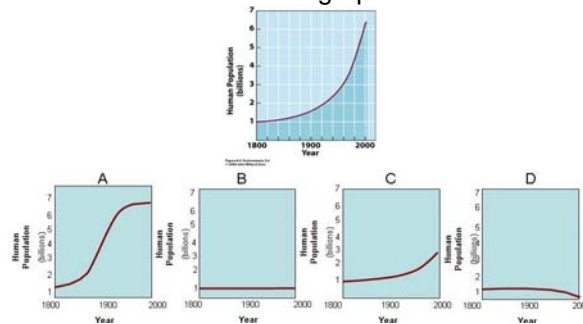
PART 1 QUESTIONS

1. The population graph below is Figure 8-9 from your book. Describe the projected trend for population that is shown on the graph. (Consider how the graph is changing.)



2. Why do you think that population is changing the way that it is?

3. How would our population graph from the book look different if the number of births had been a quarter lower starting in 1800? Choose one of the graphs below.



4. Explain why you think this will happen.

5. In the 1850s the death rate was much higher than it is now. What if death rate had stayed this high? How would our population graph from the book look different if the number of deaths were about a quarter higher than it is now? Choose from one of the graphs. (SEE GRAPHS ABOVE)

6. Explain why you think this will happen.

7. How would our population graph from the book look different if the number of births and the number of deaths were equal? Choose one of the graphs. (SEE GRAPHS ABOVE)

8. Explain why you think this will happen.

9. How are the number of births and the number of deaths related to total population? Consider how the number of births and deaths change if the total population size changes.

Figure 3. Human Population Dynamics, Part 1

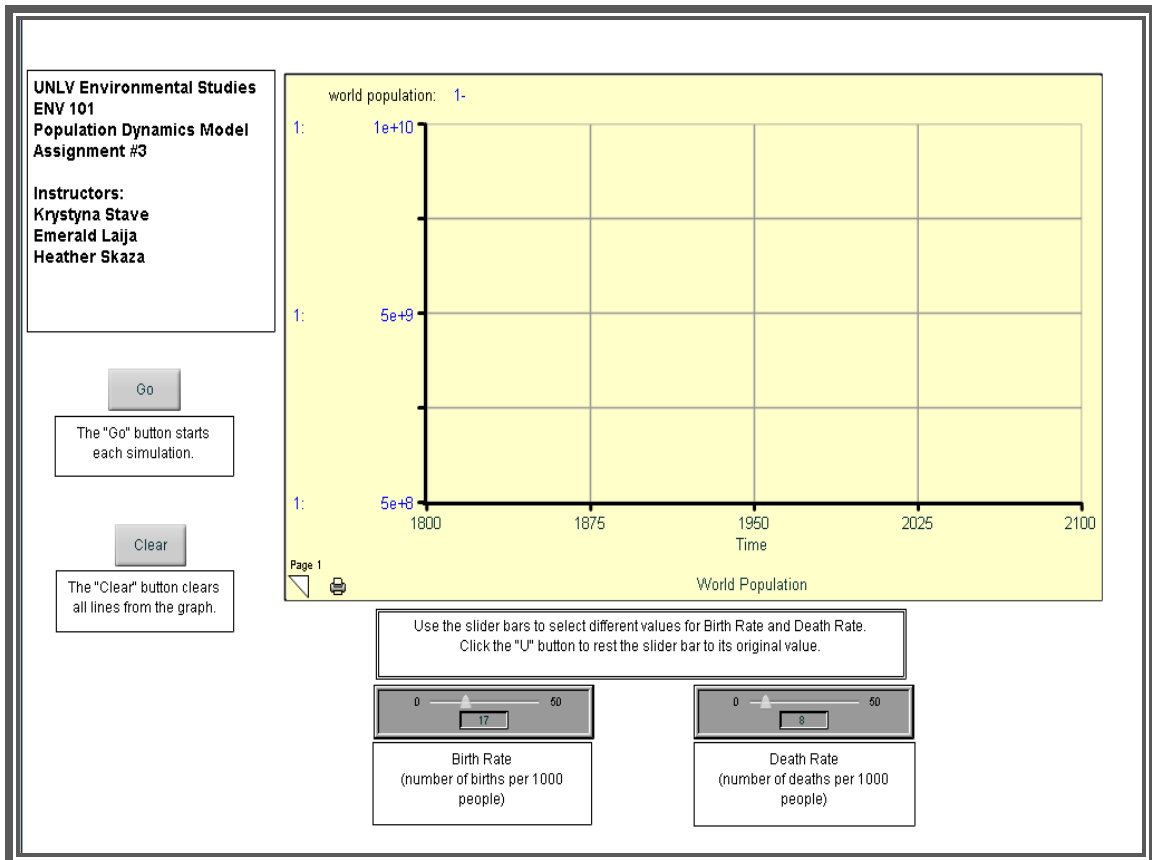


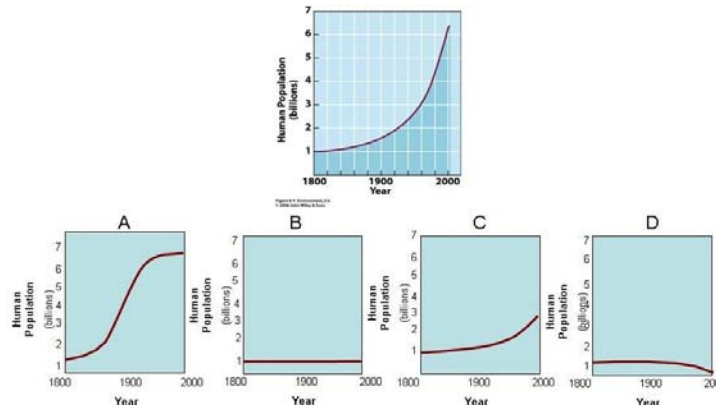
Figure 4. Simulation Interface for Population Dynamics Assignment

For Part 3 of the assignment, experimental group students answered another question set. We asked them to describe the model outputs under each set of conditions and compare them to their hypotheses in Part 1 of the assignment. We asked them to describe each output, whether this trend was surprising to them and why they thought total population changed the way that it did. The question set paralleled the questions asked on Part 1 of the assignment. The questions we asked for Part 3 of the assignment are shown in Figure 5.

Assignment #2 Human Population Dynamics

PART 3 QUESTIONS

1. (2 points) How did the total population trend change when you decreased birth rate? Choose one of the graphs below.



2. Did this surprise you? Why or why not? Why do you think population changed the way that it did?
3. What happened to the total population trend when you increased the number of deaths? Choose one of the graphs. (SEE GRAPHS ABOVE)
4. Did this surprise you? Why or why not? Why do you think population changed the way that it did?
5. What happens to the population trend when the number of births and the number of deaths are equal? Choose one of the graphs. (SEE GRAPHS ABOVE)
6. Did this surprise you? Why or why not? Why do you think population changed the way that it did?

Figure 5. Human Population Dynamics, Part3

We debriefed the assignment for all sections the day after it was submitted on-line. During lecture, we reviewed the question set from Part 1 as a group. We prompted students to tell us what graphs they chose for each question and why they believed total population would change the way that they did. Instructors discussed each question and explained the correct answer if the class did not come to it. For the experimental sections, we also discussed what happened when they ran the simulation in each of the birth rate/death rate conditions.

Assignment #4: Carbon in the Atmosphere

The second systems simulation intervention we tested was Assignment #4: Carbon in the Atmosphere. Again, the assignment was divided into three parts. This time both groups completed all three parts.

For Part 1 of the assignment, all students read John Sterman's "Risk Communication on Climate: Mental Models and Mass Balance" (2008). The article summarizes the findings of Sterman's previous work, describing a general inability for people to understand carbon accumulation in the atmosphere as the net difference between carbon emissions and carbon absorption.

Experimental group and control group students completed different activities for Part 2 of the assignment. The experimental sections read a description of carbon accumulation in the atmosphere on line and then used the Bathtub Dynamics and Climate Change simulation developed by the MIT System Dynamics Group. The simulation introduced students to the stock and flow dynamics associated with carbon accumulation in the atmosphere and then

directed them to control carbon emissions under a variety of conditions. For the first part of the simulation, the student's goal was to adjust carbon emissions relative to absorption to produce a trend for carbon in the atmosphere identical to one already displayed on the simulation screen. For the next part of the simulation, students tried to control emissions to keep carbon in the atmosphere at a particular level under conditions of sink saturation and delay. For Part 2, the control sections only read the system description that accompanied the simulation.

For Part 3 of the assignment, both groups answered the same set of questions. The question set asked students to relate carbon emissions and carbon absorption to carbon in the atmosphere in a number of ways. The question set is shown in Figure 6.

Assignment #4 Carbon in the Atmosphere

1. How are carbon emissions related to the carbon that accumulates in the atmosphere?
2. How is carbon absorption related to the carbon that accumulates in the atmosphere?
3. What happens to carbon in the atmosphere when carbon emissions are equal to carbon absorption?
4. In order for carbon in the atmosphere to increase:
 - a) carbon emissions must be less than carbon absorption.
 - b) carbon emissions must be greater than carbon absorption.**
 - c) carbon emissions and carbon absorption must be equal.
 - d) carbon emissions must be adapted to
 - e) There is not enough information to answer the question.
5. What must be true about carbon emissions and carbon absorption for carbon in the atmosphere to decrease?

Figure 6. Carbon in the Atmosphere, Part 3

Description of Assessments

Students completed a baseline quiz, four periodic quizzes throughout the semester, and a final exam. We also used the questions that students answered on Assignment #2 and Assignment #4 for analysis.

Baseline Quiz and Final Exam Questions

The baseline quiz was a pretest measure. Students took the baseline quiz online. On the first day of class, we instructed them on how to access the baseline quiz on the course website. They completed the assessment by the second class meeting, prior to any instruction. We graded the baseline quiz for completion, not correctness. Students received full credit for any answer. The baseline quiz contained five sections: general knowledge, systems knowledge, the New Ecological Paradigm assessment (Dunlap et al., 2000) (which assessed their attitude and opinions toward the environment), environmental practices, and

demographic information. We evaluated the general knowledge and systems knowledge portions of the baseline quiz for this study.

The general knowledge portion of the baseline quiz contained twelve questions that covered a variety of environmental topics. The questions came from Wright's Environmental Literacy Instrument (2007), though we edited some for clarity. We chose these questions because they had already been tested for validity and they tested knowledge that would be discussed in the course.

