Using Simulations for Discovery Learning about Environmental Accumulations

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Abstract

This paper presents preliminary findings from the use of a simulation learning environment to teach college students about principles of accumulation. This research is part of an ongoing study testing the utility of systems simulations for teaching students about complex systems relationships in environmental studies and science. In Spring 2011, we conducted a paired experiment with 188 students in multiple sections. 101 students in the experimental group used simulations in two assignments about environmental accumulations; 87 students in the control group had similar assignments on the same topic, but that did not allow simulation. While most students are able to define and identify everyday examples of accumulations, they have difficulty understanding relationships between flows and accumulations in any but the simplest cases. The pattern-matching tendency is strong. Preliminary results of the effects of simulations developed specifically to address simple issues of accumulation suggest that the simulations can help students understand and explain the connections between flows and stocks better than students who did not use the simulations. Further analysis will examine the connections between the simulations and the observed results more closely.

Introduction

Accumulations are at the heart of environmental management. Whether the goal is to increase the level of something valuable or decrease the level of something harmful, an understanding of the principles of accumulation is key. As Sterman (2008) argues, however, public understanding of accumulations is poor. This is a problem when trying to motivate people to change individual behavior or support collective policies to mitigate problems such as climate change. When people do not understand the effect of delays and accumulations on how long it will take to reverse environmental changes, they are less likely to recognize the urgency to act. If they do not understand the role of individual actions in causing problems or the potential for individual actions for helping solve

[1] Heather Skaza, Ph.D. candidate, and Ben Jurand, M.S. candidate, were an integral part of developing the computer simulations and conducting this research. Jurand contributed significantly to the discovery learning literature review and Skaza participated in the design of research and assessment questions and supervised data entry. Further discussion of the simulation development can be found in this proceedings (Stave, Jurand, and Skaza, 2011). Skaza and Stave (2010) reports on analysis of the first stages of the overall project.

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problems they may not be motivated to make personal changes (e.g., Sterman and Booth Sweeney 2007, Meadows 2008). Improving public understanding of the systemic nature of such problems, and develop skills for on-going learning in a complex, uncertain world, is critical for achieving sustainability, particularly for helping the public and decision-makers develop skills to assess and respond to problems we have not yet encountered. As Cronin *et al*. (2009) note, however, finding effective ways to promote this understanding, particularly of stock and flow concepts, is a great challenge.

Over the past five semesters we have been experimenting with using systems simulations in a team-taught, college-level Introduction to Environmental Science course. We have conducted a paired experiment to test the utility of systems simulations for improving students understanding of complex systems relationships in environmental studies and science, particularly of feedback and accumulations. We have progressively refined the systems learning objectives, simulations, and assessments from systems thinking in general, to a focus specifically on building systems understanding about the dynamics of accumulations. We find that most students are able to define and identify everyday examples of accumulations, but they have difficulty understanding how to manage stocks. This paper presents some context for the use of discovery learning with simulations, then reviews some of the findings of our overall study. The main part of the paper describes preliminary findings from our most recent test of simulations on the dynamics of accumulations. The main simulation learning environment itself is described in detail in another paper in this conference proceedings (Stave, Jurand, and Skaza 2011).

This research is part of a long-term effort to improve public understanding of human-environment systems and engagement in sustainable environmental problem-solving. Our long-term goal is to make a set of simulation learning experiences accessible on the internet for a wide variety of users. The simulations will help users better understanding of basic systems principles including system feedback, accumulations, and delays. Booth Sweeney and Sterman (2007:286) describe this as systems intelligence – a combination of conceptual knowledge of system properties, reasoning skills, and the ability to recognize patterns that recur in many different systems. This kind of learning, or preparation for future learning, is critical for operating in an uncertain, dynamic, and complex world.

Discovery Learning

Discovery learning is a pedagogical approach based in constructivist learning theory. This theory, which originated in the 1960s, proposes that learners actively constructing their own knowledge bases through exploration, experimentation, and reflection (Wang, 2009). It is believed that the more active nature of constructivist learning helps learners gain knowledge that is more meaningful and make better sense of incoming information by attaching it to already established prior knowledge (Mayer, 2004). Reiser *et al*. (1998) found that discovery learning promoted greater "self-generated information processing" that resulted in better memory and performance within the domain. Because students "learn by doing" in discovery environments, their knowledge is both more elaborate and

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robust, and is therefore not only more useful but also more transferable to other domains. Reiser *et al.*, (1998) also proposed other cognitive benefits including better problem solving skills, more effective learning from errors, and improvement of general self-monitoring and discovery/inquiry skills.

Simulations for Discovery Learning

Discovery environments often use a computer-based simulation as a platform for learning. Simulations can distill situations and simplify complex systems, allowing learners to encounter and interact with parts of system structures that are not otherwise apparent. Simulations also speed up processing times, helping learners experience and observe faster than they would be able to in the real world. Simulations are able to more closely resemble real-world situations, can keep track of learner decisions, perform complex mathematical calculations, and reduce cognitive load to help the user focus on the underlying concepts (Schmidt, 2003). In addition, simulations also provide an interactive platform that can be both perceptually and spatially rich, further facilitating the learner's understanding of domain concepts (Lindgren and Schwartz, 2009).

By emphasizing experience over explanation, simulation-based discovery learning environments allow learners to accept a greater responsibility for their learning as they actively construct their own knowledge bases (Rieber *et al.,* 2004, Swaak *et al.*, 2004). Learners experiment with independent variables and observe how dependent variables change as a result. This facilitates a more active understanding about the relationships between the variables (de Jong and van Joolingen, 1998, de Jong *et al.*, 2005).

In the literature, a good deal of attention has been given to gains in intuitive knowledge when using discovery-learning simulations (Veermans and de Jong, 2000, Swaak *et al.*, 2004, de Jong *et al.*, 2005). Intuitive knowledge is considered implicit and is therefore difficult to verbalize. It has been measured as knowledge that promotes the "quick perception of anticipated situations" (Swaak and de Jong, 2001). Therefore, gains in a learner's intuitive knowledge concerning the relationships between variables in a simulation are reflected by how quickly a learner is able to anticipate the outcomes of manipulating those variables. It is thought that by increasing intuitive understanding, this new information connects to more deeply rooted knowledge (de Jong and van Joolingen, 1998), making the learned information more meaningful and more likely to be encoded in the learner's memory (Lindgren and Schwartz, 2009). In addition to intuitive knowledge gain, researchers have found that by virtue of the scientific inquiry process, learners gain useful discovery skills that further aid them in discovery learning (Veermans and de Jong, 2000).

Challenges

There are still considerable challenges to realizing the potential cognitive benefits of discovery learning simulations. This has been attributed in part to problems learners have with the scientific inquiry process. De Jong and van Joolingen (1998) found that problems associated with discovery learning in simulations occur at all levels of the inquiry process. This includes hypothesis generation, experimental design, data interpretation, and regulation of learning (de Jong *et al*., 2005).

Additionally, there has been debate in the literature over how much freedom learners should be given to explore a domain in discovery learning environments. For example, Mayer (2004) found that pure discovery learning—where learners are given free reign to explore a domain with little or no guidance, or structure to follow—was much less effective than guided discovery learning. Mayer identified guided discovery as the best method for constructivist learning. He found that in order for effective discovery learning to be achieved, a balance needs to be reached between allowing learners the freedom to be "cognitively active in the process of sense making" and providing appropriate guidance to ensure that the knowledge is usefully constructed (Mayer, 2004). That balance can be delicate, as many research studies testing the effectiveness of guidance and support structures have found that too much support can negate the beneficial characteristics of discovery learning (Swaak *et al*., 2004).

Approach and Hypotheses

The research question guiding this project is: *Can systems simulations designed to illustrate systems principles improve the user's operational understanding of how systems work?* We use Richmond's (1994) definition of systems thinking to define operational understanding: "the art and science of making reliable inferences about behavior by developing an increasingly deep understanding of underlying structure."

We believe simulations can be particularly helpful for building a working understanding of the principles of accumulation. Simulation reduces the cognitive load of calculating changes in accumulations based on inflows and outflows, and can help users visualize accumulations. Simulations can provide a neutral platform for discovery, removing any perceived judgment about or by the messenger (instructor) from the message. In addition, because accumulations are ubiquitous in everyday life, people often think they understand the dynamics. Their mental models are difficult to change. Changing resistant mental models, as Kuhn (1970) explained in his theory of paradigm change, requires those operating under a given model or paradigm to be confronted with anomalies that can't be explained with the current model. Changing a mental model requires the person to be surprised, recognize the surprise, challenge the surprise, and develop an alternative model to explain what they see. However, we have found that presentation of the simulation – the design of the simulation learning environment – is critical. The simulation interface has to be clearly tied to the learning objectives, and the domain and discovery content and skills have to be carefully scaffolded, that is, presented with progressively less guidance, to enable user discovery (e.g. Zydney 2010). The interface has to be interesting enough to engage the user, but avoid design elements that increase cognitive load without a learning benefit.

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Results of early research

We have been conducting pilot research for this project since Fall 2009. The research began with a simple question about the value of system dynamics simulations for helping students understand environmental concepts in an introductory, college-level environmental science course. Two of the authors conducted a controlled experiment in four sections (304 students total) of a team-taught ENV 101 Introduction to Environmental Science at UNLV (Skaza and Stave 2010). 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 team structure of the course meant that all students had the same instructor for the same topics. 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, with a text description of the environmental issue and system instead of the simulation. The three assignments with simulations covered simple human population dynamics (using a simple one-stock, two-flow model we developed), reindeer-lichen dynamics (Tabacaru et al. 2009), and a bathtub representation of carbon in the atmosphere (MIT SD Group 2008).

We assessed student understanding of general environmental knowledge and environmental systems concepts as part of the assignments, on exams at the beginning of the course (baseline), throughout the term, and on the final exam. Student understanding was measured in a variety of ways, including multiple choice and short answer questions. Short answer responses were coded based on a systems thinking taxonomy proposed by Stave and Hopper (2007), based on Bloom's revised taxonomy of educational objectives (Anderson and Krathwohl 2001) and on Booth Sweeney and Sterman's (2007) Systems-Based Inquiry method.

