Creating Critical Thinking in our Students through System Dynamics

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Overview

• Why graph?
• Why map?
• Why model?
• Two passes at these questions:
  1. Focusing on systems thinking and system dynamics
  2. Focusing on the larger issues of education excellence
Why graph?

- That is, why draw Behavior Over Time graphs?
- Which is to say, Why think dynamically?
- Puts events in context. Moves from events to patterns over time.

[Graph of World Population 1500-2010]
Seeking Dynamics in a Dramatic Event…
Can you graph 9/11 over time?

(Source: Christian Science Monitor, 27 Sept 2001)

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CLE Conference, Babson College, July 2012
Moving From Events to Patterns of Behavior
(graphs illustrative only)

Tensions in the Middle East

Peace efforts

Seeing patterns in events over time: The Borton Boys

- First graders Alex, Daniel, and Nathan, best friends, but always getting into arguments and getting angry.
- Until ...

![Diagram showing a cycle between Mean words and Hurt feelings]

- Find the Borton boys talking about their loop at http://www.watersfoundation.org/webed/mod9/mod9-3-1.html
Why map?

• Visual thinking
  • Adding visual support to causal story-telling.
  • Adding stocks (accumulations) to help expose rich structure in causal stories.

• Feedback thinking
  • Uncovering reinforcing and balancing subplots in causal stories.
  • Telling more complex stories based on intuitions about interacting feedback loops.
Connection circle
Despereaux, book one
Pulling out a loop

Fear in the mouse community

Teasing of Despereaux

Amount Despereaux tries to act like a mouse
Pulling out a loop

Fear in the mouse community

Teasing of Despereaux

Amount Despereaux tries to act like a mouse

Telling the story of the loop in the Despereaux story
Why map?

• Many kinds of maps
  • Some are helpful, some are not
  • Some reflect and support systems thinking, some do not

• Stock-and-flow / feedback maps
  • Powerful supports for thinking about system structure
  • Nasty subtleties!
A diagram on the wall of a second grade classroom in the Ritenaur School District in St. Louis.
Resulting Causal Loop Diagram

This CLD was posted alongside the Connection Circle.

Excellent practice to try to pull out one or more well-formed feedback loops!
Adding Helpful Concepts

- Evaporation
- Water vapor
- Condensation
- Clouds
- Precipitation
- Water on ground

(R)
Rearranging a bit...

Water vapor in atmosphere

Evaporation

Water on ground

Condensation

Clouds

Precipitation

(R)
Showing Stocks
A very important step here

Water on ground

Evaporation

Water vapor in atmosphere

Condensation

Clouds

Precipitation
Representing the Actions as Flows

The links are pipes, not causal influences.

Not a reinforcing loop!
The total stock of water does not grow; it just moves around.
Pipes in the Picture in STELLA

Water vapor in atmosphere

Evaporation

Condensation

Water on ground

Precipitation

Couds
Environmental Connection Circle

Not a causal diagram. Rather, a flow diagram! But very hard to see in this form.

Maps often need refinement in order to derive insights.
“Which of these things is not like the other?”

Understandings of the system

Understandings of the model

Model formulation & testing

System conceptualization

Prejudice

Achievements of the minority

Discrimination

Opportunities for the minority

Carbon in atmosphere

Carbon in carnivores

Carbon in herbivores

Carbon in soil

Carbon in algae, plants & trees

Carbon in herbivores

Carbon in carnivores

Carbon in atmosphere

Carbon in algae, plants & trees

Carbon in herbivores

Carbon in carnivores

Carbon in atmosphere

Carbon in algae, plants & trees

Carbon in herbivores

Carbon in carnivores

Carbon in atmosphere

Carbon in algae, plants & trees

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Carbon in herbivores

Carbon in carnivores

Carbon in atmosphere

Carbon in algae, plants & trees

Carbon in herbivores

Carbon in carnivores

Carbon in atmosphere

Carbon in algae, plants & trees

Carbon in her
These arrows mean ‘and then’

- We start with some understandings of the problem and its systemic context, \textit{and then} we conceptualize (map) the system.

- \textit{Then} we build the beginnings of a model, which we \textit{then} test to understand it.

- \textit{Then} we reformulate, or reconceptualize, or revise our understandings, or do some of all three, \textit{and then} continue…
Arrows here are *flows* of material

The words here represent *stocks*, the arrows represent *flows*.

This is not a *causal* diagram.

This is a view of the “carbon cycle.”
Only this one is a *causal* loop

This causal loop tells a very compelling and important self-reinforcing story.
Why map with stocks?