The systems knowledge portion of the baseline quiz consisted of ten original questions designed to assess students systems thinking abilities and ability to read graphs that related to systems concepts. Five of these were evaluated for systemic understanding. One, short-answer question tested students' systemic knowledge of population dynamics. Four questions tested students' systemic knowledge of carbon accumulation in the atmosphere: three multiple choice questions and one short-answer question.

The final exam was comprehensive. We administered the final exam in class, on paper, on the last day of class. The final exam included all of the questions on the baseline assessment, except for the demographic information questions. We included these questions on the final exam as a post-test measure. A full set of the baseline quiz/final exam questions that we analyzed for this study can be found in Appendix B.

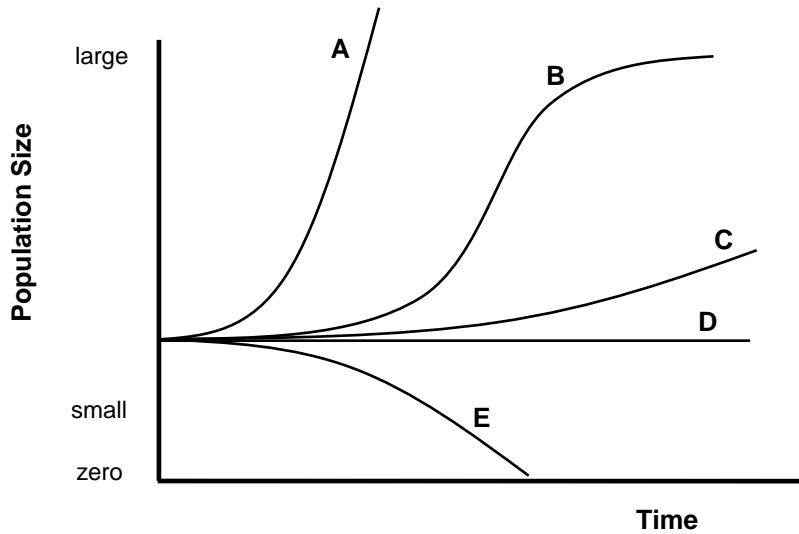
Quizzes

We administered all other quizzes during the semester in class and on paper. Each quiz between the baseline quiz and the final exam contained about

twenty questions that were either multiple choice or short answer. Multiple choice prompts were either questions to be answered or statements to be completed. There were five answer options with one clear, correct answer. Short answer questions asked the students to describe a concept in a few sentences. Quizzes that followed systems simulation interventions contained at least one question that tested students' systemic knowledge about the topic addressed by the simulation. We analyzed data from systems-related questions on Quiz #3 and Quiz #5 only, as these were the quizzes that followed Assignment #2: Human Population Dynamics and Assignment #4: Carbon in the Atmosphere.

Quiz #3 contained four multiple choice questions, asking students to identify the correct population trend over time, given a birth rate-death rate relationship. Figure 7 shows the population dynamics questions included on Quiz #3. Quiz #5 contained one multiple choice question asking students to identify the correct trend for carbon emissions that would produce an immediate decrease in carbon in the atmosphere if carbon absorption remained constant. We took this question directly from Booth Sweeney and Sterman's study on student misconceptions about climate change (2002). This question is shown in Figure 8.

Consider a group of people living on a large island. Assume that the population is isolated, that is, no one can come to or leave the island. Using the graph below, identify the population trend you would expect to see in the following situations:



If the	The population trend would look most like the line indicated by the letter (circle only one) ...						
a. (2 pts) birth rate is much smaller than the death rate ...	<table border="0"> <tr> <td>A</td> <td>B</td> <td>C</td> <td>D</td> <td>E</td> <td>none of the lines on the graph</td> </tr> </table>	A	B	C	D	E	none of the lines on the graph
A	B	C	D	E	none of the lines on the graph		
b. (2 pts) death rate is much smaller than the birth rate ...	<table border="0"> <tr> <td>A</td> <td>B</td> <td>C</td> <td>D</td> <td>E</td> <td>none of the lines on the graph</td> </tr> </table>	A	B	C	D	E	none of the lines on the graph
A	B	C	D	E	none of the lines on the graph		
c. (2 pts) death rate is about the same as the birth rate ...	<table border="0"> <tr> <td>A</td> <td>B</td> <td>C</td> <td>D</td> <td>E</td> <td>none of the lines on the graph</td> </tr> </table>	A	B	C	D	E	none of the lines on the graph
A	B	C	D	E	none of the lines on the graph		
d. (2 pts) birth rate is only a little larger than the death rate ...	<table border="0"> <tr> <td>A</td> <td>B</td> <td>C</td> <td>D</td> <td>E</td> <td>none of the lines on the graph</td> </tr> </table>	A	B	C	D	E	none of the lines on the graph
A	B	C	D	E	none of the lines on the graph		

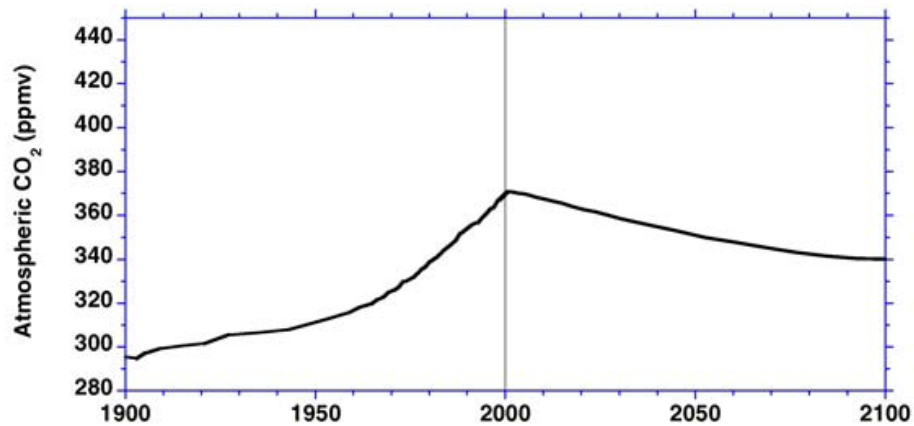
Figure 7. Human Population Dynamics Question Included on Quiz #3

The top graph below shows the rise in CO₂ levels in the atmosphere that has been recorded from 1900 to 2000. In order for the amount of CO₂ in the atmosphere to drop as shown on the graph from 2000 to 2100, what would have to happen to the global emissions of CO₂ (shown in the bottom graph from 1900 to 2000)?

CO₂ emissions would have to:

- A) Stay at current emission rates.
- B) Continue to rise through the year 2100.
- C) Rise just a little and then stabilize by the year 2100.
- D) Immediately drop below net removal rates and remain below removal rates until the year 2100.
- E) Decrease gradually to just above the net removal rate and then remain at that level until 2100.

CO₂ Levels in Atmosphere



CO₂ Emission and Removal Rates

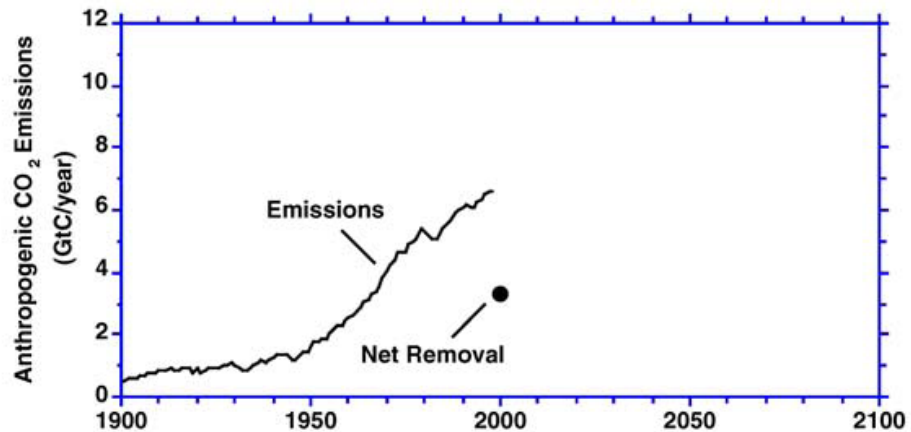


Figure 8. Carbon in the Atmosphere Question Included on Quiz #5

Assessment Questions on Assignments

All of the questions included on Assignments #2 and Assignment #4 were evaluated for systemic understanding. Assignment #2, Part 1 questions (Fig. 2) were evaluated as a pretest measure for all students. We assumed that control section students pretest and posttest scores were identical, since they had no intervention to change their understanding. We only evaluated questions 3-8 on Part 1 of the assignment. These questions had parallel questions on Part 3, so we could compare student understanding before simulation use to their understanding after. Assignment #2, Part 3 questions (Fig. 4) were evaluated as a posttest measure immediately following the intervention. Assignment #4, Part 3 questions (Fig. 5) were evaluated for all students as a post-test measure immediately following the intervention. Table 3 shows the number and types of questions were included on each assessment and how many points they were worth.

Table 3. *Assessment Questions, What They Assessed, Point Value*

Assessment	What the question(s) assessed	No. of questions	Points
Baseline Quiz and Final Exam	General knowledge	12	12
	Systems understanding of population dynamics and carbon in the atmosphere	5	13
Assignment #2 Part 1	Systemic understanding of population dynamics	1	1
Assignment #2 Part 3	Systemic understanding of population dynamics	6	18
Quiz #3	Systemic understanding of carbon in the atmosphere	1	1
Assignment #4 Part 3	Systemic understanding of carbon in the atmosphere	5	13
Quiz #5	Systemic understanding of carbon in the atmosphere	1	1

Method of Evaluation

Using the Stave and Hopper (2008) hierarchy of systems thinking skills, we devised a coding scheme for questions that tested students' systemic understanding (Skaza and Stave, 2009). The original coding scheme was used in the pilot study and aimed at classifying student responses in the one of the lower levels of the systems thinking taxonomy: recognizing interconnections, identifying feedback and differentiating types of variables and flows. Table 4 shows the original coding scheme.

Table 4. *Original Coding Scheme for Pilot Study*

Code	Systems thinking skill represented	Example answer for the question “If birth rate is decreasing then why is total population increasing?”
0	No systems thinking skill demonstrated	“Because grownups are more industrialized than babies.”
1	Recognizes interconnections	“Because women are educated more.” “Because death rate is low.”
2	Is able to identify feedback	“Because birth rate is greater than death rate and as total population increases, there is a higher number of births”
3	Is able to differentiate types of variables and flows	“Because birth rate and death rate cause total population to go up and down.”