The results showed that there was no significant difference in either general or systems knowledge between the two groups, except immediately following the population assignment. On the surface, this finding was disappointing, but closer examination of the course and experiment results led to key revisions of hypotheses, assessments, research design, and simulations. Figure 2 shows results of questions measuring systemic understanding of population dynamics ($n_{experimental} = 92$, $n_{control} = 97$, subjects completing all assignments and assessments). Comparison of the two

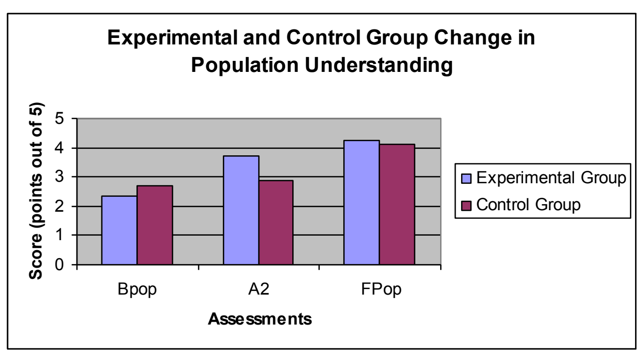


Figure 1 Change in Systemic Understanding of Population Dynamics

groups shows no significant difference on the baseline (Bpop) or final (FPop), but the difference following the assignment (A2) is significant. Although both groups ended up with a similar systems understanding of this topic, both groups significantly increased their systems knowledge, but took different paths. The experimental group had a steady increase in systems understanding while the control group's change came primarily after the population assignment. This suggests both that the simulation did promote systems learning, and that something else toward the end of the course also had a similar effect.

In the second and third semesters, we revised assessments, changed simulation content, and examined potential confounding effects. For Spring 2010, we simplified the predator-prey model, modifying a foxes and rabbits simulation available on Forio Simulation's open access website (http://forio.com/simulate/hjskaza/rabbits-and-foxes-1), and changed the types of questions we used for assessment to better reflect Swaak et al.'s (2004) WHAT-IF-WHY format. This assessment structure measures both the ability to predict an outcome (what Swaak and others call intuitive knowledge), and the reasoning behind the prediction. For Fall 2010, we revised the population exercise, replaced the predator-prey simulation with a model Stave has used in many settings for communicating water management issues in Las Vegas (Stave 2003, Stave 2010), and used a simpler climate change model available in Forio's open access format (C-LEARN).

Preliminary analysis of data from Fall 2010 shows some interesting results. We had revised assessments to better measure student understanding of accumulations, a key issue in environmental problem-solving. All students seem to understand the relationship between stocks and flows when flows are the same, but when flows are different, we found that students in the control group used the same erroneous pattern matching explanations that Sterman and Booth Sweeney (2007) describe in their work. However, students who had used the population simulation were better able to describe the behavior of the stock correctly, even when it did not match the pattern of flows.

The research to date has focused on revising the content of the simulations and the assessments of systems learning and aligning both to the learning objective – increasing systemic understanding of human-environment systems – and to each other. Although we have used a web format for the pilot simulations, we have provided user support in person at the front end, during the simulation use, and in debriefing the exercises. The pilot research has highlighted issues of support – what kind of guidance to provide, when, and in what format, how to design the simulations to minimize cognitive load, and how we might incorporate collaboration and live facilitation.

Current work on Accumulations: Spring 2011 semester

For the Spring 2011 semester, we completely redesigned the set of simulations in response to some of the discovery learning literature on design as well as feedback from students in previous semesters and responses to our assessment questions. The focal point this semester was a new simulation on the basic principles of accumulations. We also created another simulation applying these principles to understanding the dynamics of carbon in the atmosphere. We designed the new simulations early in the semester, conducted focus groups with the simulations and used the feedback to revise the simulation. We then used the simulations and non-simulation versions of the assignments as part of the course. 188 students were in the class, divided in three sections. Two sections (a total of 101 students) used the simulation; 87 students used the parallel non-simulation version of the assignment.) All sections met at the same time of day, in similar rooms and used the same team approach described above to minimize differences in delivery of the course material. Student demographics show the classes are similar across gender, age, disciplinary background and other characteristics.

Assignments

There were four assignments in the course. For the first, students used an on-line ecological footprint calculator to determine their own footprint based on their lifestyles. Both the control and experimental groups did the same assignment. For the second, third, and fourth assignments, all students accessed the assignment on-line, with a similar interface. The assignments focused on the dynamics of population (Assignment #2), the build up of drift seeds on an island (Assignment #3) and carbon in the atmosphere (Assignment #4). Both groups received similar background information. The experimental group was able to run a simple simulation to test the effect of changing flows on the particular accumulation; the control group was given static information about a couple of representative scenarios. Figure 2 shows a timeline of assignments and assessments over the course of the semester. The assignments were all done individually by students, accessed and turned in through the course website. The content of the assignments was not discussed explicitly in class, before or after the assignment. The Baseline Assessment was completed on the course website but all other quizzes and exams were completed in class.

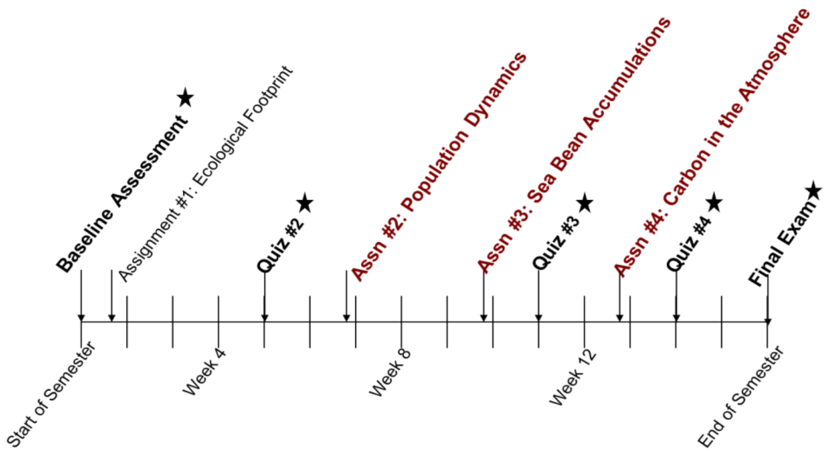


Figure 2 Timeline of assignments and assessments during the semester. Assignments in red contained simulations.

Overview of Assignments 2, 3, and 4

Each assignment included the following parts :

Part 1: introduction and pre-test on the course website

Part 2: on-line simulation learning environment, including

- explanation of relationships between the relevant flows and accumulations using static tables and graphs
- guided simulation exploration for the experimental group; static presentation of representative scenarios for the control group
- challenges or thought experiments and reflection questions

Part 3: reflection and post test on the course website

Students assigned to the simulation and non-simulation treatments accessed the assignments in the same way. They used the course website (accessible only to students in a particular section) to enter the assignment. They completed the pre-test through the course website, then followed a link to the Forio simulation website, which directed them to computer screens specific to their task – the screens looked the same, and presented the same scenario information, but the non-simulation students were only provided static graphs. The simulation students were able to run the simulation on their own. Finally, they completed the post-test through the campus website.

Simulation Learning Environments

Appendix I includes an overview of simulation learning environment developed for Assignment #3. Details of the development and lessons learned are available in another paper in this proceedings (Stave, Jurand, and Skaza 2011). The module designed for Assignment #4 follows the same design principles. These modules are the first of a series of simulation-based learning modules for teaching systems concepts underlying environmental science and management called *Island Dynamics*. . They are all based on discovery learning principles and include questions that facilitate discovery for the user and also provide assessment mechanisms for the instructor. All the modules are set in the context of a generic small island. We are deliberately vague about the location of the island to leave open all possibilities for climate and other variations as needed for specific modules. While we incorporate as many real elements as possible, we also use creative license as necessary. The current modules were developed using the Forio Systems Simulate platform and hosted under their Basic subscription.

Summary of Research Design
This experiment compares the performance of two groups of students who took a college-level introduction to environmental science course on tests of understanding about the dynamics of simple accumulations. Different sections of the course were randomly assigned to either the treatment (simulation) group or the control group, although students had previously self-selected their sections when they signed up for the course. All students received the same course material. The only difference between the groups was that the treatment group was able to simulate accumulation scenarios in Assignments 2, 3, and 4, while the control group received only static information about the same scenarios. Assignment 3 was the only assignment that explicitly presented principles of accumulation. This was presented in static form to all students, as shown in Appendix I.

Data Collected

We used a variety of types of questions to evaluate the question: Do students who use simulations in their assignments demonstrate a better understanding of basic principles of accumulation? We tested understanding at a number of levels and in a number of formats to examine student ability to make inferences about the behavior of a stock based on the flows, trying to get at the depth of the student's understanding. We were also interested in measuring retention of information over time (an indication of depth of knowledge), and transferrability. To this end, we measured student understanding of accumulations at a number of points in the semester, and in a number of ways:

-- baseline data at the beginning of the term (graded for completion only)
-- pre-test and post-test data bracketing the assignment
-- responses to prediction (simulation only) and reflection questions during the assignment
-- assessment questions on in-class exam the week following the assignment
-- assessment questions on final exam 6 weeks after the assignment

Question formats included multiple choice, short answer and drawing.

Question types fell into three main categories:

- Forecasting
  Testing the ability to predict stock behavior from flows.
  Given flow rates, ask respondent to choose and/or draw the stock's behavior.
- "Backcasting"
  Explain what the relationship must be between flows to generate the observed Behavior of the stock.
  Given a drawing or description of the stock behavior, as respondent to choose or describe relationship between flows.
- Application to real world problems

I describe three pairs of questions and results here. The first set, shown in Figure 3, is a question giving a graph of population over time and asking respondents to choose or describe what the relationship between the rates must be to produce the trend shown on part of the graph. In the baseline quiz, given the first week of class, the responses were multiple choice. On the final exam, 15 weeks later, we asked students to respond to the same question in short answer format. The short answer responses were coded based on the degree to which they demonstrated understanding of the principles.