• Tell more correct stories.
• Tell more insightful stories!
• Grow in the understanding of the importance of accumulations, and how they are different

  • Apartment buildings
  • Momentum
  • Pages in a report
  • Distance traveled on a trip
  • Memories

  • Muscles
  • Practiced musical abilities
  • CO2 in atmosphere
  • Capital stocks in an economy
  • Self-esteem
An Insightful Stock in Terrorism

- Terrorist group
- Terrorist actions
- Terrorist funding
An Insightful Stock in Terrorism

- Terrorist group
- Terrorist funding
- Recruiting new terrorists
- Terrorist actions
- Terrorists dying in actions
- Terrorist martyrs to the cause
- Terrorist zeal

(B) (R)
An Insightful Stock in Terrorism

- Interfering with terrorist funding
  - Efforts to suppress terrorists
  - Terrorists dying in actions
  - Terrorists martyrs to the cause
  - Terrorist zeal
  - Recruiting new terrorists
  - Terrorist group
  - Terrorist funding

(B)

(R)
An Insightful Stock in Terrorism

Stock of Martyrs.
What is the inflow?
What is the outflow?
Why model?

• Really two questions:
  • Why should learners “exercise” models?
  • Why should learners build models?

• Exercising models means
  • Simulating a given model repeatedly under various circumstances
  • Creating hypotheses, changing parameters, predicting behavior, observing simulated behavior, repeating, ... all with a given model

• Building models means
  • Create a simulatable model following the complete modeling process from conceptualization through equations and parameterization
  • Exercising the model thoroughly and reformulating to improve it.
Examples of exercising a model

• Increase the parameter Jobs Per Business Structure in URBAN1 and simulate the model. Create a feedback explanation of the behavior.

• URBAN1 contains four parameters that could be interpreted as policy parameters. Change each one plus-or-minus 30% and compare the results.

• Implement ZPG in the World Dynamics model at time 1970 and compare the results to the base run of the model.
Examples of exercising a model

- Change the consumption and savings assumptions in a model of lifetime savings. What does the model suggest for wise personal financial policy?
- Change the mass on the end of a spring and see what happens to the oscillations. Change the initial position. Why are the results so different?
Saving and spending

Income

Fraction consumed

Income to current consumption

Income to invest

Money in bank

Depositing

Interest rate

Earning interest
Exercising the Saving and Spending Model

Money in bank

Money in bank : consume 95%
Money in bank : consume 90%
Money in bank : consume 85%
Money in bank : consume 80%
Money in bank : consume 75%
What if we started withdrawing some for current consumption when the balance is high enough?!

What does your mental model say?

Fraction consumed

Fraction withdrawn p yr

<Time>
Withdraw none, early, or late

Withdraw late shows classic worse-before better behavior

Income to current consumption:
- Late withdrawal
- Early withdrawal
- No withdrawal

Money in bank:
- Late withdrawal
- Early withdrawal
- No withdrawal
Examples of exercising a model

- URBAN1 contains six parameters that could be interpreted as policy parameters. Change each one plus-or-minus 30% and compare the results.
Exercising URBAN1

Population

Business structures

Housing

Labor to job ratio

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Exercising URBAN1

Eight simulations changing four parameters +/- 30% produce essentially no change in the high unemployment of the built-up city. There is something important here to understand about cities.
Why exercise models?

• Simulation plays out the precise dynamics implied by the model’s assumptions.
  • We can’t simulate our qualitative maps or our mental models with any reliability.

• Simulation enables dynamic hypothesis testing
  • If we assume this in the model, then we get this behavior, which we (hope to) explain from the model’s structure.

• Exercising models can reveal connections between structure and behavior that can teach us about the real world.
Forrester’s observations on complex systems

(Urban Dynamics, 1968)

- Counterintuitive behavior
- Insensitivity to parameter changes
- Resistance to policy changes
- Control through influence points
- Corrective programs countered by the system
- Long-term versus short-term response
- Drift to low performance
Dana Meadows’s additions

- Addiction (persistent attractiveness of the short-term policy)
- Official addition – shifting the burden to the intervener
- High leverage, wrong direction
Why build models?

• Grow in qualitative conceptualization skills and quantitative model formulation skills
• Achieve ownership of a dynamic hypothesis and the conclusions it can support
• Grow in abilities to build models to help others with difficult problems in complex systems
• Get into Law School
• …But becoming modelers is not for everyone.
Three kinds of modeling assignments

- “Build a model of an epidemic”
  - Build a model to fit a “canned” description. See next pages for details.
- “Add taxes to URBAN1.”
  - Add structure to an existing model that already runs.
- “Build a model of the structure and dynamics of Fish Banks”
  - Build a model starting from a blank page.
“Build an epidemic model…”

Background
Consider an epidemic, such as influenza, in which the disease is transmitted directly by close contact between infected people and susceptible people. We shall suppose that
• The disease lasts in an average individual about 10 days;
• After contracting the disease, it takes 3 days on the average to start showing symptoms and becoming aware one is infected, but one is infectious to others right from the start;
• There are thus four significant populations: susceptibles, infectious-but-not-symptomatic, symptomatic, and recovered;
• There are no deaths, no births, and no migration in or out of the system;
• After recovering from the disease people are immune and can not contract it again, at least over the course of the single epidemic that is to be simulated in this exercise.
Problem
Formulate a model of an epidemic. Capture in equations the following assumptions:

• There are four populations to distinguish, as described above.
• A susceptible person makes contact with a number of people per day. For simplicity, assume the average number of people contacted per susceptible per day is constant throughout the epidemic (5? 10? 25?).
• Susceptible contacts per day is defined as the number of susceptibles times the average number of people contacted per susceptible per day.
• Some fraction of the susceptible contacts per day is with infectious people. The probability that a contact is infectious is the ratio of the infectious population to the total population.
• Finally, some constant fraction of the susceptible contacts with infectious people per day will result in transmitting the disease. The infection rate is the number of susceptibles infected per day. It equals the number of susceptible contacts with infectious people per day times the fraction of contacts transmitting disease.
Compare that to these…

• Build a model of the structure and dynamics of *Fish Banks*.