While evaluating student responses for the pilot study, we discovered that students very rarely identified feedback within a system, but they could differentiate types of flows and variables. They did have an understanding of how the flows within a system worked together to produce and increase or decrease in the stock of the system. Also, the original coding scheme allowed for several types of answers to be coded the same way. For example, a student who was able to recognize interconnections may have recognized interconnections between the variable we described in the system or they could have recognized interconnections between other variables that were not directly related to the stock and flows we described. Student responses fell into more specific categories than we originally believed they would.

We used this information to revise the original coding scheme. The current study codes student responses in five ways, based on experience with student responses during the pilot studies. Table 5 shows the way we coded

student responses, the systems thinking ability each code represented and an example of answer that might be coded that way. Short answer questions on all assessments were evaluated using this coding scheme. Multiple-choice questions were given a score of one for a correct answer and a score of zero for an incorrect answer.

For the general knowledge portion of the baseline quiz and final exam, we did not use the coding scheme for short answer questions. All questions were evaluated as correct (and given one point) or incorrect (and given zero points). This way the systems portion of the general knowledge assessment was not given more weight than the other questions, since we also evaluated these questions separately for the systems knowledge score.

We measured the relative effect of using a systems simulation on students' systemic understanding in a number of ways. We expected that we would see a greater systemic understanding of environmental issues for the group of students using the systems simulations than for the students who did not. From this came several subhypotheses, each of which were tested. For these analyses, we used a subset of our population that completed the Baseline Quiz, Assignment #2, Quiz #3, Assignment #4, Quiz #5 and the Final Exam.

Table 5. Coding Scheme for Short Answer Questions

Code	Systems thinking skill represented	Example answer for the question “If birth rate is decreasing then why is total population increasing?”
0	No systems thinking skill demonstrated	“Because grownups are more industrialized than babies.”
1	Recognizes interconnections based on lecture or text material, but without mention of any system variables	“Because women are educated more.”
2	Recognizes interconnections between system variables, but misunderstands variable relationships	“Because you are starting at a higher total population.”
3	Demonstrates understanding of one flow connected to the system’s stock	“Because death rate has gone down.”
4	Demonstrates understanding of both flows connected to the system’s stock, but not to each other	“Birth rate is increasing, but death rate is decreasing.”
5	Demonstrates understanding of flow relationships to produce an increase or decrease in the stock	“Birth rate is still higher than death rate. When more people are added to the population than taken away, total population increases.”

CHAPTER 4

INITIAL ANALYSES AND RESULTS

Combining the Sections

Mean scores and standard deviations for class assessments show that class size did not affect a student's success. Therefore, we combined the large and small experimental sections and the large and small control sections for analysis. Table 6 shows the means scores and standard deviations for all quizzes and the final exam. The baseline quiz was not included, since we graded it for completion, not correctness.

Initial Analyses

For our first analyses, we calculated mean scores and standard deviations for assessments that tested each one of our hypotheses. We expected that the experimental group would have significantly higher mean scores on each assessment, supporting each subhypothesis.

We calculated mean scores and standard deviations for baseline quiz questions that assessed baseline general knowledge, systemic knowledge, systemic population knowledge and system carbon in the atmosphere knowledge. We assumed that all students were starting the class with the same baseline general knowledge level, systemic knowledge level, systemic understanding of population dynamics and systemic understanding of carbon in the atmosphere. This was important to establish so that all subsequent analyses would be comparable.

Table 6. *Mean Scores and Standard Deviations for Quizzes and Final Exam*

Section Number	N	Quiz #2		Quiz #3		Quiz #4		Quiz #5		Final Exam	
		M	SD	M	SD	M	SD	M	SD	M	SD
001	32	76.0	27.8	78.0	14.9	74.6	22.0	81.4	12.2	103.6	11.3
002	65	70.8	24.7	72.9	17.7	70.1	23.6	78.1	13.0	101.4	10.1
003	34	74.7	19.2	75.7	14.7	78.2	19.2	76.4	12.3	99.7	10.3
004	58	78.0	16.6	74.3	18.7	67.2	26.2	79.5	13.0	102.4	8.7

We assumed that all sections would demonstrate the same systemic knowledge level on Part 1 of Assignment #2: Human Population Dynamics. It was important to again verify a common baseline knowledge level. To verify this assumption, we calculated mean scores and standard deviations for question set on Part 1 of the assignment, prior to simulation use.

We calculated mean scores and standard deviations for final exam questions that assessed baseline general knowledge, systemic knowledge, systemic population knowledge and system knowledge on carbon accumulation in the atmosphere. We expected to see significantly higher scores on each set of assessments for the experimental group.

We also calculated scores for Assignment 2, Part 3, Quiz #3, Assignment 4, Part 3 and Quiz #5 to test students' systemic knowledge of population dynamics and carbon in the atmosphere during the semester. We expected to see significantly higher scores on each assessment for the experimental group. Table 7 shows the assessments that tested knowledge for each subhypothesis.

Table 7. *Hypothesis, Intervention, Measure and Analysis*

Hypothesis	Intervention	Measure	Analysis
No hypothesis tested; Necessary to establish common baseline knowledge level	None	BGK, BSK, BPop, BCO2	Mean scores and standard deviations
No hypothesis tested; Necessary to establish common baseline knowledge level prior to Assignment #2	None	A2pre	Mean scores and standard deviations
1) Simulation users would perform better on assessments that tested their general knowledge of environmental issues by the end of the course.	Assignment #2: Population Dynamics, Assignment #4: Carbon in the Atmosphere	FGK	Mean scores and standard deviation
2) Simulation users would perform better on assessments that evaluated systems knowledge by the end of the course.	Assignment #2: Population Dynamics, Assignment #4: Carbon in the Atmosphere	FSK	Mean scores and standard deviation
3) At the end of the course, simulation users would demonstrate a greater systemic understanding of the environmental issues addressed by the systems simulations.	Assignment #2: Population Dynamics	FPop	Mean scores and standard deviation
	Assignment #4: Carbon in the Atmosphere	FCO2	
4) Simulation users would show a greater systemic understanding of the environmental issues addressed by the simulations on assessments following the interventions.	Assignment #2: Population Dynamics	A2Post, Q3	Mean scores and standard deviation
	Assignment #4: Carbon in the Atmosphere	A4, Q5	

BGK=Baseline general knowledge, FGK=Final General Knowledge, BSK=Baseline systems knowledge, FSK=Final Systems Knowledge, BPop=Baseline population knowledge, FPop=Final population knowledge, BCO2=Baseline knowledge on carbon in the atmosphere, FCO2=Final knowledge on carbon in the atmosphere, A2Pre=Assignment 2, pre-simulation questions, A2Post=Assignment 2, post simulation questions, A4=Assignment 4, Q3=Quiz 3, Q5=Quiz 5

Our first subhypothesis stated that simulation users would perform better on assessments that tested their general knowledge of environmental issues by the end of the course. We expected to find that that the experimental group would have significantly higher mean scores for the general knowledge portion of the final. This hypothesis was not supported. The experimental group's scores ($M=12.41$, $SD=2.32$) were not significantly higher than the control group's scores ($M=12.81$, $SD=2.25$), $t(189)=1.21$, $p=.23$.

Our second hypothesis stated that simulation users would perform better on assessments that evaluated systems knowledge by the end of the course. We expected to find that the experimental group would have significantly higher scores on the portion of the final exam that tested systemic knowledge. This hypothesis was not supported. The experimental group's scores ($M=10.51$, $SD=2.74$) were not significantly higher than the control group's scores ($M=10.70$, $SD=2.51$), $t(189)=.50$, $p=.62$.

Our third subhypothesis stated that, at the end of the course, simulation users would demonstrate a greater systemic understanding of the environmental issues addressed by the systems simulations. We expected to see significantly higher scores for the experimental group on final exam questions that tested both systemic knowledge of population dynamics and carbon accumulation in the atmosphere. This hypothesis was not supported. The experimental group's scores on the population dynamics questions ($M=4.25$, $SD=1.11$) were not significantly higher than the control group's scores ($M=4.12$, $SD=1.14$), $t(189)=.77$, $p=.44$. The experimental group's scores on the questions that tested

knowledge on carbon accumulation in the atmosphere ($M=6.26$, $SD=2.12$) were not significantly higher than the control group's scores ($M=6.58$, $SD=1.79$), $t(189)=1.11$, $p=.27$.

Our fourth subhypothesis stated that simulation users would show a greater systemic understanding of the environmental issues addressed by the simulations on assessments following the interventions. We expected that the experimental group would demonstrate significantly higher scores on Assignment 3, Part 3, Quiz #3, Assignment #4, Part 3, and Quiz #5. There were mixed results for this hypothesis. The experimental group's scores on Assignment #2, Part 3 ($M=14.30$, $SD=2.94$) were significantly higher than the control group's scores ($M=12.40$, $SD=3.45$), $t(189)=4.09$, $p<.01$. This result supports our hypothesis. The experimental group's scores on the Quiz #3 questions ($M=3.70$, $SD=.72$) were not significantly higher than the control group's scores ($M=3.48$, $SD=.89$), $t(189)=1.78$, $p=.08$. This does not support the hypothesis. The experimental group's scores on Assignment #4, Part 3 ($M=10.54$, $SD=2.42$) were not significantly higher than the control group's scores ($M=10.11$, $SD=2.89$), $t(189)=1.03$, $p=.30$. This did not support the hypothesis. The experimental group's scores on the carbon in the atmosphere question on Quiz #5 ($M=.49$, $SD=.50$) were not significantly higher than the control group's scores ($M=.41$, $SD=.50$), $t(189)=1.06$, $p=.29$.

Table 8 shows mean scores, standard deviations, t-values and p-values for all assessments.