Figure 4 shows the responses by control (non-sim) and experimental (sim) group for this question on the baseline and the final exam. The results are shown for Question 33 on the baseline quiz and Question 24b on the final exam. Both groups improved, but the experimental group improved more than the control group (in this case, we used the strictest coding condition, that is, to be considered "correct" on the final exam, the response had to be fully correct. Partially correct answers were marked incorrect for this analysis. Figure 5 shows the changes for individual students in each group. The highlighted boxes show those whose responses improved between the baseline and final exam.

The second example of comparison questions, shown in Figure 6, are two questions asking students to identify the trend in a stock they would expect to see given certain trends in flow rates. The first question, asked on Quiz 3, after the groups had completed Assignments 2 and 3 which included simulations for the experimental group, used a population stock. The second question, asked on Quiz 4 after they had completed an assignment about carbon in the atmosphere, referred to carbon accumulation. In both cases, students were asked to match a graph of the most likely pattern of accumulation to each set of flow trends, then explain their choice. The short answer responses were coded based on the degree to which they demonstrated understanding of the principles.

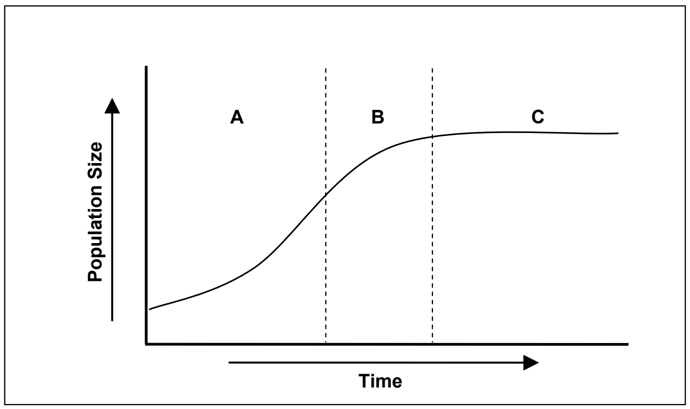
Figure 7 shows the distribution of responses to the graphs of declining rates. This graph was the most challenging for respondents, and clearly shows the pattern-matching behavior described

Figure 3: Pre-test – Post-test question assessing change in understanding.

Baseline Assessment

33. (Points: 1.0)

How is the relationship between birth rate and death rate changing in Part B of the graph?



a. Birth rate is increasing and/or death rate is decreasing; they are getting further apart from each other.

b. Birth rate and death rate are the same as in part A; the relationship is not changing.

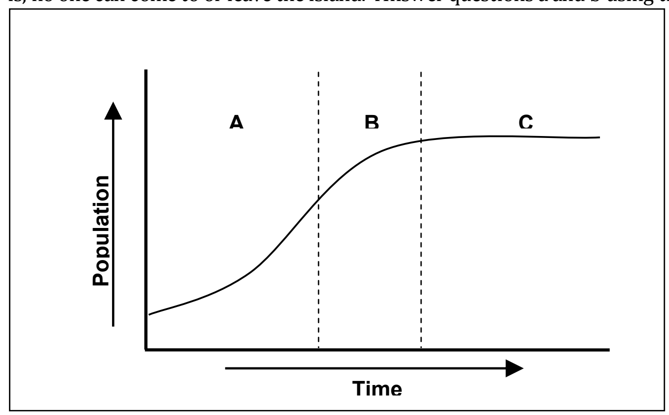
c. Birth rate and death rate are equal.

d. Birth rate is decreasing and/or death rate is increasing; birth rate and death rate are getting closer together.

e. I don't know.

Final Exam

24. 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. Answer questions a and b using the graph below.



a. What must be true about birth rate and death rate to yield the total population trend shown in Part A of the graph?	
b. How are birth rate and/or death rate changing in Part B of the graph?	

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Figure 4 Comparison of responses on pre- and post-test

Baseline vs. Final Exam
Explain flow relationship from behavior

Group	BASELINE CORRECT	BASELINE INCORRECT
NON-SIM (n=76)	47% (36)	53% (40)
SIM (n=96)	34% (33)	66% (63)
(172)	40% (69)	60% (103)

Group	FINAL EXAM CORRECT	FINAL EXAM INCORRECT
NON-SIM (n=77)	69% (53)	31% (24)
SIM (n=90)	77% (69)	23% (21)
(167)	73% (122)	27% (45)

Figure 5 Crosstabulation of results of the 167 students who took both pre- ai post-test

Baseline vs. Final Exam
Explain flow relationship from behavior, Change from INCORRECT to CORRECT

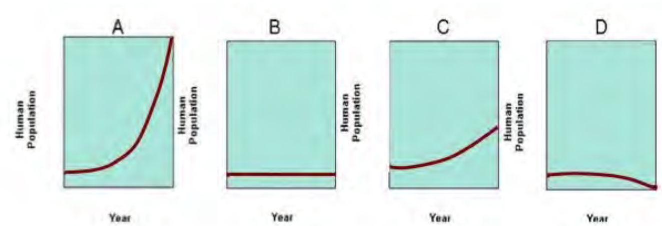
Group	FINAL EXAM CORRECT	FINAL EXAM INCORRECT
BASELINE CORRECT (n=77)	69% (53)	31% (24)
BASELINE INCORRECT (n=90)	77% (69)	23% (21)
(167)	73% (122)	49% (45)

Group	BASELINE INCORRECT FINAL CORRECT	BASELINE INCORRECT, FINAL INCORRECT
NON-SIM (n=32	63% (20)	38% (12)
SIM (n=58)	71% (41)	29% (17)
(90)	68% (61)	32% (29)

Figure 6 Questions assessing ability to predict stock behavior given trends in flow rates

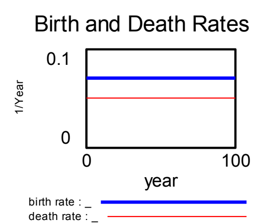
Quiz 3 (after Assignments 2 and 3)

11. (6 pts total) Use the following graphs to indicate the change you would expect to see in the total population for each of the conditions of birth and death rate shown below:



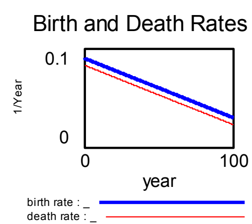
11a. (1pt) Which of the graphs above best approximates the way the population would change, given the rates shown on the right?
a. graph A
b. graph B
c. graph C
d. graph D
e. none of the above

(2 pts) Explain your answer:



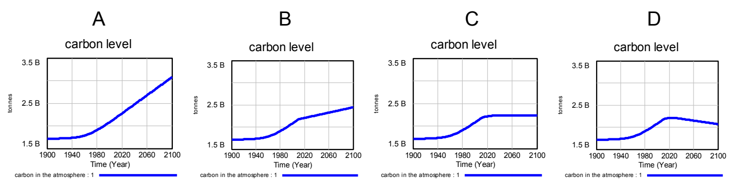
11b. (1pt) Which of the graphs above best approximates the way the population would change, given the rates shown on the right?
a. graph A
b. graph B
c. graph C
d. graph D
e. none of the above

(2 pts) Explain your answer:



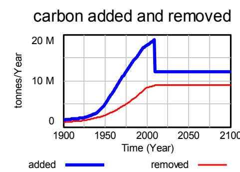
Quiz 4 (after Assignments 2, 3 and 4)

24. (6 pts total) Use the following graphs to indicate how you would expect the level of carbon in the atmosphere to change for each of the conditions of carbon added (emissions) and carbon removed shown below:



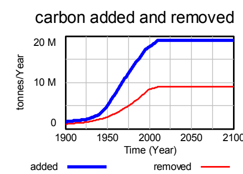
a. (1 pt) Which of the graphs above best approximates the way carbon would change, given the flows shown on the right?
a. graph A
b. graph B
c. graph C
d. graph D
e. none of the above

(1 pt) Explain your answer:



b. (1 pt) Which of the graphs above best approximates the way carbon would change, given the flows shown on the right?
a. graph A
b. graph B
c. graph C
d. graph D
e. none of the above

(1 pt) Explain your answer:



c. (1 pt) Which of the graphs above best approximates the way carbon would change, given the flows shown on the right?
a. graph A
b. graph B
c. graph C
d. graph D
e. none of the above

(1 pt) Explain your answer:

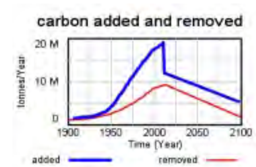
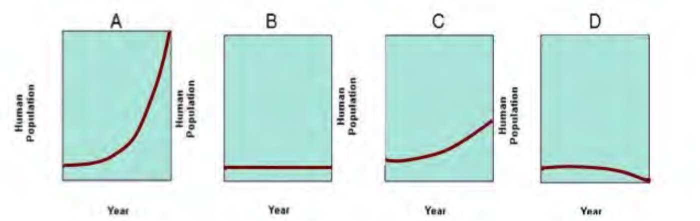


Figure 7 Responses to graphs of declining flow rates, (correct response highlighted)

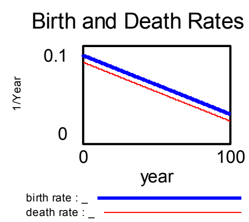
Quiz 3 (after Assignments 2 and 3)

11. (6 pts total) Use the following graphs to indicate the change you would expect to see in the total population for each of the conditions of birth and death rate shown below:



11b. (1pt) Which of the graphs above best approximates the way the population would change, given the rates shown on the right?

a. graph A
b. graph B
c. graph C
d. graph D
e. none of the above



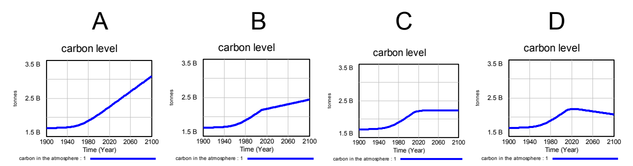
(2 pts) Explain your answer:

A	B	C	D	E
3%	20%	26%	41%	9%

No difference between groups

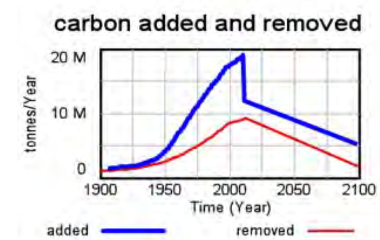
Quiz 4 (after Assignments 2, 3 and 4)

24. (6 pts total) Use the following graphs to indicate how you would expect the level of carbon in the atmosphere to change for each of the conditions of carbon added (emissions) and carbon removed shown below:



c. (1 pt) Which of the graphs above best approximates the way carbon would change, given the flows shown on the right?

a. graph A
b. graph B
c. graph C
d. graph D
e. none of the above



(1 pt) Explain your answer:

A	B	C	D	E
0%	14%	27%	54%	4%

No difference between groups

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by a number of researchers (e.g. Cronin et al. 2009). In these results, there was no difference between the control and experimental groups.

