the Creative Learning EXCHANGE

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Making Friends

The text of Lesson 2: *Making Friend*s, from the book ***The Shape of Change Stocks and Flows***
by Rob Quaden, Alan Ticotsky and Debra Lyneis, illustrated by Nathan Walker
Published by the Creative Learning Exchange © June 2006
Prepared with the support of **The Gordon Stanley Brown Fund,** based on work supported by **The Waters Foundation**

Introduction

The original Friendship Game, Version 1.0, © September 1996, was created by Peg Clemans. Peg was with the System Dynamics Project, Catalina Foothills School District, 1911 E. Orange Grove Rd., Tucson, AZ 85718.

The Friendship Game was updated and modified as one of the lessons in *The Shape of Change*, by Rob Quaden, Alan Ticotsky, and Debra Lyneis, 2004. In *The Shape of Change* lessons, students engaged in games and other classroom activities to focus on *what* was changing. Then they used behavior-over-time graphs to express and examine *how* those patterns of change took shape. In "Making Friends," they saw the line on their graph curve upward in a pattern of exponential growth as new friends doubled each round.

The Shape of Change Stocks and Flows builds on the lessons developed in the first book. In the lessons in the new book, we take the next step, to help students understand *why* these things changed. Students learn that all change over time can be viewed as a process of accumulation: the number of friends on the team is an accumulation that grows as new friends join every round.

> *The level of water in a bathtub is an accumulation that increases by the flow of water in through the faucet and decreases by the flow of water out the drain over time. This analogy is used throughout the book.*

We call these accumulations "Stocks." The amounts entering and leaving the stocks over time are called "Flows." Envisioning change over time in this framework helps students understand the similar structures that underlie all change.

Frequently Asked Questions

Why would students need to learn about stocks and flows?

Learning about stocks and flows gives students a way to visually represent and examine the causes of change over time in a common language that applies across disciplines.

Does this approach engage kids?

Yes. Using the language of stocks and flows to explore the causes of change raises the level of dialog, reflection, and critical thinking in the classroom because students must make their assumptions very explicit. Students use the diagrams to share and refine their thinking together.

So what? Does an understanding of stocks and flows apply beyond the classroom?

As students proceed through the lessons, they begin to recognize similar stock/flow structure in the systems that surround them. Students learn that stocks are changed only by their flows, so any policy to change a stock—in the game or in real life—must focus on altering its flows. Students can build practical

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THIS ISSUE AT A GLANCE

FROM THE LIST-SERVE…

This is an excellent summary of what is going on in climate change with system dynamics. It was posted by "Andrew Jones" <apjones1@bellsouth.net> on the system dynamics listserve

Dear System Dynamicists:

Mitchel Kling asked about efforts to use system dynamics to address climate change. Here are several current activities, primarily from a US perspective.

1. Tom Fiddaman has built a suite of insightful climate-economy models, captured in his MIT PhD thesis, a flight simulator with Bert de Vries, and the *SD Review* paper for which he won the most recent Forrester award (18(2) Summer 2002). Resources at: http://www.metasd.com/index.html

2. We at Sustainability Institute have been working with Rocky Mountain Institute to help electrical utility leaders and their investors explore the dynamics of reducing their CO_2 output and strategies for possible future carbon taxes, using a system dynamics model and flight simulator. Article at: http://www.sustainabilityinstitute.org/pubs/Systems_Climate_Utilities.pdf

3. John Sterman and Linda Booth Sweeney's experimental work aimed at understanding public complacency on climate change action from a system dynamics perspective was recently published in *Climatic Change*. Their article is here: http://web.mit.edu/jsterman/www/Understanding_public.html

4. Aiming to correct the problems identified in the previous paper, there are two efforts:

a. A team including Sterman, Sweeney, Sustainability Institute, Peter Senge at SoL, and Michael Tempel at SEED are working to create an online educational simulation that will help learners understand climate dynamics using a stock-flow-bathtub perspective. The work is in progress and will eventually reside at: http://www.seed.slb.com/en/scictr/watch/climate_change/index.htm

b. Beth Sawin and Phil Rice at Sustainability Institute are developing approaches that employ systems thinking concepts to educate the public on the need to act on climate change— "Our Climate Ourselves." http://www.sustainabilityinstitute.org/oco/index.html

5. Chris Soderquist and team have built an online system dynamics game, CO_2FX, that explores addressing climate change from a national perspective. Play it at www.globalwarminginteractive.com.