Table 8. Mean Scores, Standard Deviations, t-values, and p-values

Assessment	Experimental Group		Control Group		t	p
	N					
	M	SD	M	SD		
	(points)	(points)	(points)	(points)		
BGK	9.04	3.09	9.78	2.83	1.72	.09
BSK	6.61	3.30	7.21	3.26	1.25	.21
BPop	2.34	1.70	2.70	1.67	1.49	.14
BCO2	4.27	2.45	4.51	2.45	.65	.51
FGK	12.41	2.32	12.81	2.25	1.21	.23
FSK	10.51	2.74	10.70	2.51	.50	.62
FPop	4.25	1.11	4.12	1.14	.77	.44
FCO2	6.26	2.12	6.58	1.79	1.11	.27
A2pre	12.12	3.21	12.40	3.42	.56	.58
A2post	14.30	2.94	12.40	3.45	4.09	p<.01
Q3	3.70	.72	3.48	.89	1.78	.08
A4	10.54	2.42	10.11	2.89	1.03	.30
Q5	.49	.50	.41	.50	1.06	.29

BGK=Baseline general knowledge, FGK=Final General Knowledge, BSK=Baseline systems knowledge, FSK=Final Systems Knowledge, BPop=Baseline population knowledge, FPop=Final population knowledge, BCO2=Baseline knowledge on carbon in the atmosphere, FCO2=Final knowledge on carbon in the atmosphere, A2pre=Assignment 2, pre simulation questions, A2Post=Assignment 2, post simulation questions, A4=Assignment 4, Q3=Quiz 3, Q5=Quiz 5

CHAPTER 5

REGRESSION ANALYSES AND RESULTS

Multiple Regression Analyses

When we didn't find significant differences in the experimental and control group's knowledge levels on the final exam assessments, we used multiple regression analyses to take a more detailed look at the relationship between students' performance on assessments and simulation use. Multiple regression analysis allows us to consider the effect of more than one variable on a dependent variable, enabling better explanations for the value of the dependent variable (Anderson, Sweeney & Williams, 2007). We used this method to test for a relationship between general and systemic understanding on a number of analyses and simulation use.

We formed new hypotheses, based on what we expected to see in the regression results:

- 1) Regression results would show a positive relationship between performance on questions that tested students' general knowledge of environmental issues by the end of the course and simulation use.
- 2) Regression results would show a positive relationship between performance on questions that tested that evaluated systems knowledge by the end of the course and simulation use.
- 3) Regression results would show a positive relationship between performance on questions that tested students' knowledge on the subjects addressed by the systems simulations and simulation use.

4) Regression results would show a positive relationship between performance on questions that tested students' knowledge on the subjects addressed by the simulations on assessments following the interventions and simulation use.

Our first subhypothesis was that regression results would show a positive relationship between performance on questions that tested students' general knowledge of environmental issues by the end of the course and simulation use. We tested this hypothesis by using a multiple regression model to model Final General Knowledge as a function of Baseline General Knowledge and simulation use.

$$FGK = b_0 + bBGK + bSIM$$

Our second hypothesis stated that regression results would show a positive relationship between performance on questions that tested that evaluated systems knowledge by the end of the course and simulation use. We tested this hypothesis by using a multiple regression model to model Final Systemic Knowledge as a function of Baseline Systemic Knowledge and simulation use.

$$FSK = b_0 + bBSK + bSIM$$

Table 9. Hypothesis, Intervention, Measure and Regression Model

Hypothesis	Intervention	Measure	Model
1) Regression results would show a positive relationship between performance on questions that tested students' general knowledge of environmental issues by the end of the course and simulation use.	Assignment #2: Population Dynamics, Assignment #4: Carbon in the Atmosphere	FGK	$FGK = b_0 + bBGK + bSIM$
2) Regression results would show a positive relationship between performance on questions that tested that evaluated systems knowledge by the end of the course and simulation use.	Assignment #2: Population Dynamics, Assignment #4: Carbon in the Atmosphere	FSK	$FSK = b_0 + bBSK + bSIM$
3) Regression results would show a positive relationship between performance on questions that tested students' knowledge on the subjects addressed by the systems simulations and simulation use.	Assignment #2: Population Dynamics	FPop	$FPop = b_0 + bBPop + bSIM$
	Assignment #4: Carbon in the Atmosphere	FCO2	$FCO2 = b_0 + bBCO2 + bSIM$
4) Regression results would show a positive relationship between performance on questions that tested students' knowledge on the subjects addressed by the simulations on assessments following the interventions and simulation use.	Assignment #2: Population Dynamics	A2Post Q3	$A2Post = b_0 + bBPop + bSIM$ $Q3 = b_0 + bBPop + bSIM$
	Assignment #4: Carbon in the Atmosphere	A4, Q5	$A4 = b_0 + bCO2 + bSIM$ $Q5 = b_0 + bCO2 + bSIM$

BGK=Baseline general knowledge, FGK=Final General Knowledge, BSK=Baseline systems knowledge, FSK=Final Systems Knowledge, BPop=Baseline population knowledge, FPop=Final population knowledge, BCO2=Baseline knowledge on carbon in the atmosphere, FCO2=Final knowledge on carbon in the atmosphere, A2Post=Assignment 2, post simulation questions, A4=Assignment 4, Q3=Quiz 3, Q5=Quiz 5

Our third hypothesis stated that regression results would show a positive relationship between performance on questions that tested students' knowledge on the subjects addressed by the systems simulations and simulation use. We tested this hypothesis by using a multiple regression model to model:

- 1) Final Population Knowledge as a function of Baseline Systemic Knowledge and simulation use.

$$FPop = b_0 + bBPop + bSIM$$

- 2) Final Carbon Accumulation Knowledge as a function of Baseline Carbon Accumulation Knowledge and simulation use.

$$FCO2 = b_0 + bBCO2 + bSIM$$

Our fourth hypothesis stated that regression results would show a positive relationship between performance on questions that tested students' knowledge on the subjects addressed by the simulations on assessments following the interventions and simulation use. We tested this hypothesis by using a multiple regression model to model:

- 1) Assignment #2, Part 3 scores as a function of baseline population knowledge and simulation use.

$$A2Post = b_0 + bBPop + bSIM$$

Control group scores on Part 3 were assumed to be the same as their scores on Part 1 of the assignment, as they had no intervention to cause a

change in understanding. Since pre-simulation scores and post-simulation scores were the same for this group, we did not use the pre-intervention score as a variable for baseline knowledge in the regression analysis.

2) Student performance on Quiz #3 as a function of baseline population knowledge and simulation use.

$$Q3 = b_0 + bBPop + bSIM$$

3) Assignment #4, Part 3 scores (A4post) as a function of baseline systemic knowledge about carbon in the atmosphere (BCO2) and simulation use (SIM).

$$A4 = b_0 + bCO2 + bSIM$$

4) Quiz #5 performance as a function of baseline knowledge and simulation use.

$$Q5 = b_0 + bCO2 + bSIM$$

Multiple Regression Analysis Results

Our first hypothesis was not supported. There was no significant relationship between performance on the final general knowledge questions and simulation use, $\beta=-0.17$, $t(189)=-0.56$, $p=0.58$. In this case, baseline general

knowledge was the predictor of final general knowledge, $\beta=0.32$, $t(189)=6.18$, $p<0.01$.

Our second hypothesis was not supported. There was no significant relationship between students' final systemic knowledge level at the end of the course and simulation use, $\beta=-0.04$, $t(189)=-0.12$, $p=0.91$. Again, baseline systemic knowledge was the most significant predictor of final systemic performance, $\beta=0.25$, $t(189)=4.49$, $p<0.01$.

Our third hypothesis was not supported. There was no significant relationship between systemic understanding of population dynamics at the end of the course and simulation use, $\beta=0.18$, $t(189)=1.14$, $p=0.25$. In this case, baseline systemic knowledge had a significant impact on final systemic understanding of population dynamics, $\beta=0.14$, $t(189)=3.02$, $p<0.01$.

There was no significant relationship between systemic understanding of carbon accumulation at the end of the course and simulation use, $\beta=-0.27$, $t(189)=-0.100$, $p=0.32$. In this case, baseline systemic knowledge of carbon accumulation was the main predictor of final exam performance on the carbon accumulation questions, $\beta=0.22$, $t(189)=3.89$, $p<0.01$.

Analyses that tested our third hypothesis showed mixed results. Multiple regression model results showed a significant positive relationship between scores on Assignment #2, Part 3, post-intervention and simulation use, $\beta=2.08$, $t(189)=4.64$, $p<0.01$. There was also a significant positive relationship between post-intervention assessment scores and baseline systems knowledge on population dynamics, $\beta=0.50$, $t(189)=3.74$, $p<0.01$.

There was a significant positive relationship between students performance on Quiz #3 and simulation use, $\beta=0.24$, $t(189)=2.01$, $p<0.05$.

Performance on Quiz #3 was also significantly correlated with baseline population knowledge, $\beta=0.08$, $t(189)=2.24$, $p<0.05$.

Performance on Assignment 4, Part 3 was not significantly related to simulation use, $\beta=0.63$, $t(189)=1.56$, $p=0.12$. In this case, baseline systemic knowledge of carbon accumulation was a significant predictor of success on the assessment questions, $\beta=0.39$, $t(189)=4.62$, $p<0.01$.

Students performance on Quiz 5 was not significantly related to simulation use, $\beta=0.09$, $t(189)=1.33$, $p=0.19$. Performance on Quiz 5 was significantly related to baseline systemic knowledge about carbon accumulation (BCO₂), $\beta=0.05$, $t(189)=3.35$, $p<0.01$.

Multiple regression results an all analyses are shown in Table 10.

Table 10. *Multiple Regression Results*

Variable	Final general knowledge	Final systems knowledge	Final population knowledge	Final CO2 knowledge	Assignment 2 post intervention	Quiz 3: Population Dynamics questions	Assignment 4 post intervention	Quiz 5: CO2 Question
SIM	-0.17	-0.04	0.18	-0.27	2.09*	0.24*	0.53	0.09
BGK	0.32*	-	-	-	-	-	-	-
BSK	-	0.25*	-	-	-	-	-	-
Bpop	-	-	0.14*	-	0.50*	0.08	-	-
BCO2	-	-	-	0.22*	-	-	0.41*	0.05*
Bgraph	-	-	-	-	-	-	-	-
A2Pre	-	-	-	-	-	-	-	-
A2Post	-	-	-	-	-	-	-	-
A4Post	-	-	-	-	-	-	-	-
Fgraph	-	-	-	-	-	-	-	-
				-	-	-	-	-
Intercept	9.71	8.91	3.73	5.61	11.05	3.28	8.27	0.19
r square	0.18	0.10	0.05	0.08	0.15	0.04	0.11	0.06
Adjusted r square	0.17	0.09	0.04	0.07	0.14	0.03	0.10	0.05
	*p<.01							

CHAPTER 6

DISCUSSION

We found that scores were significantly better for simulation users immediately after using the simulations, but not later on in the semester. Two possible explanations are:

- 1) Students in the experimental sections may have lost the systemic knowledge that they gained through simulation use and that they displayed on assessment immediately following simulation use.
- 2) Students in the control sections increased their systemic understanding through a number of other class activities.