The third pair of questions asked students to draw a graph of the pattern of accumulation they would expect in a stock given a particular pattern in its flows. The questions are shown in Figure 8. The first was asked in a quiz after Assignment 3, and the second was asked approximately 5 weeks later, after another simulation assignment. Figure 9 shows response patterns that were coded as correct, as well as response patterns coded as incorrect, and labeled as expressions of correlational reasoning. There were other incorrect responses given that did were neither roughly correct in shape nor corresponded in shape to either of the flow patterns.

Figure 10 shows the distribution of responses by treatment group. There is essentially no difference in the distribution of correct responses between groups on the first question, but there appears to be a difference in the second instance of this type of question, with more of the students in the treatment group (SIM) giving a correct response (note, tests of statistical significance have not yet been run on the data). The second table in Figure 10 shows the distribution of incorrect responses that seemed to follow the pattern matching heuristic. On the earlier question, more students in the SIM group who gave an incorrect response drew a graph that matched the pattern of the flows. However, when the question was asked on the final exam at the end of the course, a higher proportion of the students in the control group (NON-SIM) who gave incorrect responses used the correlation heuristic than the treatment group (SIM).

Discussion

These initial results, while very limited, suggest that there is a difference in some level of systems thinking between students who used simulations in their assignments and those who did not. We are continuing to analyse the data as well as reflect on the lessons learned in this process about setting appropriate learning objectives for systems assignments in this type of class, effective simulation design, and best measures of assessment.

This overall research project began when an opportunity arose to teach the introductory environmental science class as a team with other instructors also well versed in systems thinking. With the ability to minimize instructor differences across sections, we started thinking of ways to incorporate systems teaching more directly into the class, and to set up a way to measure the effect. This organic experiment has continued and evolved for the last 5 semesters to the form described in this paper. Although we did our best to control for influences on students other than the simulation treatments, it is not possible in a live class setting to conduct a truly "clean" experiment. Sorting through all the possible factors influencing the outcome of the research is complex. However, working in a real-life setting also provides opportunities for learning that might not be possible in a laboratory setting.

In some ways, this overall research project has been as much a discovery learning process for the researchers as for the students.

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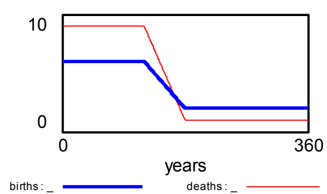
Figure 8 Questions asking students to predict and draw the pattern of a stock given a set of flows

Multiple Interventions

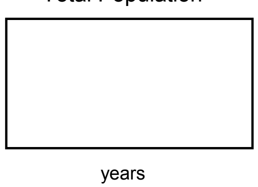
Quiz 3 (after Assn 3)

12. (3 pts) On the axes below labeled "Total Population", draw the line that would best represent the shape of the graph of total population over the same time period shown for this set of births (inflow) and deaths (outflow). The actual numbers are not important, but the shape of the line should accurately reflect the relative changes in the flows over the time period.

Births and Deaths



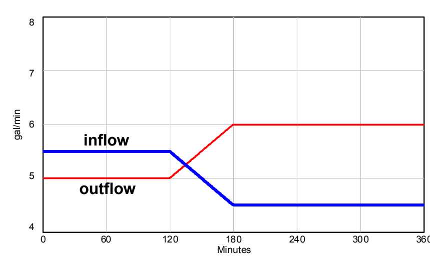
Total Population



Final Exam (after Assn 3 and 4)

25. In the box below, draw the line representing what happens to the amount of water in the pool given the flows shown below. The initial amount of water is indicated by the **X**.

water in the pool -- flows



amount of water in the pool

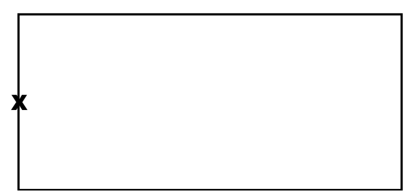


Figure 9 Typical responses to the questions in Figure 8, showing patterns coded correct and incorrect

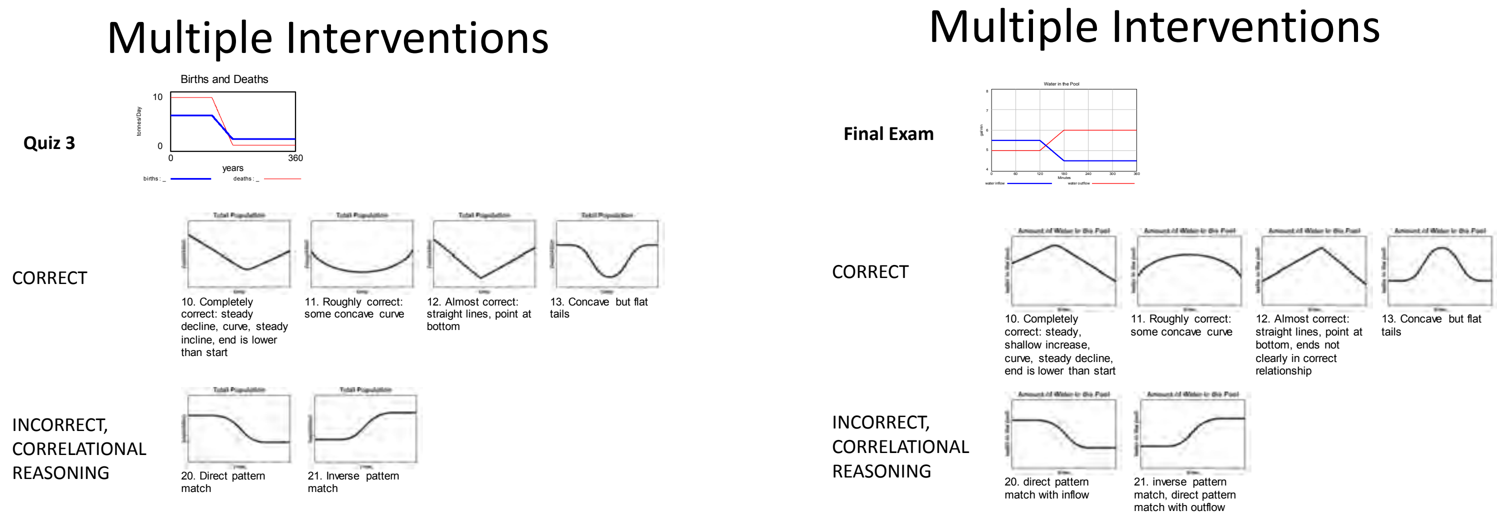


Figure 10 Initial anlaysis of responses to the questions in Figure 8, by group

Quiz 3 vs. Final Exam
Draw Behavior, Given Flows

Group	Q3 GRAPH CORRECT	Q3 GRAPH INCORRECT
NON-SIM (n=77)	34% (26)	66% (51)
SIM (n=96)	38% (37)	62% (59)
(173)	36% (63)	64% (110)

Group	FINAL EXAM GRAPH CORRECT	FINAL EXAM GRAPH INCORRECT
NON-SIM (n=79)	46% (36)	54% (43)
SIM (n=93)	56% (52)	44% (41)
(172)	51% (88)	49% (84)

Quiz 3 vs. Final Exam
Draw Behavior, Given Flows
Of those INCORRECT, % CORRELATIONAL

Group	Q3 GRAPH INCORRECT, Pattern Matching	Q3 GRAPH INCORRECT, Other
NON-SIM (n=51)	39% (20)	61% (31)
SIM (n=59)	51% (30)	49% (29)
(110)	46% (50)	55% (60)

Group	FINAL EXAM GRAPH INCORRECT, Pattern Matching	FINAL EXAM GRAPH INCORRECT, Other
NON-SIM (n=43)	47% (20)	54% (23)
SIM (n=41)	22% (9)	78% (32)
(84)	35% (29)	66% (55)

References

Anderson, L.W. and D.R. Krathwohl. (2001). *A taxonomy for learning, teaching, and assessing*. Longman: New York.

Booth Sweeney, L. and J.D. Sterman. (2007). Thinking about systems: student and teacher conceptions of natural and social systems. *System Dynamics Review* 23(2/3): 285-312.

Cronin, M.A., C. Gonzalez, and J.D. Sterman. (2009). Why don't well-educated adults understand accumulation? A challenge to researchers, educators, and citizens. *Organizational Behavior and Human Decision Processes* 108: 116-130.

De Jong, T. (2006). Technological Advances in Inquiry Learning. *Science*, *312*(5773), 532-533.

De Jong, T., Beishuizen, J., Hulshof, C. D., Prins, F., Van Rijn, H., Van Someren, M., Veenman, M., Wilhem, P. (2005). Determinants of Discovery Learning in a Complex Simulation Environment. In *Cognition, Education, and Communication*. Mahwah, N.J.: Lawrence Erlbaum Associates.

De Jong, T., & Van Joolingen, W. R. (1998). Scientific discovery learning with computer simulations of conceptual domains. *Review of Educational Research*, *68*(2), 179.

De Jong, T., Joolingen, W. R. V., Swaak, J., Veermans, K., Limbach, R., King, S., & Gureghian, D. (1998). Self-directed learning in simulation-based discovery environments. *Journal of Computer Assisted Learning*, *14*(3), 235-246.

Forio Simulate [Computer Software package] Available from: http://forio.com/

Hulshof, C. D., & Jong, T. D. (2006). Using just-in-time information to support scientific discovery learning in a computer-based simulation. *Interactive Learning Environments*, *14*(1), 79-94.

Jonassen, D. H., & Rohrer-Murphy, L. (1999). Activity theory as a framework for designing constructivist learning environments. *Educational Technology Research and Development*, *47*(1), 61–79.