6. Two sessions at the Society for Organizational Learning's "Sustainability Consortium" Business Forum March 27-29 in Atlanta USA will focus on using models and learning tools to help business address climate change. The event is open to non-SoL members. Info at: http://www.solsustainability.org/forum2007.htm

AND, this long list is paltry, relative to the potential impact our field could have. We have SO much to contribute. Bring it on!

Drew Jones
Sustainability Institute
Posted by "Andrew Jones"
<apjones1@bellsouth.net>
posting date Sun, 4 Feb 2007 10:16:40

EDITORIAL

As this winter (or lack of it until now, in New England!) wends on, we are looking at a variety of interesting things happening across the world. This February, in Utrecht, a conference highlighting systems thinking in K-12 schools is bringing together Peter Senge, Daniel Kim, Michael Fullan, Linda Booth Sweeney, Tracy Benson, and Joan Yates in a 4-day event to strengthen the use of systems thinking in both the organization and the classroom, in the Netherlands and beyond.

This initiative, and those in Columbia (See page nine.), Singapore, China, Norway, and elsewhere, are encouraging to us here at the CLE about the future of our planet. Over the past year, more and more discussion is occurring in the body politic about climate change and global warming. We are very conscious about cultivating the links between climate, sustainability education, and systems thinking and system dynamics. (See the post in the SD listserve from Drew Jones, printed herein.) System dynamics is a perfect methodology for both exploring the consequences of CO_2 and other factors of climate change as well as helping people and students learn about it.

As always, we love to hear from you. Send us updates, articles or just an e-mail line about what is going on with you!

Take care,

Lees Stuntz (stuntzln@clexchang.org)

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problem-solving skills based on this basic understanding of how the system works.

Making Friends

In Lesson 2 of *The Shape of Change,* students played a game to observe and compare how the number of friends grew as new friends were added each round, first by a constant number and then by doubling. [See Pages 17-25 in *The Shape of Change* for the complete lesson.]

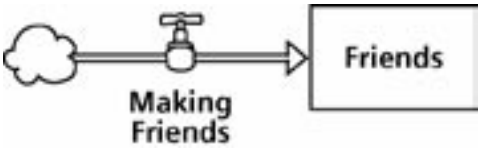
Overview

Of the two games played in Making Friends, Game 1 is based on the same stock/flow structure as the In and Out Game. During each round of the game, the number of new friends is constant. This causes the total number of friends to increase at a steady rate.

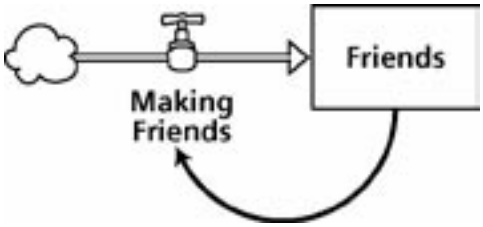
However, the structure of Game 2 is completely different. In that game, the number of existing friends *caused* an increase in the number of new friends, because *each* existing friend chose a new friend each round. As a result, the number of friends increased at an increasing rate. This represents the fundamental concept of **feedback**.

Seeing the Structure

1. Ask students to draw a stock/flow map of Game 1. [If students have completed lesson 1, the In and Out Game, point out that the maps looks similar to each other.]



2. Ask why this map would not explain Game 2. Students should realize that the flow "Making Friends" changed throughout the game. It was not constant.
3. Ask students to explain why the number of friends in Game 2 increased so much faster. The number of friends in the stock determined the number of new friends flowing in because each friend recruited a new friend each round. In other words, the stock influenced the flow. To show this on the map, draw a connector arrow from the stock to the flow.



Note: The curved arrow is not a flow – no friends are moving from the stock. Rather, the arrow indicates that ***information*** *about the size of the stock affects the size of the flow.*

This is an example of **positive feedback,** also called **reinforcing feedback.** The stock increases the flow, which increases the stock, which in turn increases the flow, etc. This process goes on and on, increasing the value of the stock faster and faster.

Refer back to the game. At first, one friend chose one friend, making two friends in the stock. In the next round, the two friends each chose a new friend, making four friends in the stock. Then those four friends each added a friend to make a total of eight friends in the stock, and so on, doubling each round.

Positive feedback is another name for a vicious (or virtuous) cycle. Growth that is gathering speed can also be called snowballing, escalation or compounding growth. It is a feedback loop that reinforces itself.

A Causal Loop

The drawing below is another way to show feedback. The causal arrows mean that an increase in friends on the team causes an increase in making new friends, which in turn causes an increase in the friends on the team, and so on.