If the experimental group lost the systemic knowledge that they demonstrated on the Assignment #2 and on Quiz #3, then we would expect to see lower scores on the final systemic knowledge assessment than on Assignment #2 or Quiz #3. To test this, we compared scores on short answer population questions on the baseline quiz (BPop), Assignment #2 (A2) and the final exam (FPop). Figure 9 shows both groups' change in systemic understanding over the course of the semester. The experimental group showed an increase in systemic understanding between Assignment #2 and the final exam, confirming that students in the experimental sections retained the systemic knowledge they gained through simulation use.

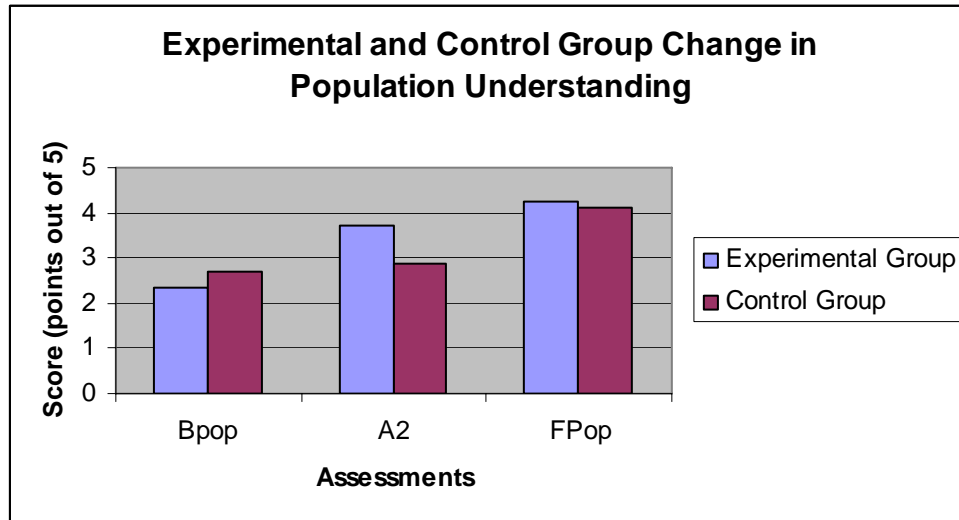


Figure 9. Change in Systemic Understanding of Population Dynamics

Figure 9 also shows that the control group's scores increased between Assignment #2 and the end of the semester. Another possible explanation for the lack of difference in systemic understanding by the end of the course is that the control group's systemic understanding could have increased. We believe that the control group showed an increase in their systemic knowledge due to an emphasis on systems principle throughout the course.

Course material was presented in lecture with systems thinking principles in mind. The course textbook emphasized interconnections between the human and natural world. Each day, class lectures began with the graphic shown in Figure 10, which was intended to reinforce the idea that the human/environment relationship is one of reciprocal feedback. Lecturers then highlighted how that relationship was present in the topic they were lecturing on that day. Figure 11 shows how the graphic was presented for the fossil fuels lecture.

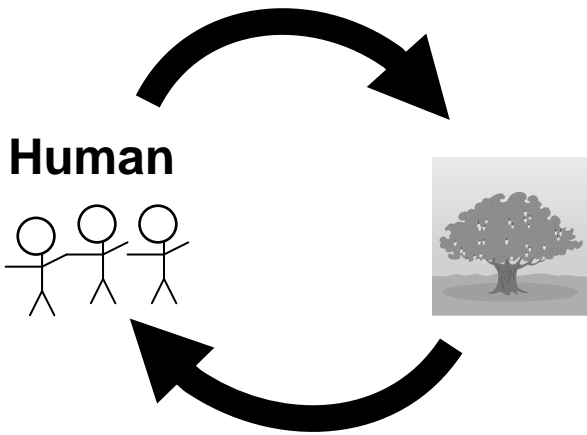


Figure 10. Human/Environment Relationship

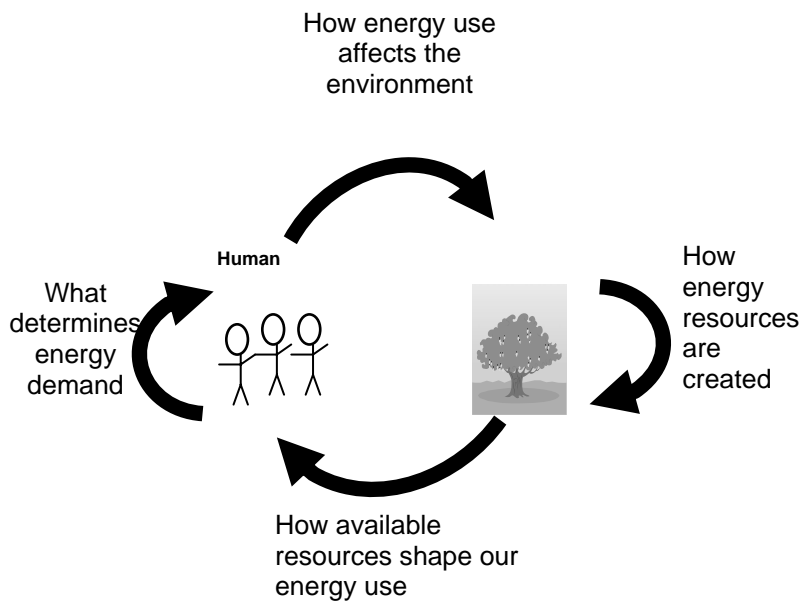


Figure 11. Human/Environment Relationship within Fossil Fuels

Course lectures and the textbook emphasized system connections, feedback and dynamic behavior. We believe the reason we did not see a greater difference in the performance of the two groups was largely due to the overall

emphasis on systems principles throughout the course for both groups of students. We delivered this message to both the experimental sections and control sections consistently throughout the course.

Another important part of class assignments was the debriefing that we conducted for all students after they turned the assignment in. All students who came to lecture that day would have heard the debriefing. Instructors read each question in the assignment and asked students to respond. Students called out answers. If no answer was called out, instructors encouraged student response with hints. If no answer was given, instructors gave students the correct answer to the question. Although student response drove each debriefing session, any misconceptions about the systems principles involved in the assignment were corrected. Both the experimental and the control sections received the debriefing.

Although we are pleased that the systemic understanding of all students appears to have increased, we did expect that the simulations would have had a greater effect. Why don't we see more of an increase in systemic understanding for the experimental group over the control group? Why didn't the systems simulations have more of an impact on student understanding than the other course materials?

Intervention issues

We had several restrictions for this study. Students would complete the assignments on their own, without guidance from an instructor. We assumed

that they had no previous environmental science education. We assumed they had no experience in a simulation environment. Part of our challenge was being able to design effective systems simulation interventions for a large, lecture-based course.

Lack of Guidance

Students worked with the simulations without live instruction or guidance, because we did not have classroom computers available for the number of students that we had. Students were given written instructions and descriptions of the system the simulation was modeled after. Students using the simulation had only a surface interaction with it. There was no instructor present to encourage them to think about what sort of interactions were taking place within the system to produce the trend they saw on the screen. As a result, student often explained stock and flow interactions in terms of variables that were not represented in the system they were working with. For example, if a student was asked, “What causes carbon to accumulate in the atmosphere?” a student might answer, “Too much industry.” If they were asked, “Why is total population increasing even though birth rate is decreasing?” they might answer, “Because this population has more medicine available.” Because there was not enough support during the exercise, students tended to rely heavily on knowledge that had acquired from other course materials.

Assignment Design

Sawicka (2005) discusses the role of a learner’s cognitive capacity in using a systems simulation. She argues that when the working memory is

primarily devoted to extraneous information in simulation design (i.e. interface operation), the less 'surplus' working memory there is to develop an understanding of the underlying system. Each simulation that we used was different in presentation and what it asked the user to do. Every time the student interacted with a new simulation, they had to interpret a new interface, understand new subject matter, understand the task and come up with a problem-solving strategy. This decreased the potential for students to 'get better' at simulation use and focus on the lesson it was trying to teach. During each debriefing session, students expressed frustrations about accessing the simulation, interaction with the interface and understanding the goal of simulation use. If the simulations we used were more similar in these areas, the students could have been better able to understand the subject matter within the simulation (i.e. human population dynamics or carbon accumulation in the atmosphere).

Assessment issues

If the interventions had been perfectly designed to facilitate students' systemic understanding, we still may not have seen the difference that we expected to see between the experimental and the control groups. Carefully designed assessments allow students to demonstrate their change in understanding. To improve our understanding of students' change in systemic knowledge, more assessment techniques should be tested.

More Assessment Methods

We saw the most significant relationship between simulation use and systemic understanding on the assessment questions for Assignment #2. These questions asked students to identify a trend over time for a given birth rate/death rate condition and explain why they chose the trend that they did. We asked students to express their understanding in more than one way. We should have done this for other assessments as well.

Part of what we wanted to test was how to best assess systemic understanding. However, we only used two assessment techniques: multiple choice questions and short-answer explanations of system characteristics. Systems dynamicists use causal maps and stock and flow diagrams to express stock and flow relationships. Future studies should use these representations to assess systemic understanding. While students may have been unable to create a stock and flow or causal loop diagram, it is reasonable to assume that they could have completed a partially-created diagram in with the appropriate variables. In our next steps, we will test more assessment techniques and use several when assessing understanding of even one interconnection to get a sense for what a student really knows.

Cheek (1992) discusses the need for the advancement of assessment tools parallel to the advancement in instructional techniques in science education. One method he describes for evaluating student understanding is evaluating student performance of the task. This would involve observing the student as they complete the task. While this may not have been possible in the

context of this study, we could have incorporated assessment questions that asked the student what they did when working with the simulation. This would have given us more data on the students' experience with the simulation. Combining this information with their performance on systemic understanding questions would have led to a better understanding about what parts of the simulation were effective in increasing systemic understanding.