Kirschner, P. A. (2002). Cognitive load theory: implications of cognitive load theory on the design of learning. *Learning and Instruction*, *12*(1), 1-10.

Korfiatis, K., E. Papatheodorou, E., Stamou, G. P. (1999). An investigation of the effectiveness of computer simulation programs as tutorial tools for teaching population ecology at university. *International Journal of Science Education*, 21(12), 1269-1280.

Proceedings of the 29th International Conference of the System Dynamics Society. Washington, DC, July 24-28, 2011.
Available at: http://www.systemdynamics.org/conferences/2011/proceed/index.htm

Kuhn, T. (1970) *The Structure of Scientific Revolutions*. Chicago: The University of Chicago Press.

Lazakidou, G., & Retalis, S. (2010). Using computer supported collaborative learning strategies for helping students acquire self-regulated problem-solving skills in mathematics. *Computers & Education*, *54*(1), 3-13.

Lindgren, R., & Schwartz, D. L. (2009). Spatial Learning and Computer Simulations in Science. *International Journal of Science Education*, *31*(3), 419-438.

Massachusetts Institute of Technology System Dynamics Group (MIT SD Group). (2008). Bathtub Dynamics and Climate Change. Retrieved February 10, 2010, from http://scripts.mit.edu/~jfmartin/sip/master/

Mayer, R. E. (2004). Should there be a three-strikes rule against pure discovery learning. *American Psychologist*, *59*(1), 14–19.

Meadows, D.H. (2008). *Thinking in Systems: A Primer.* Chelsea Green Publishing: White River Jct, VT.

Reiser, B. J., Copen, W. A., Ranney, M., Hamid, A., & Kimberg, D. Y. (1998). Cognitive and Motivational Consequences of Tutoring and Discovery Learning.

Rieber, L. P., Tzeng, S., & Tribble, K. (2004). Discovery learning, representation, and explanation within a computer-based simulation: finding the right mix. *Learning & Instruction*, *14*(3), 307-323.

Schmidt, S. J. (2003). Active and cooperative learning using web-based simulations. *The Journal of Economic Education*, *34*(2), 151–167.

Schwartz, D., Lindgren, R., & Lewis, S. (2009). Constructivism in an age of non-constructivist assessments. *Constructivist Instruction: Success or Failure*. New York: Rutledge.

Skaza, H.J. and K.A. Stave. (2010). Assessing the effect of systems simulations on systems understanding in undergraduate environmental science courses. *Proceedings of the 28th International Conference of the System Dynamics Society.* Seoul, Korea, July 25-29, 2010.

Stave, K.A. (2003). A System Dynamics Model to Facilitate Public Understanding of Water Management Options in Las Vegas, Nevada. *Journal of Environmental Management* 67:303-313.
Available at: http://www.systemdynamics.org/conferences/2010/proceed/index.html

Stave, K.A. (2010). Participatory System Dynamics Modeling for Sustainable Environmental Management: Observations from Four Cases. *Sustainability* 2:2762-2784 doi:10.3390/su2092762.

Stave, K.A. and M. Hopper. (2007). What Constitutes Systems Thinking? A Proposed Taxonomy. *Proceedings of the 25th International Conference of the System Dynamics Society.* Boston, MA, July 29-August 3, 2007. Available at: http://www.systemdynamics.org/conferences/2007/proceed/index.htm.

Stave, K., B. Jurand, and H. Skaza. (2011). Description and demonstration of a simulation learning environment for discovery learning about accumulations. *Proceedings of the 29th International Conference of the System Dynamics Society.* Washington, D.C., July 24-28, 2011. Available at: http://www.systemdynamics.org/conferences/2011/proceed/index.htm.

Sterman, J.D. (2008). Risk Communication on Climate: Mental Models and Mass Balance. *Science* 322: 532-533.

Sterman, J.D. and L. Booth Sweeney. (2007). Understanding public complacency about climate change: adults' mental models of climate change violate conservation of matter. *Climatic Change* 80:213-238

Swaak, J., & De Jong, T. (2001). Discovery simulations and the assessment of intuitive knowledge. *Journal of Computer Assisted Learning*, *17*(3), 284-294.

Swaak, J., Jong, T. D., & Joolingen, W. R. V. (2004). The effects of discovery learning and expository instruction on the acquisition of definitional and intuitive knowledge. *Journal of Computer Assisted Learning*, *20*(4), 225-234.

Tabacaru, M., B. Kopainsky, A. Sawicka, K.A. Stave, and H. Skaza. (2009). How can we assess whether our simulation models improve the system understanding for the ones interacting with them? *Proceedings of the 27th International Conference of the System Dynamics Society.* Albuquerque, New Mexico, July 26-30, 2009. Available at: http://www.systemdynamics.org/conferences/2009/proceed/index.html

Veermans, K., De Jong, T., & Van Joolingen, W. R. (2000). Promoting Self-Directed Learning in Simulation-Based Discovery LearningEnvironments Through Intelligent Support. *Interactive Learning Environments*, *8*(3), 229.

Veermans, K., Joolingen, W. V., & De Jong, T. (2006). Use of Heuristics to Facilitate Scientific Discovery Learning in a Simulation Learning Environment in a Physics Domain. *International Journal of Science Education*, *28*(4), 341-361.

Wang, Q. (2009). Designing a web-based constructivist learning environment. *Interactive Learning Environments*, *17*(1), 1 - 13.

Yasarcan, H. (2009). Improving Understanding, Learning, and Performances of Novices in Dynamics Managerial Simulation Games: A Gradual-Increase-in-Complexity Approach. *Complexity*15(4):31-42.

Zhang, J., Chen, Q., Sun, Y., & Reid, D. J. (2004). Triple scheme of learning support design for scientific discovery learning based on computer simulation: experimental research. *Journal of Computer Assisted Learning*, *20*(4), 269-282.

Zydney, J. M. (2010). The effect of multiple scaffolding tools on students' understanding, consideration of different perspectives, and misconceptions of a complex problem. *Computers & Education*, *54*(2), 360-370.

APPENDIX I

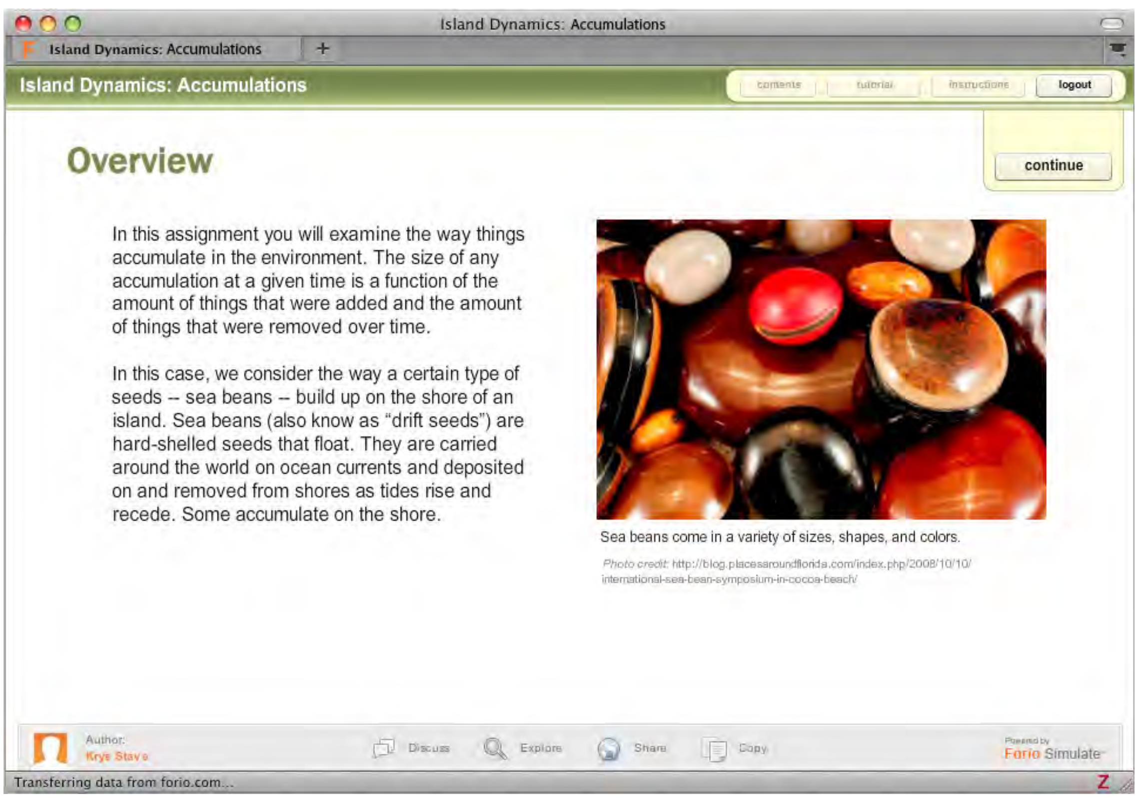
Overview of Assignment #3   Island Dynamics: Accumulations

This assignment was the only assignment that explicitly presented the principles of accumulation and set them in a discovery learning context. For further information about the development of this simulation, see Stave, Jurand, and Skaza (2011).