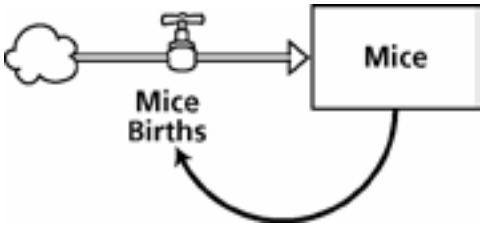
A causal loop diagram is a quick sketch of the feedback loops, while a stock/flow diagram shows us more precisely how the changes work. We use them together to think about change over time.

Making Friends *continued on page 4*

Making Friends *continued from page 3*

4. Ask students to think about real-life examples of positive feedback. There are countless examples of positive feedback in the world around us

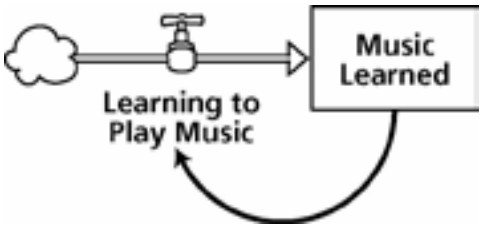
Example 1:



If you start with just a few mice, they give birth to baby mice, which grow into adult mice, which give birth to more baby mice, etc. Given that most people consider mice pests, this is an example of a vicious cycle.

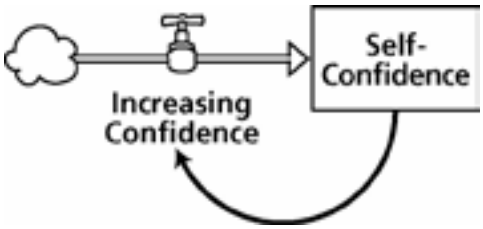
Note that this map is incomplete and does not show the complete dynamics of mice populations. For example, the map does not show mice deaths and it does not specify a birth rate. More on these later.

Example 2:



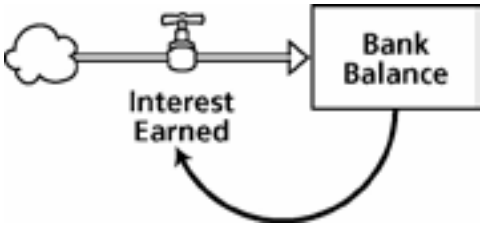
Once you learn to play a simple piece of music, you are able learn a more complicated piece, and so on. Here the reinforcing loop would be a virtuous cycle.

Example 3:



The more self-confidence you have, the more willing you are to take on new situations, which then increases your self-confidence.

Example 4:

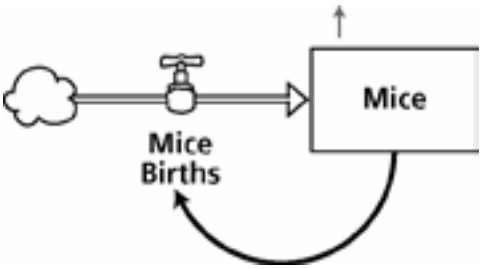


The more money you have in a bank account, the more interest you earn, giving you even more money in the account, and so on.

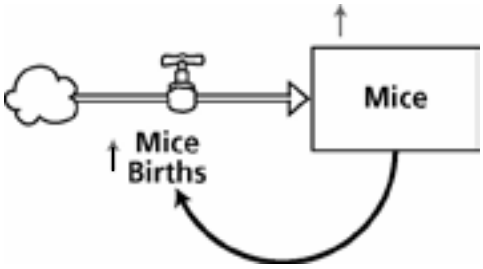
Note: Time is implicit in every stock/flow diagram. For example, money is deposited to the bank balance per month, adding to the total accumulation of dollars in the stock over time.

5. After drawing each map, trace the feedback loop by following the direction of the flow and the connector arrow. To understand how the stocks and flows change, it is helpful to draw up or down arrows to show increases or decreases around the loop.

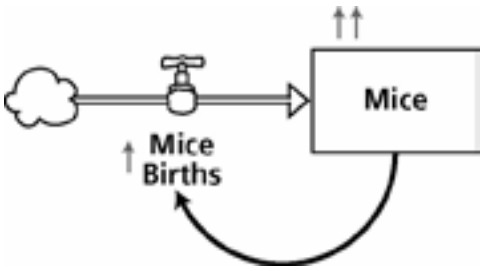
Using the mice example, show an initial **increase** in the number of mice by placing an up arrow in or near the stock:



Tracing the connector, the increase in the number of mice will **increase** the number of mice births because more mice will have more babies. Show this by drawing an up arrow near the flow:

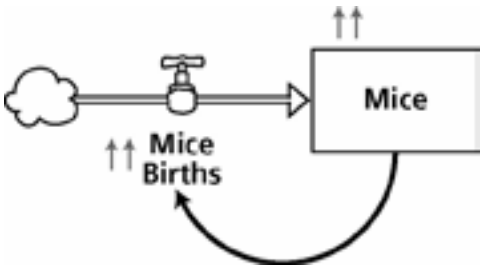


Following the flow "pipe," this increase in mice births further **increases** the number of mice above what it would have been. Add another up arrow near the stock:



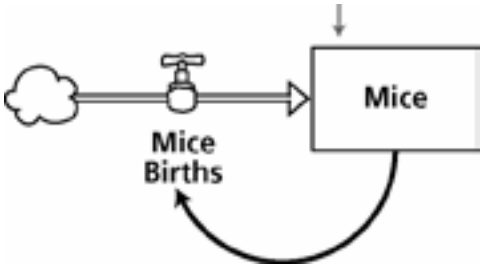
Note: Mice births always increase the population, but increasing the births produces even more mice than there would have been otherwise.

An increase in mice further **increases** the mice births:

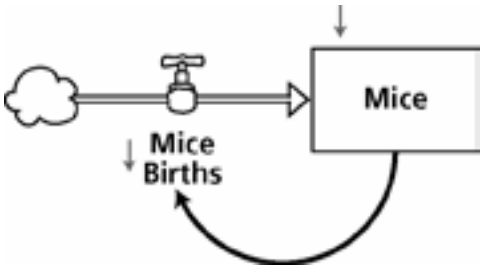


No matter how long we follow this process, more and more arrows will line up, all pointing in the same direction. This indicates that the number of mice will increase at a faster and faster rate.

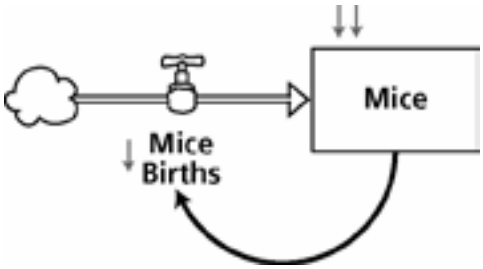
6. Note that we started this process by increasing the number of mice. We could also have decreased the number of mice at the start, in which case the initial arrow would point down:



The result of this decrease would be that, all other things being equal, the number of mice births would also **decrease**. Show this by placing a downward arrow near the flow:



If the number of births decreases, the number of mice **decreases** relative to what it would have been if there had been no decrease in the number of births. (With any new births, the number of mice is still growing, but because fewer mice produce fewer births, the stock is growing at a slower rate.) Show this by adding another downward arrow near the stock:



The situation with the downward arrows is analogous to the one with the upward arrows. No matter how long we continue the process, more and more arrows will line up, all pointing in the same direction.

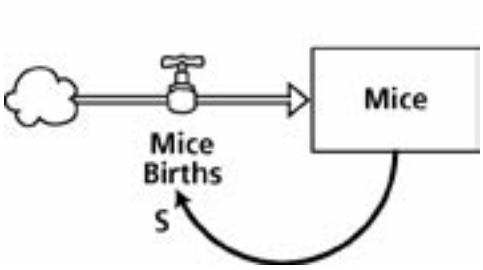
In a reinforcing feedback loop, any change is amplified each time around the loop.

***Making Friends** continued on page 6*

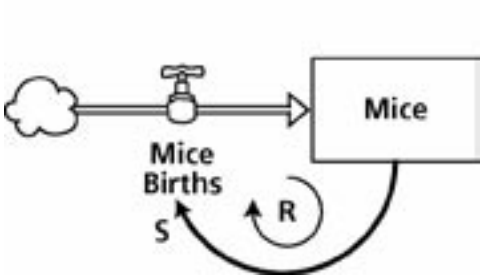
Making Friends *continued from page 5*

7. There are two distinct, but related concepts that need clarification.

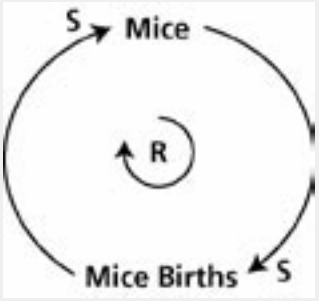
   o First, note that, all else being equal, an **increase** in the stock leads to an **increase** of the flow and that a **decrease** in the stock leads to a **decrease** in the flow. In other words, the change from the stock to the flow is in the ***same*** direction. This is shown by either adding the letter S (for "same") or the + sign near the arrowhead. Doing so eliminates the need for the up/down arrows, although they are helpful at first.