Assessment as a Teaching Tool

A qualitative review of student responses in Assignment #2 and Assignment #4 showed that students' answers improved from the beginning of the assignment to the end. For both assignments we started with simple questions that asked students to describe the relationship between two variables in the system. The last questions of the question set asked them to relate both flows and the stock in the system. It is possible that students learned how to put the variables together by working their way through the questions. This is problematic if we are trying to assess their change in understanding as a result of simulation use only, although it does present an interesting way to increase the effectiveness of simulation use.

Conclusions and Recommendation for Further Study

This study furthers Stave and Hopper's (2008) work by implementing interventions and assessment based on the Taxonomy of Systems Thinking Characteristics. It begins the work of revising and verifying the taxonomy through controlled, experimental research. Future studies should address the assessment and intervention deficiencies described in this paper. Interventions

need to be revised to include a higher level of interaction with simulation. We should expect the students to learn more about the system underlying the simulation to have a richer understanding of what the simulation is designed to teach.

We need to devise new ways for assessing student systemic understanding. New assessment methods should ask students to express their mental models in a number of ways: verbally, graphically, in a diagram, etc. Future studies should test assessment techniques for their effectiveness in making student thinking visible, while they are testing the effectiveness of the systems simulation intervention.

We asked the question “Does the use of systems simulations in an introductory environmental science course increase students’ systemic understanding of environmental issues?” We found support for the use of systems simulations in the environmental science classroom. We also found the need for more rigorous assessment methods and better interventions design. Large, introductory courses like the one in this study present several challenges in designing and implementing a systems simulation lesson, but they also provide a great opportunity for increasing systemic understanding of environmental issues.

APPENDIX A: COURSE SYLLABUS

<p>ENV 101 Introduction to Environmental Science Fall 2009</p>
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SYLLABUS

Section 001 MW 10:00 am – 11:15 am GUA 2202
Section 002 MW 11:30 am – 12:45 pm CBC A106
Section 003 TR 10:00 am – 11:15 am WRI C239
Section 004 TR 11:30 am – 12:45 pm BPB 102

Environmental Studies Departmental Course

Faculty Instructors: Krystyna Stave, Shama Perveen, David Hassenzahl, Bill Smith

Graduate Student Instructors: Heather Skaza, Jill Dale, Carrie Bojda

All sections use the WebCampus website for the course. It is your responsibility to make sure you have access to the site and check it regularly throughout the course.

Contact Information for Course Coordinators:

Heather Skaza and Carrie Bojda Greenspun Hall 3205 895-4771 e-mail through WebCampus Office Hours: Tuesday and Thursday: 1:00 – 3:00 pm	Krystyna Stave, Ph.D. Greenspun Hall 3104 895-4833 e-mail through WebCampus
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Course Overview:

In this course, we examine the interconnections between human activity and the biophysical environment. We begin by exploring the scientific and social system foundations of environmental science and management. Then, we cover topics including population growth, resource consumption, environmental quality, and land use that further explain the complexity of environmental problems and help you understand the part you play in this interrelated world.

Course Objectives:

The objectives of this course are to:

- help students understand and apply fundamental theories from the natural and social sciences to environmental issues, and identify the multiple dimensions of environmental issues;
- examine how laws of matter and energy and principles of ecology interact with human activity;
- help students evaluate the desirability of changing individual behavior and

society's patterns of consumption, growth, and use of technology.

Required Text

Raven, P.H., L.R. Berg, and D.M. Hassenzahl, 2008. *Environment 6th Edition*. John Wiley & Sons, Inc. New Jersey

Course Format

This is a lecture-based course that includes lectures, readings, assignments and activities, and assessments. You are expected to do the assigned readings before class, complete the assignments by the due date, and attend the lectures.

There will be six quizzes throughout the course, including a baseline assessment on the first day of class, four quizzes during the semester, and a final quiz during finals week. The baseline assessment is to help the instructors tailor the course to the class. Your grade on the baseline assessment is based simply on your completion of the assessment, not on the knowledge you have at the beginning of the course. All other assessments will test your knowledge. The extended quizzes will each be approximately 30 minutes long. The final quiz is scheduled in a regular 2-hour final exam slot.

The instructions for the assignments are on the WebCampus course website. All assignments will be turned in through WebCampus.

Grade Distribution

Assessments: 60% of overall grade

Quiz 1: Baseline assessment (grade = # of questions completed, 5% of overall grade)

Quiz 2-5: throughout the term (10 % each)

Quiz 6: Final Quiz (15%)

Assignments: 30% of overall grade

5 assignments (6% each)

Assignment 1: Ecological Footprint

Assignment 2: Population

Assignment 3: Ecosystem Balance

Assignment 4: Climate Change

Assignment 5: Story of Stuff

Activity: 10% of overall grade

Participation in one activity and in-class exercises is required. Activity opportunities include field trips, volunteer projects, etc., and will be announced throughout the term on the website and in class. Additional activities may be done for extra credit.

Types of Activities will include:

Wetlands Park visit
 Environmental volunteer projects
 Trash budget

FINAL QUIZ:

Quiz #6 will be given during the official final exam period for your section in the same place you meet for class. Final exam time and date will be announced.

Fall 2009 Schedule

Week	Class 1 (M, T)	Class 2 (W, R)
Week 1 8/24	Introduction to Course QUIZ #1 (Baseline, take on WebCampus)	Chapter 1: Introducing Environmental Science START ASSN #1: Ecological Footprint
Week 2 8/31	Chapter 2: Environmental Laws, Economics and Ethics	Chapter 3: Ecosystems and Energy ASSN #1 DUE on-line
Week 3 9/7	<i>Monday: No Class</i> <i>Tuesday: No Class</i>	Chapter 4: Ecosystems and Organisms
Week 4 9/14	Chapter 5: Ecosystems and the Physical Environment	QUIZ #2 (Chapters 1-5) in class Chapter 6: Major Ecosystems
Week 5 9/21	Chapter 7: Human Health and Environmental Toxicology	Chapter 8: Population Change START ASSN #2: Population Dynamics
Week 6 9/28	Chapter 9: Problems of Overpopulation	Chapter 11: Fossil Fuels ASSN #2 DUE on-line
Week 7 10/5	Chapter 12: Nuclear Energy	Chapter 13: Renewable Energy and Conservation
Week 8 10/12	QUIZ #3 (Chapters 6-13) in class Chapter 14: Water	Chapter 15: Soil Resources Chapter 16: Minerals
Week 9 10/19	Chapter 17: Biological Diversity START ASSN #3: Ecosystem Balance	Chapter 18: Land Resources
Week 10 10/26	Chapter 19: Food Resources ASSN #3 DUE on-line	QUIZ #4 (Chapters 14-19) in class Chapter 20: Air Pollution
Week 11 11/2	Chapter 21: Atmospheric Changes START ASSN #4: Climate Change	Chapter 22: Water Pollution
Week 12 11/9	Chapter 23: Pesticides ASSN #4 DUE on-line	<i>Wednesday: No Class</i> <i>Thursday: No Class</i>
Week 13	Chapter 24: Solid and Hazardous	QUIZ #5 (Chapters 20-24) in class

11/16	Waste START ASSN #5: Story of Stuff	Chapter 10: Urban World
Week 14 11/23	<i>Make up day for missed quizzes</i> ASSN #5 DUE on-line	<i>Wednesday: No Class</i> <i>Thursday: No Class</i>
Week 15 11/30	Chapter 25: Tomorrow's World	Review for Final
Week 16 12/7	FINAL QUIZ (#6 Comprehensive)	

Note: The instructors reserve the right to modify the schedule during the term. All changes will be announced in class and on the WebCampus course website.

APPENDIX B: BASELINE QUIZ AND FINAL EXAM QUESTIONS

Env 101
Introduction to Environmental Science
Spring 2009

BASELINE ASSESSMENT/FINAL EXAM QUESTIONS

Questions 1-15 are designed to help us gain a sense of your current level of knowledge about the environment in general. PLEASE SELECT THE BEST ANSWER FOR EACH QUESTION.

1. There are many different kinds of animals and plants, and they live in many different types of environments. What word is used to describe this idea?
 - a. multiplicity
 - b. ecosystem
 - c. evolution
 - d. biodiversity
 - e. I don't know.

2. Which of the following resources is/are considered renewable?
 - a. oil
 - b. trees
 - c. iron ore
 - d. coal
 - e. I don't know.

3. What is the most common source of pollution of streams, rivers, and oceans?
 - a. nutrients and chemicals carried by water from yards, streets, farms
 - b. decreases in pH due to acid rain
 - c. natural chemicals produced in the atmosphere
 - d. oil leaks from recreational vehicles
 - e. I don't know.

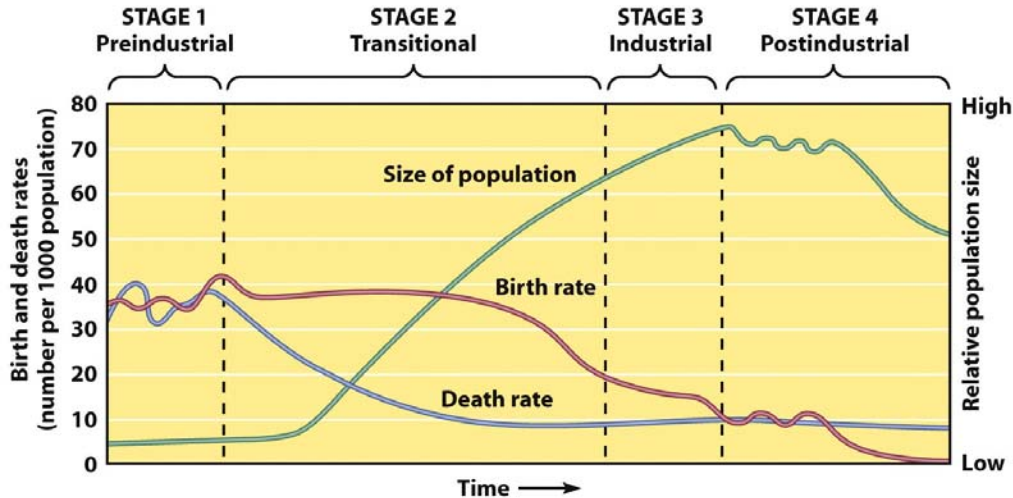
4. Most electricity in the U.S. is generated from what source of power:
 - a. hot springs/geothermal
 - b. dams/hydroelectric
 - c. burning of coal, oil, wood
 - d. wind
 - e. I don't know.