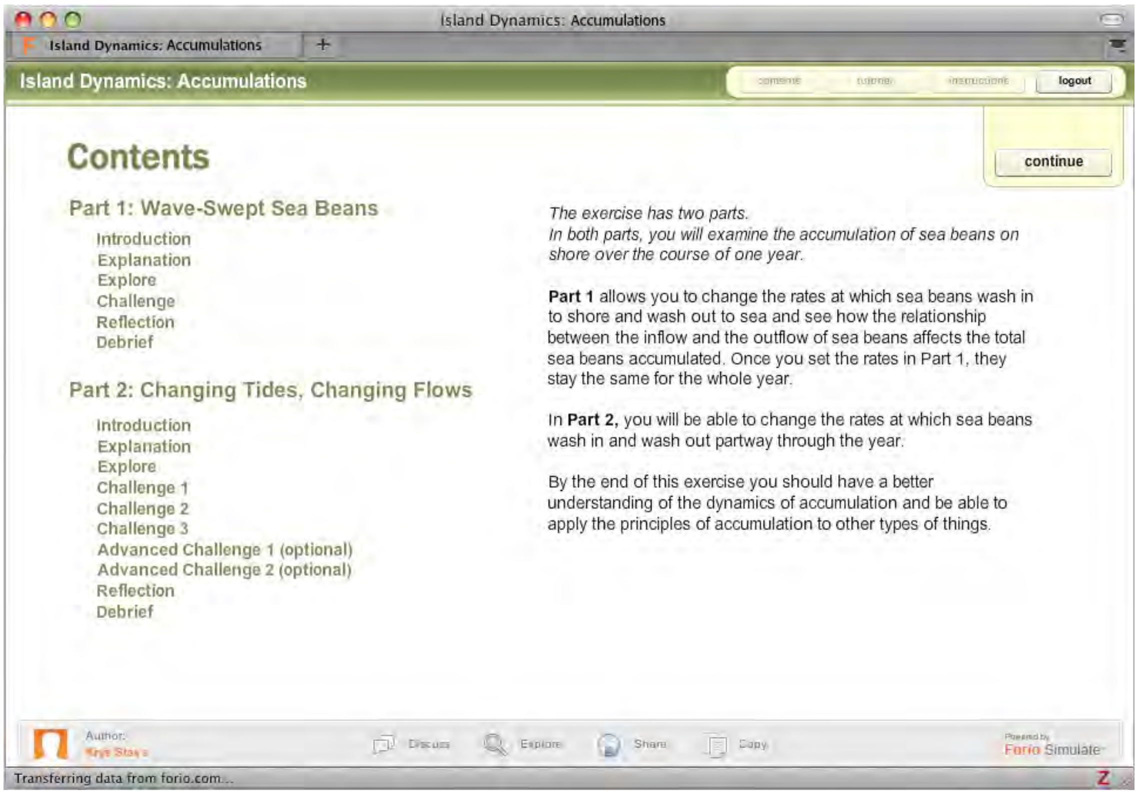
Summary of the Simulation Storyboard for Assignment #3

In this module, we use the movement of sea beans (a large category including seeds from a variety of species that drift on waterways, including ocean currents), to examine simple accumulation concepts. The accumulation of sea beans on the island depends only on addition and removal from the sea. There is only one inflow – sea beans washing in to shore – and one outflow – sea beans washing out to sea. There is no feedback from the accumulation to the flows. The length of the simulation period is one year and the interval is one day.

We start with an overview:



There are two parts to the exercise. The first is very simple, exploring the relationship between flows and accumulation when the flows remain constant over the course of the year. In the second part, we allow users to change the rates four months into the simulation. That is, the rates are constant for the first 4 months, they change linearly to the new rates between four and six months, then stay constant at the new rates for the last six months. In both parts, we start with an explanation of the basic concepts, illustrated with static graphs, then allow users to explore the simulation on their own, then present them with challenges to prompt them to explore more. Prompts for prediction and reflection are included throughout the simulation. Finally, we repeat the main concepts in the debrief section.

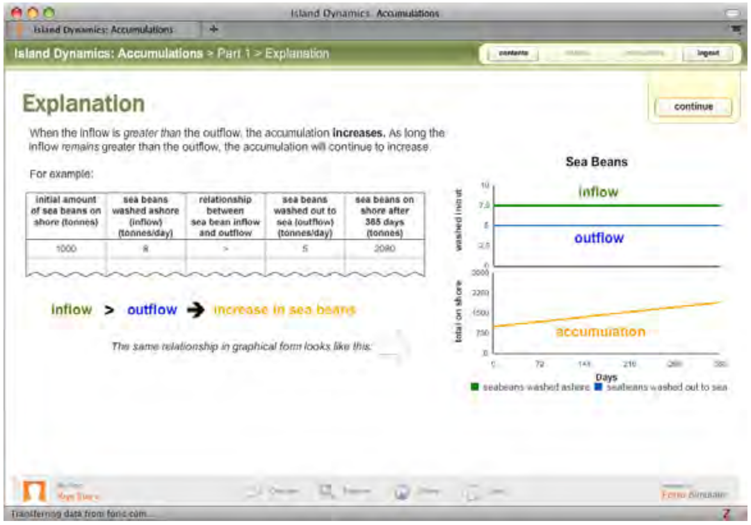


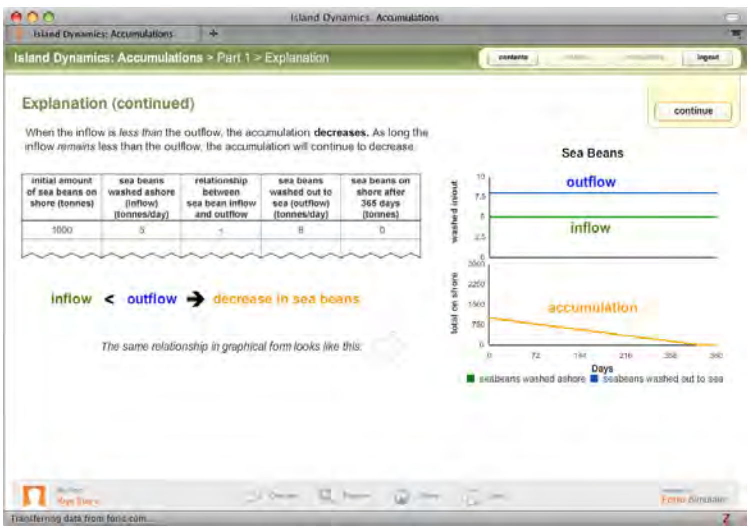
Part 1: Wave-Swept Sea Beans

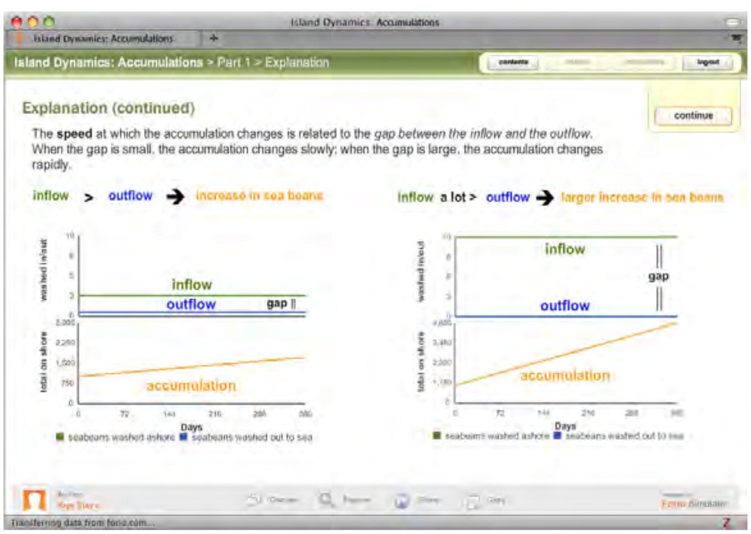
After an introduction to sea beans and their penchant for travel, we ask users to tell us what they know about accumulations. Forio's Basic level subscription allows data like this to be collected.

The next three screens provide the equivalent of a simple lecture on accumulations. Users can page through these screens at their own pace. They also introduce users to the graphs they will see on the simulation page.

After the explanation, users can go directly to the simulation or see a tutorial page that takes them through the sequence of steps in the simulation and identifies the navigation buttons.


Island Dynamics: Accumulations
Island Dynamics: Accumulations > Part 1 > Explanation
Explanation
continue
When the inflow is greater than the outflow, the accumulation increases. As long the inflow remains greater than the outflow, the accumulation will continue to increase.
For example:
initial amount of sea beans on shore (tonnes)
sea beans washed ashore (inflow) (tonnes/day)
relationship between sea bean inflow and outflow
sea beans washed out to sea (outflow) (tonnes/day)
sea beans on shore after 365 days (tonnes)
1000
8
>
5
2090
inflow > outflow → increase in sea beans
The same relationship in graphical form looks like this:
Sea Beans
inflow
outflow
accumulation
washed in/out
total on shore
Days
seabeans washed ashore
seabeans washed out to sea


Island Dynamics: Accumulations
Island Dynamics: Accumulations > Part 1 > Explanation
Explanation (continued)
continue
When the inflow is less than the outflow, the accumulation decreases. As long the inflow remains less than the outflow, the accumulation will continue to decrease.
initial amount of sea beans on shore (tonnes)
sea beans washed ashore (inflow) (tonnes/day)
relationship between sea bean inflow and outflow
sea beans washed out to sea (outflow) (tonnes/day)
sea beans on shore after 365 days (tonnes)
1000
5
<
8
0
inflow < outflow → decrease in sea beans
The same relationship in graphical form looks like this:
Sea Beans
outflow
inflow
accumulation
washed in/out
total on shore
Days
seabeans washed ashore
seabeans washed out to sea


Island Dynamics: Accumulations
Island Dynamics: Accumulations > Part 1 > Explanation
Explanation (continued)
continue
The speed at which the accumulation changes is related to the gap between the inflow and the outflow. When the gap is small, the accumulation changes slowly; when the gap is large, the accumulation changes rapidly.
inflow > outflow → increase in sea beans
inflow a lot > outflow → larger increase in sea beans
inflow
outflow
gap
accumulation
washed in/out
total on shore
Days
seabeans washed ashore
seabeans washed out to sea