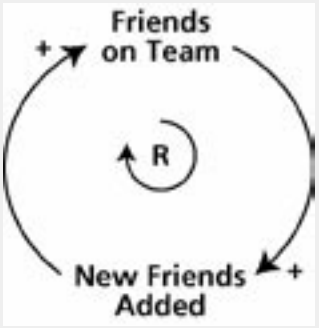
o The second concept is that positive feedback produces a **reinforcing loop**. Each time around the loop, an initial increase (or decrease) is reinforced again and again. To show that the number of mice will increase faster and faster (with more arrows always pointing in the same direction) write an R in the loop for "Reinforcing."



Causal Loop Diagrams



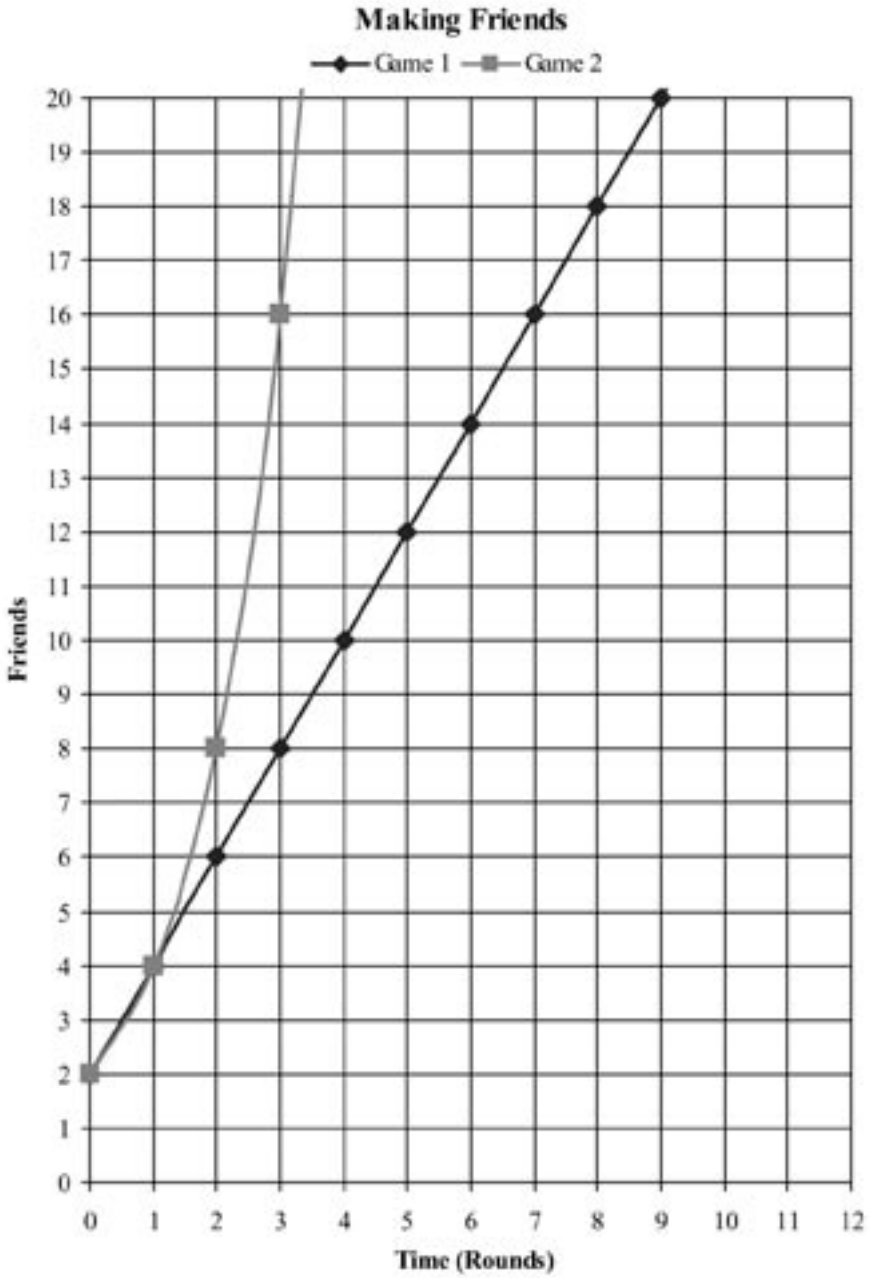
An increase in mice causes an increase in baby mice which causes an increase in the number of mice, and so on around the loop. Likewise, a decrease in mice would trigger a decrease in births, producing fewer mice than there would have been otherwise, and so on. The label "R" tells us that this is a reinforcing feedback loop.



Now we can also complete our Making Friends causal loop drawing. The "+" sign is another way to show that an increase (decrease) in one variable causes an increase (decrease) in the next variable, beyond what it would have been.