5. Where does most household trash and garbage eventually end up once it leaves your home?
 - a. compost piles
 - b. incinerators
 - c. it's recycled
 - d. landfills
 - e. I don't know.

6. Which of the following is a key ecosystem service provided by wetland areas?
- enhanced recreational opportunities
 - land area for commercial development
 - removal of pollutants in the water
 - decreased species diversity
 - I don't know.
7. What is the largest source of carbon monoxide in the U.S.?
- motor vehicles
 - the atmosphere
 - plant life
 - evaporation from the ocean
 - I don't know.
8. What is the most common reason that animal species can become extinct quickly?
- over-hunting/fishing
 - loss of critical habitat
 - natural death
 - pollution
 - I don't know.
9. Which of the following is true about fossil fuels:
- We have used all of the fossil fuels on Earth.
 - We only use fossil fuels in our cars.
 - We are using fossil fuels faster than they can be created.
 - The main ingredient in a fossil fuel is nitrogen.
 - I don't know.
10. To reduce the amount of greenhouse gas in the atmosphere, we need to ...
- reduce the amount we add to the atmosphere each year by only 10 percent.
 - do nothing; the level of greenhouse gases in the atmosphere is decreasing naturally.
 - sure the amount added to the atmosphere is less than the amount that is removed.
 - It is not possible to reduce the amount of greenhouse gases in the atmosphere.
 - I don't know.
11. Carrying capacity is the maximum average number of organisms that an environment can support indefinitely. When a population reaches the carrying capacity of its environment, we would not expect the population to ...
- collapse.
 - continue to increase over time.
 - decrease slowly.

- d. level off.
- e. I don't know.

12. The demographic transition graph below shows the relationship between birth rates, death rates and the overall size of the population at different stages of a society's economic development. Use the graph to answer the next three questions.



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12.1 In which of the following sections of the graph is the birth rate consistently below the death rate?

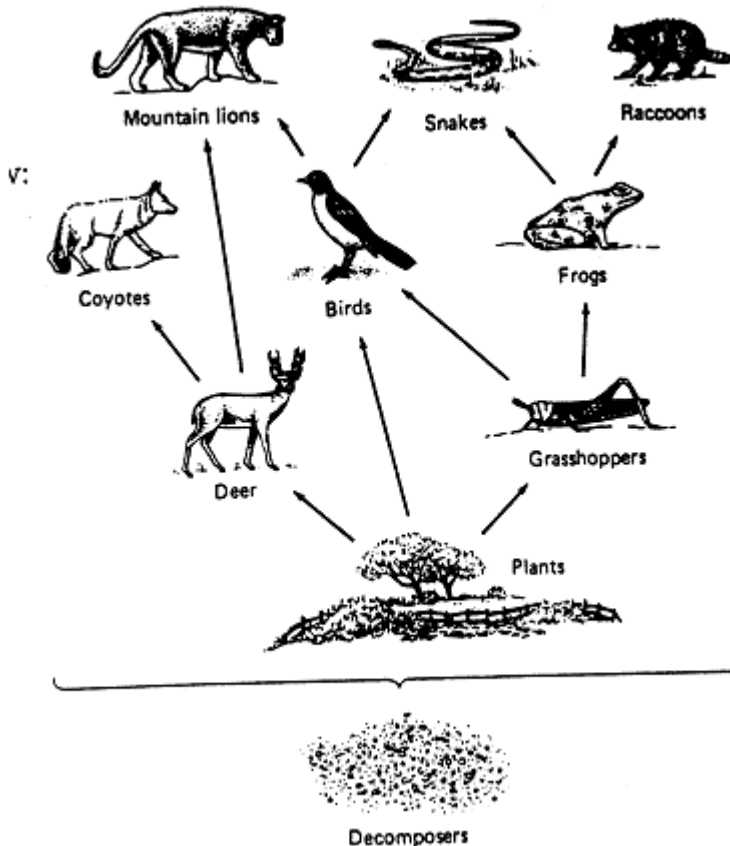
- a. STAGE 1
- b. STAGE 2
- c. STAGE 3
- d. 1st half of STAGE 4
- e. 2nd half of STAGE 4

12.2 In which part(s) of the graph is the population relatively stable (that is, not increasing or decreasing significantly)?

- a. STAGE 3
- b. 2nd half of STAGE 4
- c. 1st half of STAGE 4 and STAGE 1
- d. 1st half of STAGE 4 and STAGE 3
- e. STAGE 1 and STAGE 2

12.3 The birth rate is falling in STAGE 3. Why is the size of the population increasing in STAGE 3?

The diagram below is called a food web. It is used to describe how energy moves around in an ecosystem by showing what each organism eats and what it is eaten by. The organism at the head of the arrow eats the organism at the tail of the arrow. Use this food web to answer the next three questions.



13. Describe what would be likely to happen in this system if the number of deer increased significantly.

14. If all the grasshoppers were removed from this ecosystem, describe all the changes that would likely follow.

15. If humans were added to this food web, where would they be and how would they affect the rest of the food web?

Many environmental issues involve managing the accumulation of something in the environment. We generally want to increase the level of things we consider good, or valuable, and decrease the level of things we consider bad, or harmful.

Some of the things we consider good are the amount of nutrients in the soil or level of dissolved oxygen in water. Some of the things we consider harmful include pesticides in the environment, or carbon dioxide in the atmosphere. We manage the levels of things in the environment by controlling the rate at which we add to the level or the rate at which we remove things, or some combination of the two. Use the diagram below to answer the next three questions.

16. Under what conditions would the amount of the thing in the environment increase?

- a. rate of removal = rate of addition
- b. rate of removal < rate of addition
- c. rate of removal > rate of addition
- d. Cannot be determined with the information given.

17. Under what conditions would the amount of the thing in the environment decrease?

- a. rate of removal = rate of addition
- b. rate of removal < rate of addition
- c. rate of removal > rate of addition
- d. Cannot be determined with the information given.

18. Based on this framework, what would have to be done to decrease the amount of carbon dioxide in the atmosphere?

With questions 16-31, we would like to get a sense of your beliefs concerning the environment. PLEASE SELECT THE RESPONSE THAT BEST REPRESENTS YOUR BELIEF.

19. We have exceeded or are approaching the limit of the number of people the earth can support.

- a. Strongly Agree
- b. Agree
- c. Unsure
- d. Disagree
- e. Strongly Disagree

20. Humans have the right to modify the natural environment to suit their needs.

- a. Strongly Agree
- b. Agree
- c. Unsure
- d. Disagree
- e. Strongly Disagree

21. When humans interfere with nature it often produces disastrous consequences.
- a. Strongly Agree
 - b. Agree
 - c. Unsure
 - d. Disagree
 - e. Strongly Disagree
22. Human ingenuity will insure that we do NOT make the earth unlivable.
- a. Strongly Agree
 - b. Agree
 - c. Unsure
 - d. Disagree
 - e. Strongly Disagree
23. Humans are severely abusing the environment.
- a. Strongly Agree
 - b. Agree
 - c. Unsure
 - d. Disagree
 - e. Strongly Disagree
24. The earth has plenty of natural resources if we just learn how to develop them.
- a. Strongly Agree
 - b. Agree
 - c. Unsure
 - d. Disagree
 - e. Strongly Disagree
25. Plants and animals have as much right as humans to exist.
- a. Strongly Agree
 - b. Agree
 - c. Unsure
 - d. Disagree
 - e. Strongly Disagree
26. The balance of nature is strong enough to cope with the impacts of modern industrial nations.
- a. Strongly Agree
 - b. Agree
 - c. Unsure
 - d. Disagree
 - e. Strongly Disagree
27. Despite our special abilities humans are still subject to the laws of nature.

- a. Strongly Agree
- b. Agree
- c. Unsure
- d. Disagree
- e. Strongly Disagree

28. The so-called "ecological crisis" facing humankind has been greatly exaggerated.

- a. Strongly Agree
- b. Agree
- c. Unsure
- d. Disagree
- e. Strongly Disagree

29. The earth is like a spaceship with very limited room and resources.

- a. Strongly Agree
- b. Agree
- c. Unsure
- d. Disagree
- e. Strongly Disagree

30. Humans were meant to rule over the rest of nature.

- a. Strongly Agree
- b. Agree
- c. Unsure
- d. Disagree
- e. Strongly Disagree

31. The balance of nature is very delicate and easily upset.

- a. Strongly Agree
- b. Agree
- c. Unsure
- d. Disagree
- e. Strongly Disagree

32. Humans will eventually learn enough about how nature works to be able to control it.

- a. Strongly Agree
- b. Agree
- c. Unsure
- d. Disagree
- e. Strongly Disagree

33. Humans should seek to coexist with nature rather than to control it.

- a. Strongly Agree
- b. Agree

- c. Unsure
- d. Disagree
- e. Strongly Disagree

34. If things continue on their present course, we will soon experience a major ecological catastrophe.

- a. Strongly Agree
- b. Agree
- c. Unsure
- d. Disagree
- e. Strongly Disagree

With questions 33-40, we would like to get a feel for your environmental knowledge and behaviors. PLEASE SELECT THE RESPONSE THAT FITS YOU BEST.

35. How much do you know about the environment?

- a. A great deal
- b. A lot
- c. Some
- d. A little
- e. Not much

36. How confident are you in your ability to make responsible environmental decisions?

- a. Completely confident
- b. Very confident
- c. Somewhat confident
- d. A little confident
- e. Not confident at all

37. In the past month, I have biked, walked, car-pooled or used some form of public transportation instead of driving a car.

- a. True
- b. False

38. In the past month, I have made an effort to reduce my driving mileage (by combining trips or eliminating unnecessary trips, for example).

- a. True
- b. False

37. In the past month, I have made an effort to recycle.

- a. True
- b. False

38. In the past month, I have purchased a product because it is environmentally-friendly.

- a. True
- b. False

39. In the past month, I have chosen not to purchase an item because I felt that it was bad for the environment.

- a. True
- b. False

40. In the past month, I have made an effort to reduce the amount of water I use.

- a. True
- b. False

With questions 41-45, we would like to get an idea of who you are. PLEASE SELECT THE MOST RELEVANT RESPONSE.