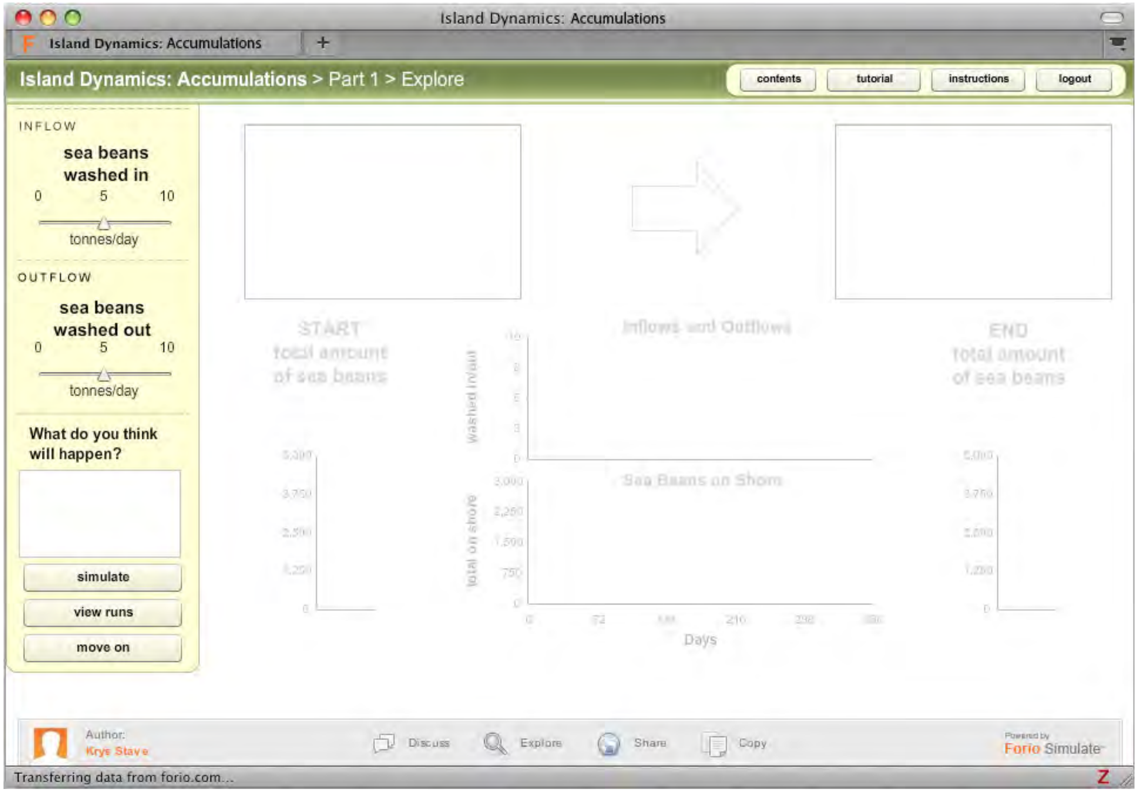
Simulation

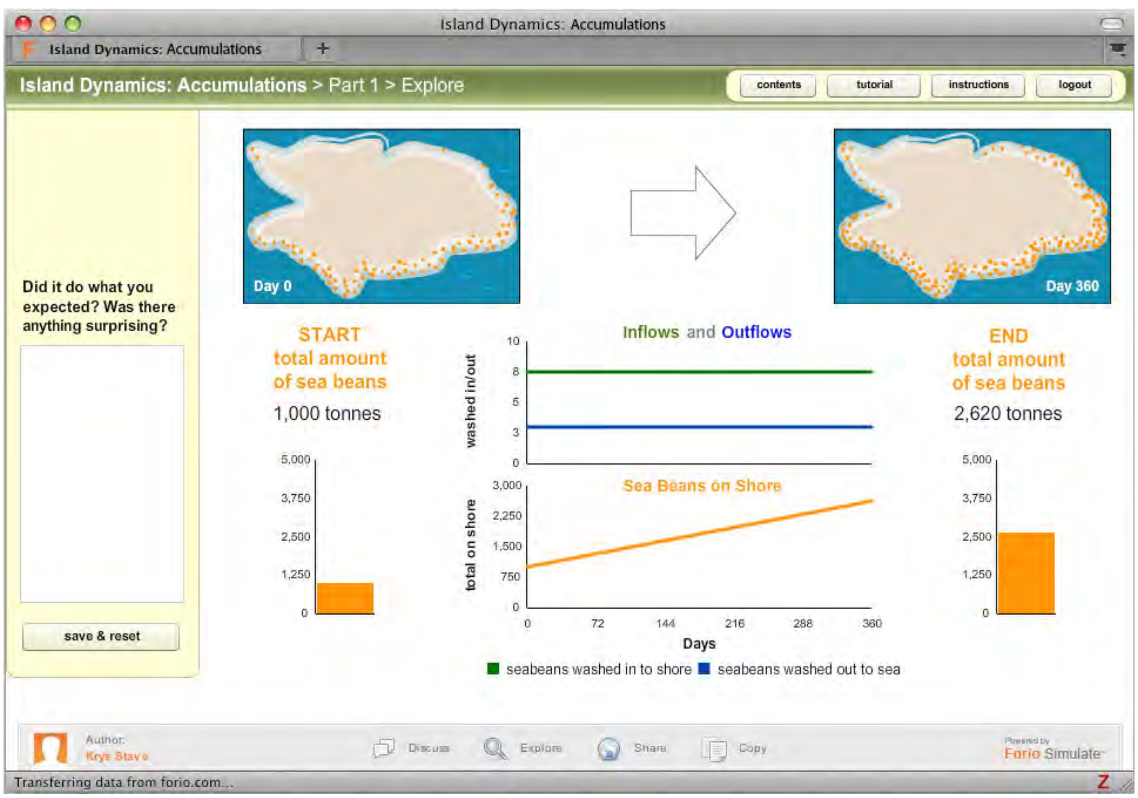
To run the simulation, users first set initial inflow and outflow rates using slider bars.
We ask them to predict what will happen with those values.

Once they have made their decisions and click "simulate", the results display in multiple ways.
We ask them to note what happened after the run, and comment on what they saw.

After the first run, they can also view a table of runs that give the input and output values for each run, and allows them to see the graph again.

A key feature for discovery learning is the prompt to articulate what they think will happen when they run a particular simulation. After the simulation we ask the user to compare what happened to what they thought would happen.





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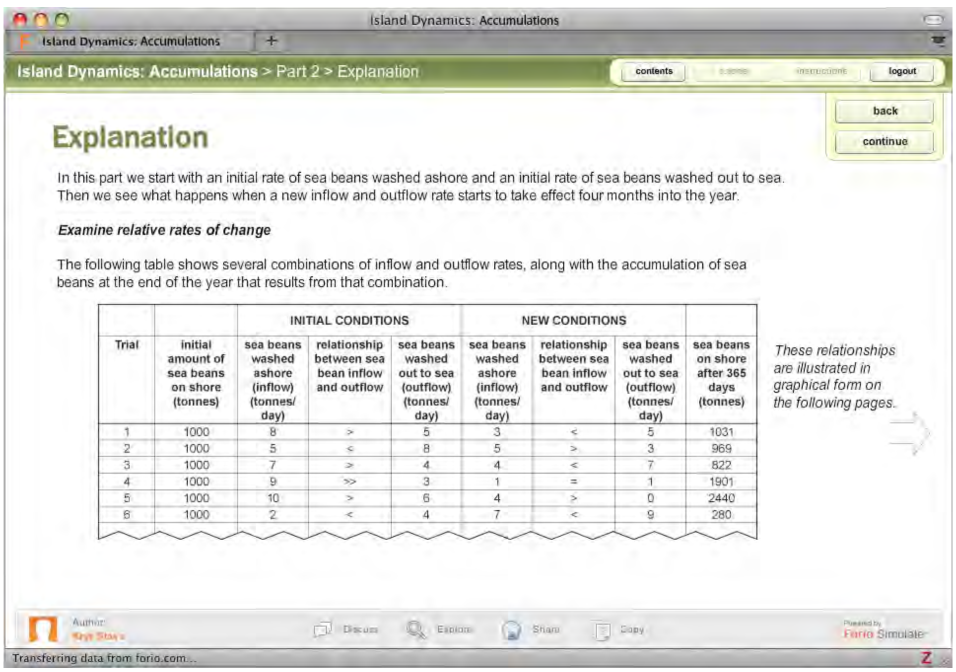
After running the simulation as many times as they wanted, they move on to the challenge, then are asked to reflect on what they did and describe their understanding of flows and accumulations after Part 1.

Part 2: Changing Tides, Changing Flows

Part 2 follows the same structure as Part 1, but allows the user to change rates. The scenario states:

> Imagine that four months into the year (at 120 days) the tides change. This could happen as a result of seasonal change, major weather patterns like El Nino, or climate change. When the tides change, the rates at which sea beans wash ashore and are washed back out to sea also change. It takes about 60 days for the tides to change completely to the new rates.

This is followed by a similar static explanation of the principles, again illustrated by tables and graphs.



Island Dynamics: Accumulations

Island Dynamics: Accumulations > Part 2 > Explanation

contents | logout | back | continue

Explanation

In this part we start with an initial rate of sea beans washed ashore and an initial rate of sea beans washed out to sea. Then we see what happens when a new inflow and outflow rate starts to take effect four months into the year.

Examine relative rates of change

The following table shows several combinations of inflow and outflow rates, along with the accumulation of sea beans at the end of the year that results from that combination.

		INITIAL CONDITIONS			NEW CONDITIONS			
Trial	initial amount of sea beans on shore (tonnes)	sea beans washed ashore (inflow) (tonnes/ day)	relationship between sea bean inflow and outflow	sea beans washed out to sea (outflow) (tonnes/ day)	sea beans washed ashore (inflow) (tonnes/ day)	relationship between sea bean inflow and outflow	sea beans washed out to sea (outflow) (tonnes/ day)	sea beans on shore after 365 days (tonnes)
1	1000	8	>	5	3	<	5	1031
2	1000	5	<	8	5	>	3	969
3	1000	7	>	4	4	<	7	822
4	1000	9	>>	3	1	=	1	1901
5	1000	10	>	6	4	>	0	2440
6	1000	2	<	4	7	<	9	280

These relationships are illustrated in graphical form on the following pages.

Author: | Discuss | Explore | Share | Copy | Powered by Forio Simulate

Transferring data from forio.com...