? How do these stock/flow maps relate to the graphs we drew of the friends game in *The Shape of Change*?

In the first game, the number of new friends was constant each round, so the line on the graph showed linear growth, a straight line. In the second game, however, the number of new friends depended on the number of friends already on the team because ***each*** *friend chose a new member for the team each round. More friends led to even more friends. This escalating growth appeared as a curved line on the graph.*



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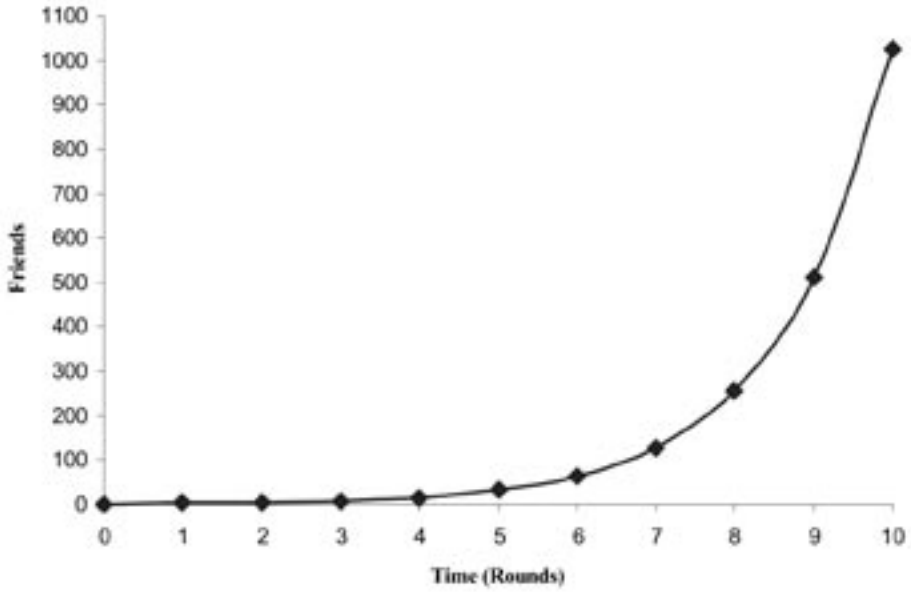
Making Friends *continued from page 7*

? In Game 2, we could play only three rounds before running out of players. What would the graph look like if we had enough students to play ten rounds?

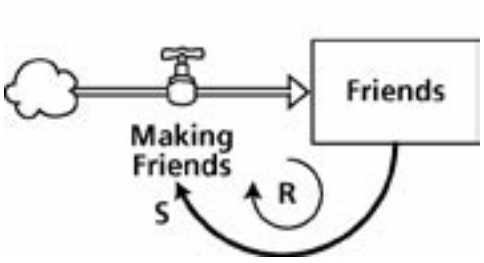
Growth would escalate rapidly. Starting with one student on the friends team and doubling the number of members each round, there would be more than a thousand members after ten rounds! A reinforcing feedback loop produces this pattern called ***exponential growth****.*



? Think about our mice. Does our stock/flow map produce this same behavior for them? What about money in the bank and the other examples we discussed?

Yes, they are all examples of reinforcing feedback loops that can cause the stocks to grow exponentially until something limits their growth.

? Think again about the Making Friends game and graph. Tell the story of this completed stock/flow diagram.



Colombian Classroom Experiments: A Preliminary Report

by Margarita Cruz*, Maria Teresa González*, Maria del Pilar Restrepo*, and Marta Lucía Zuluaga*

**Editors' note: The authors are second-year system dynamics master's degree students at the University of Bergen in Norway.*

Regular readers of the *CLExchange* are well acquainted with the pioneering efforts of K-12 teachers using and promoting system dynamics modeling and systems thinking methods ("SD tools") across the curriculum. Understandably, the emphasis of those efforts has been on the diffusion process—getting SD tools in the hands of teachers and training them to use those tools. As a result, assessment has lagged behind implementation.[1] Hoping to help close that gap, we are engaged in four projects that focus on assessment. The common denominator of our work is the design of experiments to measure the effectiveness of SD-enhanced instruction in four disciplines: history (Margarita Cruz), civics (Maria Teresa González), physics (Maria del Pilar Restrepo), and management (Marta Lucía Zuluaga).

The first phase of experiments was conducted in Colombia during the summer 2006. For the history, civics, and physics experiments, participants were high school students. Three different schools participated, with students drawn from grades 9-11, the last three years of high school in Colombia. The participants in the management instructional experiment were undergraduates at the National University of Colombia. This article provides a brief summary of the overall experience and some preliminary impressions.