41. What age range do you fall into?

- a. under 18
- b. 18 to 24 years
- c. 25 to 39 years
- d. 40 to 65 years
- e. over 65

42. How long have you lived in Las Vegas?

- a. less than 1 year
- b. 1-5 years
- c. 5-10 years
- d. more than 10 years
- e. I don't live in Las Vegas

43. Prior to this course, have you ever taken a college-level environmental science course for credit?

- a. Yes
- b. No

44. I am taking this class for the following reasons (PLEASE MARK ALL THAT APPLY):

- a. I have a personal interest in the subject.
- b. It fulfills the UNLV general education science requirement.
- c. It is required for my major/minor.
- d. Other (please explain): _____

45. If you are not a Las Vegas native, where do you say you are from?

APPENDIX C : ASSIGNMENTS

Assignment #2 Population Dynamics

PART 1

1. The population graph below is Figure 8-9 from your book. Describe the projected trend for population that is shown on the graph. (Consider how the graph is changing.)

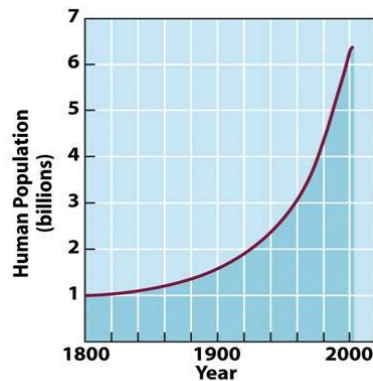
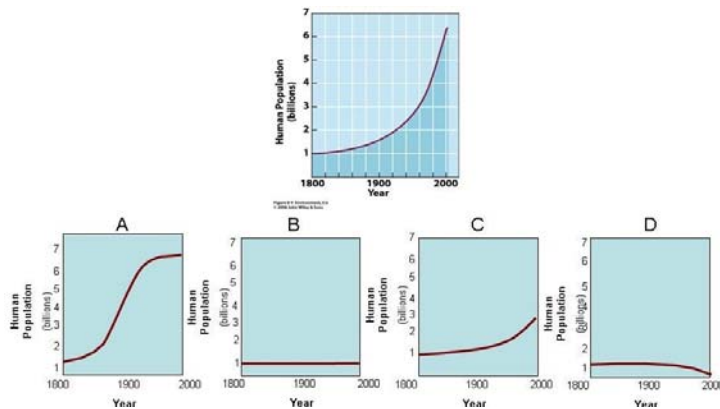


Figure 8-9 Environment, 5/e
© 2006 John Wiley & Sons

2. Why do you think that population is changing the way that it is?

3. How would our population graph from the book look different if the number of births had been a quarter lower starting in 1800? Choose one of the graphs below.

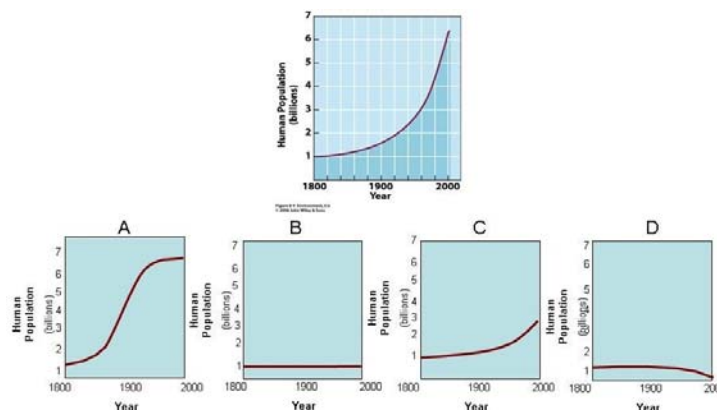


4. Explain why you think this will happen.

5. In the 1850s the death rate was much higher than it is now. What if death rate had stayed this high? How would our population graph from the book look different if the number of deaths were about a quarter higher than it is now?

6. Explain why you think this will happen.

7. **(1 point)** How would our population graph from the book look different if the number of births and the number of deaths were equal? Choose one of the graphs below.



8. Explain why you think this will happen.

9. How are the number of births and the number of deaths related to total population? Consider how the number of births and deaths change if the total population size changes.

10. Copy and paste the following link into your browser window and use Part 2's Word document to guide you through the activity (GIVEN TO EXPERIMENTAL SECTIONS ONLY).

http://forio.com/broadcast/netsim/netsims/UNLVEEnvSystemsLab/population_dynamics/index.html

Assignment #2 Population Dynamics

PART 2-SIMULATION INSTRUCTIONS FOR EXPERIMENTAL SECTIONS

The link provided to you in Part 1 will direct you to a computer simulation of total population. The model that you see can be used to test the effect of changing birth rate and death rate on total population.

First, **click on the 'Go' button** located on the left-hand side of the screen. The graph that you see shows the projected trend for world population. The graph starts in 1800 and is projected to 2100. This trend is the same as Figure 8-9 in your book.

The **levers** that you see below the graph can be used to change the births per 1000 people per year and the deaths per 1000 people per year. The number of births per year and deaths per year are what cause population to change. To change these levers, click on the triangular button near the center of the slider bar and drag it to change the value.

So, let's test this out. **Slide the 'number of births' lever** to increase it from 17 to 25. Now, click the 'Go' button. The graph that you see shows the original trend and a new line that represents how population will change with a higher birth rate.

To set the 'number of births' or the 'number of deaths' lever back to their original values, click the 'U' button in the lower, left-hand corner of the slider bar.

If you want to clear all lines from the graph, click the 'Clear' button.

Now let's explore some of the population changes we talked about in Part 1 using the computer model. You may want to note the changes as you complete each exercise, so that you can talk about them in Part 3 of this assignment.

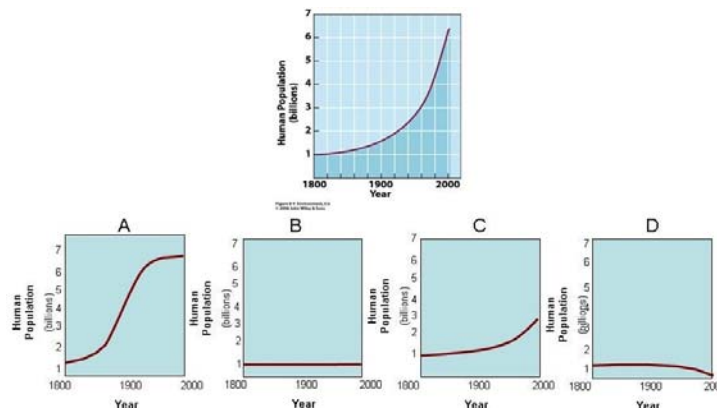
- 1) How would our population graph from the book look different if the number of births decreased by about a quarter?
Test it out using the model. Change the birth rate from 17 to about 13. What happened? How does this graph look different from the original? Why do you think population changed the way that it did?
- 2) In the 1850s, the death rate was much higher than it is now. What if the number of deaths increased by about a quarter?
Test it out using your model. Change the number of deaths from 8 to 10. What happened? Why do you think population changed the way that it did?
- 3) How would our population graph from the book look different if the number of births and the number of deaths were equal?

Test it out using your computer model. To do this, change the number of births to 7 and the number of deaths to 7 also. What happened? How does this graph look different than the original trend?

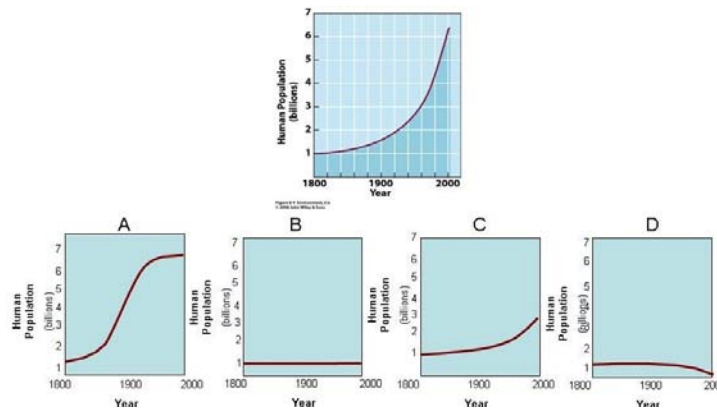
Assignment #2 Population Dynamics

PART 3

- How did the total population trend change when you decreased birth rate? Choose one of the graphs below.

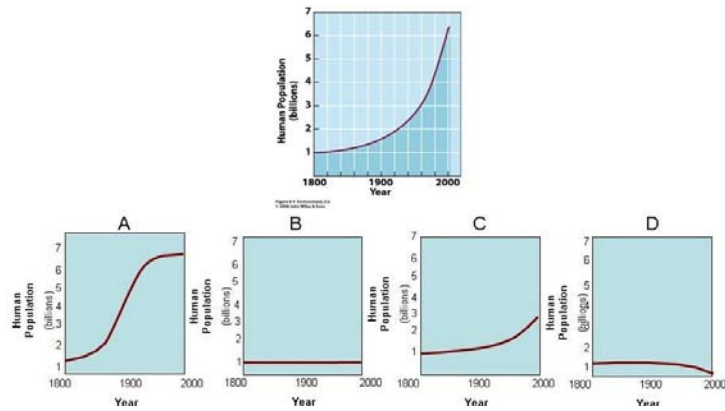


- Did this surprise you? Why or why not? Why do you think population changed the way that it did?
- What happened to the total population trend when you increased the number of deaths? Choose one of the graphs below.



- Did this surprise you? Why or why not? Why do you think population changed the way that it did?

5. What happens to the population trend when the number of births and the number of deaths are equal? Choose one of the graphs below.



6. Did this surprise you? Why or why not? Why do you think population changed the way that it did?

Assignment #4
Carbon in the Atmosphere

PART 3

1. How are carbon emissions related to the carbon that accumulates in the atmosphere?
2. How is carbon absorption related to the carbon that accumulates in the atmosphere?
3. What happens to carbon in the atmosphere when carbon emissions are equal to carbon absorption?
4. In order for carbon in the atmosphere to increase:
 - a) carbon emissions must be less than carbon absorption.
 - b) carbon emissions must be greater than carbon absorption.**
 - c) carbon emissions and carbon absorption must be equal.
 - d) carbon emissions must be adapted to
 - e) There is not enough information to answer the question.
- 5. What must be true about carbon emissions and carbon absorption for carbon in the atmosphere to decrease?**
6. What are some things that human beings can do to cause carbon in the atmosphere to decrease?

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