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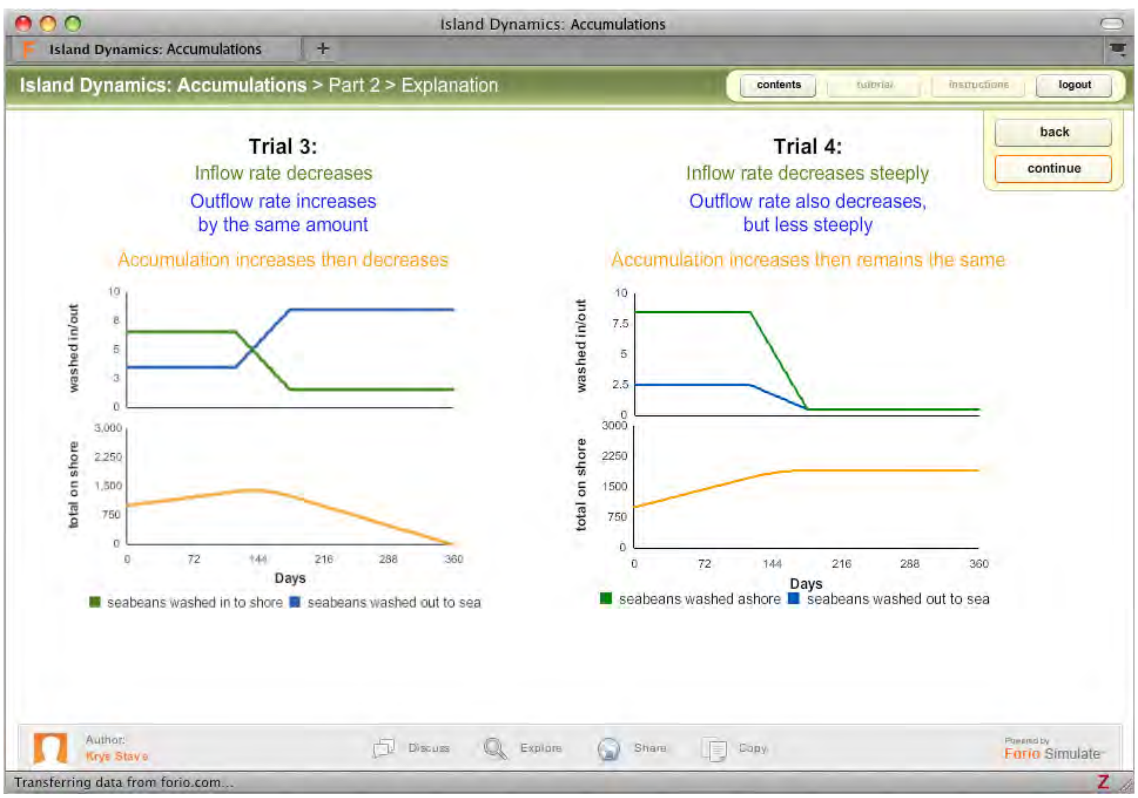
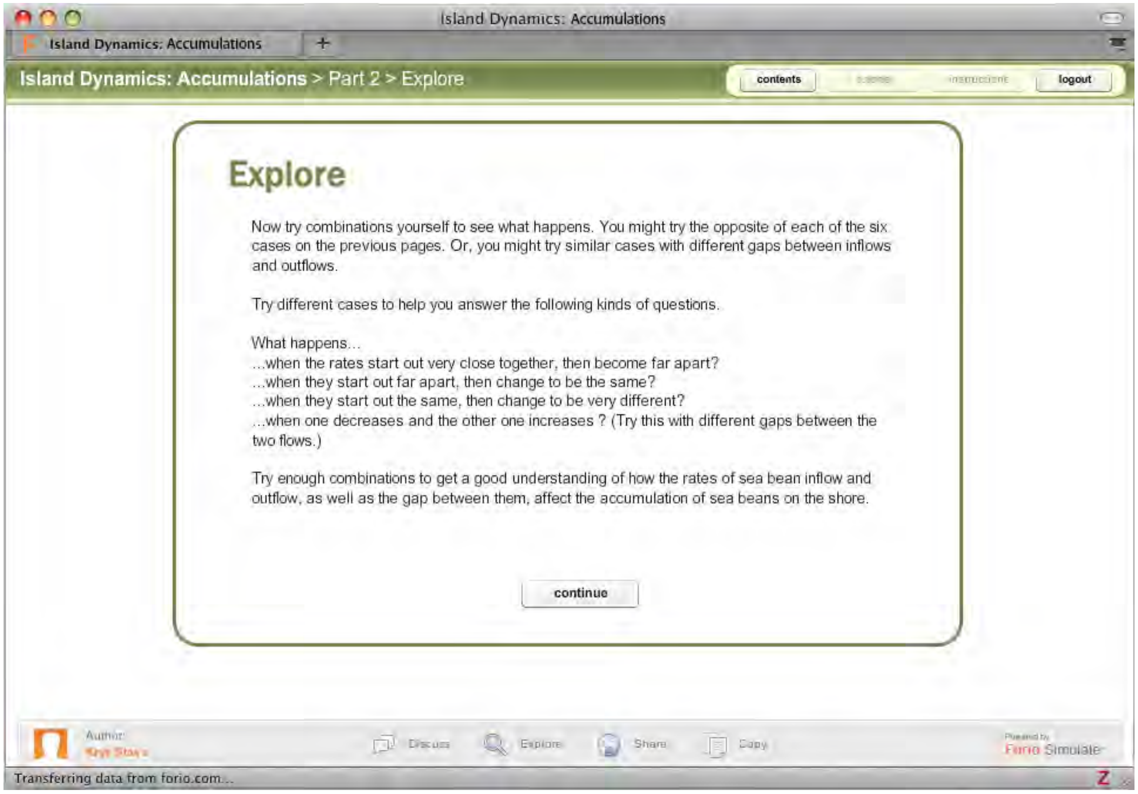
Available at: http://www.systemdynamics.org/conferences/2011/proceed/index.htm


Island Dynamics: Accumulations
Island Dynamics: Accumulations > Part 2 > Explanation
contents
logout
back
continue
Trial 1:
Inflow rate decreases
Outflow rate stays the same
Accumulation increases then decreases
Sea Beans
washed in/out
total on shore
Days
seabeans washed ashore
seabeans washed out to sea
Trial 2:
Inflow rate stays the same
Outflow rate decreases
Accumulation decreases then increases
Sea Beans
washed in/out
total on shore
Days
seabeans washed ashore
seabeans washed out to sea
Transferring data from forio.com...


Island Dynamics: Accumulations
Island Dynamics: Accumulations > Part 2 > Explanation
contents
logout
back
continue
Trial 3:
Inflow rate decreases
Outflow rate increases
by the same amount
Accumulation increases then decreases
washed in/out
total on shore
Days
seabeans washed in to shore
seabeans washed out to sea
Trial 4:
Inflow rate decreases steeply
Outflow rate also decreases,
but less steeply
Accumulation increases then remains the same
washed in/out
total on shore
Days
seabeans washed ashore
seabeans washed out to sea
Transferring data from forio.com...

Simulation

The simulation pages are the same as in Part 1, except there are four sliders for the two sets of rates: initial and new inflows and outflows. They are introduced with this screen:



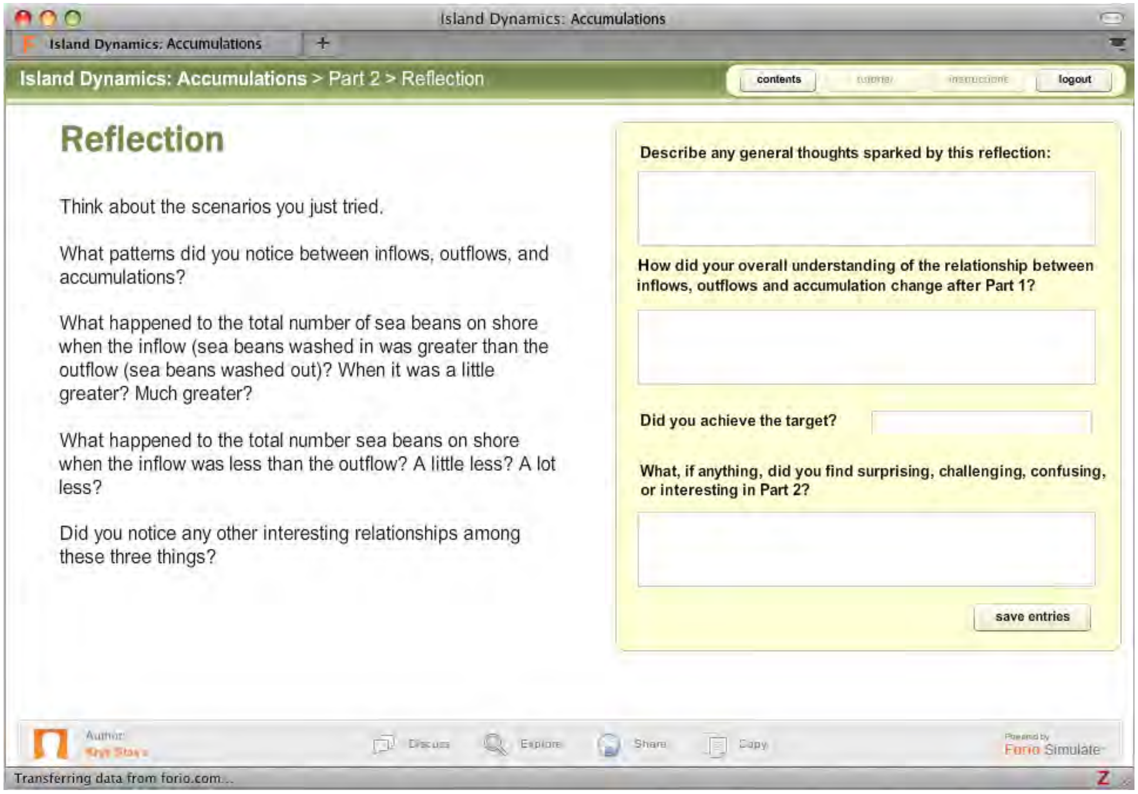
Challenges

There are five challenges in Part 2:

1. Achieve an accumulation in the target range of 2,000 – 2,500 tonnes.
2. Achieve the target range with a pattern that first increases, then decreases.
3. Achieve the target range with a pattern that first increases quickly, then increases more slowly.
4. Achieve the target range with a pattern that first decreases, then increases.
5. Achieve an accumulation in the range 500 – 750 tonnes with a pattern that first decreases quickly, then decreases more slowly.

Reflection

After the user moves on from the simulations, we ask them to reflect on the experience.



Part 2 concludes with a Debrief section that summarizes the principles presented in the explanation pages, and again allows the user to return to Part 1 or Part 2.

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