In-service Training for Colombian Teachers

At each high school, prior to the classroom experiments, we conducted a three-hour in-service training session for teachers, none of whom had prior knowledge of system dynamics. The bathtub analogy was used to introduce stocks and flows, followed by explanation and illustration of feedback loops. The teachers participated in a physical simulation game—the Infection Game[2]—the purpose of which was to illustrate dynamics and the impact of structure on behavior. After the game, there was a discussion of the behavior of epidemics in terms of the diffusion model (Sterman 2000, ch. 9), which was also the primary conceptual structure for the history and civics classroom teaching experiments.

The teachers were attentive and enthusiastic. They wanted to find new ways to motivate their students and improve their instructional methods. As they learned about SD and experienced the epidemic game first-hand, they began to understand how such generic models could be used to pursue learning goals in a variety of academic disciplines, and they became enthusiastic and interested in learning how to use the SD tools.

History and Civics Experiments

Traditionally, history in Colombian schools has been presented as isolated facts that are hardly related to the present, the future, or changes over time. Therefore, students find it difficult to relate their study of the past to an understanding of the present. The knowledge of history needs to be placed in a structured pattern that students may use for understanding historical facts. Therefore, the purpose of the history experiment is to answer questions such as: *Does SD place historical facts into a structured pattern that improves understanding?*

Experiments *continued on page 10*

Making Friends *continued from page 8*

The total number of friends on the team, the stock of Friends, is increased by the inflow of new friends each round. As players make new friends, the team grows.

This map describes the second game when the number of friends on the team affected the flow of new friends because each friend chose a new friend each round. The more friends there were on the team, the more new friends were added (a change in the same direction labeled "S"). The number of friends kept growing at an increasing rate, producing a steepening curve on the graph. We call this pattern exponential growth, a hallmark of a reinforcing feedback loop (labeled "R").

If, partway through the game, we decreased the stock by taking some players out of the game, that would cause a decrease in the number of new friends below what it would have been otherwise (a change in the same direction). With fewer new friends, the team would grow more slowly than it would have otherwise. Like the mice population, the team would still grow but at a slower rate.

> The stock/flow maps lay out the structure for us. The causal loop diagrams and the behavior over time graphs give us another view of the same thing. Used together, they help us understand how and why things change over time.

This lesson from ***The Shape of Change Stocks and Flows*****: *****A Beginning,*** *by Rob Quaden, Alan Ticotsky and Debra Lyneis, 2006, Creative Learning Exchange, builds on the classroom activities described in* ***The Shape of Change,*** *by Rob Quaden, Alan Ticotsky and Debra Lyneis, 2004, The Creative Learning Exchange. You can get the graphics and layout in the books or download the text of both the original and this lesson from the CLE at* www.clexchange.org.

Colombian Classroom Experiments *continued from page 9*

Does SD enhance the understanding of systemic relationships that caused history to unfold in certain ways?

A goal of civics instruction in Colombia is to help students recognize the importance of civic participation and develop a commitment to civic responsibility. However, the benefits of civic engagement are often distant in time and location, and individual costs and benefits may not correlate with the costs and benefits to the community. Thus, it is especially hard for students to understand why it is worthwhile to be active. The purpose of the civics experiment is to test whether the process of civic activation is better understood when the dynamic structure of that process is demonstrated and, more importantly, if better understanding fosters an attitude that is conducive to civic participation.

The history and civics instructional experiments were built around the diffusion model and consequent s-shaped growth of populations of revolutionaries and civic activists, respectively. In the introductory sessions, the students received verbal instruction about the basic concepts of SD, and they also played the epidemic game and received a debriefing in terms of the diffusion model. On the second day, the students received computer slide show instruction built around diffusion models of revolutionary movements in the history session and civic activism in the other session. The instruction included stock and flow diagrams as well as causal loop diagrams.

The history students learned about the French Revolution as a diffusion process, with people flowing from the stock of non-revolutionaries to the stock of revolutionaries over time. In the civics session, the model was adapted to a process of people passing from the condition of non-activist to activist. The civics lesson integrated an additional feedback structure connecting persons' sense of civic efficacy with their participation rates. Afterwards, students in both sessions took tests designed to measure their understanding relative to their performance on pre-tests administered several days earlier. On the third day, the students made small group presentations in which they applied their understanding of the diffusion model in the context of a conceptually similar case study. Finally, the history and civics students traded places and repeated the instructional and assessment phases of days two and three. Thus, the same students participated in both the history and civics experiments.

Physics and Management Experiments

There is evidence of positive effects of SD tools in physics classrooms (Hirsh 2002). However, there has been no assessment of the process of conceptual change in physics students' mental models when working with SD. The goal of this project is to develop a description of the way in which SD elements affect student understanding of physics concepts. The most important feature of this study is the proposal for a new conceptualization of students' misconceptions in physics. For instance, all the alternative conceptions in kinematics can be explained by the incomprehension of the simple SD bathtub structure. Once the modification of students' conceptions is described, the description can be used to address other misconceptions in physics exhibiting the same generic structure. If we can obtain enough information to describe the process for kinematical concepts, for example, we can use that pattern of learning to create new strategies of teaching with SD. In addition, we could transfer this process to other concepts sharing the same generic structure. Thus, we could provide physics research with a more generalized conceptualization of students' alternative conceptions.

In a business firm, resources are accumulated and depleted over time according to the decisions made by managers (Warren, 2002). Ensuring desirable levels of various resources is a challenge that managers face continuously. That decision-making process demands a clear understanding of the dynamics embedded in the firm and, particularly, the stock and flow relationships. As Sterman and Sweeney (2000) have shown, however, such understanding does not come easy. This problem motivated an experiment to determine whether university business students—Colombia's future entrepreneurs and managers—could experience improvement in their mental models through the use of SD instructional tools.

The general procedures for the physics and management instructional experiments were similar and had three stages. The first task for students was designed to reveal their prior mental models. In the second stage, the objective was to modify individual mental models through a teaching process that relied on SD tools, particularly the bathtub analogy for explaining stock-and-flow relationships. Finally, students were engaged in two tasks designed to measure indicators of mental model change as a result of the instructional treatment.

Preliminary Impressions

The in-service training session was too short for the teachers to fully grasp and display an understanding of stocks, flows, and feedback loops. However, they were intrigued by the prospect of approaching different fields (such as science, history, and civics) from a common systemic perspective. They were curious about previous applications of SD in the classroom and the impact on student learning. Some were eager to know how to apply SD tools to physics and biology.

Most history and civics students understood the notion of change-over-time and flows between stocks, as well as factors affecting decisions in the diffusion process. However, they had more difficulty with the process of stock accumulation and feedback loop effects.

In the civics session, the additional reinforcing structure relating a sense of civic efficacy to activism proved difficult for students to grasp. In November's second phase of the experiment, the instructional content was simplified in both the history and civics sessions and a control group was taught without SD tools. Detailed results of both phases will be available this summer.

Results from the first phase of the physics experiment confirmed the existence of students' misconceptions and that the potential for change in students' mental models depends significantly on the strength of previous misconceptions. At the university, management students were optimistic about SD tools facilitating their understanding of business firm dynamics and wanted to learn more about system dynamics. Follow-up experiments with new groups of physics and management students have also been conducted.

In-depth statistical analysis of the data collected in both phases of all four experiments is underway, and a final report will be available this summer. We are encouraged by the receptivity of Colombian school administrators and teachers to the SD instructional approach, as well as their appreciation of the need to develop assessment strategies in parallel with classroom implementation of SD teaching methods.

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[1] Examples of SD assessment research relevant to our work include Potash *et al.* (1996, 2006), Hirsh (2002), and Wheat (2007).

[2] The Infection Game is adapted from "The Epidemic Game" developed by Will Glass at the Catalina Foothills School District, Tucson, Arizona, 1993.

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DynamiQUE*ST* 2007
May 11, 9am—3pm, Worcester, MA

Come join us for the eighth annual DynamiQUE*ST*!
Look over the guidelines provided on the CLE website. Begin to plan, with your students, what you will bring to DynamiQUEST 2007!

*We seek to encourage students and teachers to develop an understanding of the use of SD/ST tools. DynamiQUEST provides an environment, free from the "winner/loser" constraint, where kids can receive feedback from other kids as well as from teachers and professionals well versed in SD/ST. DynamiQUE**ST** creates a venue for both celebrating what has been done and providing encouragement for all to continue!*

DynamiQUE***ST*** 2007 will provide a venue for students in Grades 3-12 to showcase work in which they have employed the tools and method of system dynamics. This effort has several purposes:

- Provide a way for students to meet other students and see what they are doing. Give them (and their teachers) a chance to see their work as a point in time along a learning continuum and see where they can go next.
- Permit teachers from various schools to see evidence of student work in SD/ST
- Provide a venue for teachers and kids to network.
- Provide rubrics for any combination of SD/ST tools from a simple (but powerful) BOTG to a full-blown, dynamic model.
- Have some fun and celebrate with the kids!

Look over the guidelines provided on the CLE website. Begin to plan, with your students, what you will bring to DynamiQUEST 2007!

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