• Work in a team of three to talk with the *Sleepy Time Child Care Center* to help them achieve a solve their problem of overcrowding. The Sleepy Time folks are excited about model building so they would like a model-based analysis and policy recommendations.

• What differences do you see among these three types?
Why graph, map and model for systems understandings?

• Move from thinking about events and decisions to thinking over time

• Anticipate that long-term policy results are always different from short-term policy results
  • Worse before better – Better before worse

• Understand that complex systems compensate for well-intentioned policies, and be able to uncover and communicate compensating feedback loops

• Understand that real systemic understanding is hard.
Focusing on larger issues of education excellence

• Why graph for education excellence?
• Why map for education excellence?
• Why model for education excellence?
  • Why exercise models for education excellence?
  • Why build models for education excellence?
Why graph for education excellence?

• First graders’ graphs of story dynamics build understandings that later emerge as x- and y-axes in coordinate systems.
• Sixth graders’ graphs of history dynamics deepens understanding of historical pressures and sequences
• High school students’ graphs of phenomena surrounding current events puts those events in context
• Graphs in history, English, biology, civics, and so on reinforce graphing in mathematics. Slope becomes real.
Three 1st graders at Borton telling me a story

A little  Early  Middle  Later  End

Some

A lot
I asked, “What if it looked like this?”
Then I asked, “How about this?”

A lot         Some         A little
Start         Early        Middle        Later         End
Why map for education excellence?

• We are bringing into the modern classroom classic patterns of powerful circular thinking that have existed for centuries.
• We are making feedback thinking accessible to kids (and their parents), and Society needs it!
• We are exposing the mechanisms of growth, stability, and oscillation.
• We are exposing the mechanisms of compensating feedback and policy resistance.
Why map?

- We provide tools to enable people to map complexity and to try to understand it.
- Mapping supports “visual thinking” and stands ready to contribute to other modes of thought.
- Maps enable “assembling complexity”
- …Sometimes a mixed blessing --
Ritenaur High School students address tensions in their school

“Which of these things is not like the other?”
Students participating
Relationships
Tension

[Diagram showing concepts related to tension, such as prevention strategies, coping techniques, and factors increasing or decreasing tension.]
Refined map to tell vivid stories
Why map for education excellence?

• Another great tool for a growing citizen’s intellectual toolkit.
Why model for education excellence?

- Remember our distinctions:
  - Why should learners “exercise” models?
  - Why should learners build models?

- Exercising models means
  - Simulating a given model repeatedly under various circumstances
  - Creating hypotheses, changing parameters, predicting behavior, observing simulated behavior, repeating, ... all with a given model

- Building models means
  - Create a simulatable model following the complete modeling process from conceptualization through equations and parameterization
  - Exercising the model thoroughly and reformulating to improve it.
Why model for education excellence?

• Modeling involves the very essence of the scientific method, repeatedly, over and over...
• Modeling involves hypothesis generation and testing at almost every step:
  - Conceptualization
  - Formulation
  - Simulation
  - Reconceptualization and reformulation

Generating hypotheses

Testing hypotheses
But hypothesis generation and testing is present throughout

- A map contains hypotheses, all of which were tested mentally as the map was created. Some hypotheses were rejected along the way and never made it into the map.

- An equation contains hypotheses, which are tested mentally as the equation is written, and later tested with simulation and reflection.
Why model for education excellence?

• Modeling as the scientific method:
  • Observe dynamics in the real world
  • Tell rich causal stories, to act as hypotheses for real-world structure underlying the observed behavior
  • Build a formal model capturing the hypothesized structure
    • Test each equation for plausibility, robustness and operational thinking as you go
  • The model is a collection of hypotheses. Test the model rigorously, trying to prove it fails.
  • Find structural weaknesses, fix, and repeat until “done”
Three kinds of modeling assignments

- Build a model to fit a “canned” description.
  - At the level of “word problems” in Freshman algebra
- Add structure to an existing model that already runs.
  - Advantage is that the student starts with something that works, but gets to experience modeling as the scientific method, big time! Excellent pedagogy.
- Build a model starting from a blank page.
  - May not be necessary in K-12 education, but some kids will insist on it!
Why model for education excellence?

• Exercising models
  • Essential for all students to grow in understandings the dynamics of systems
  • Builds understandings of the connections between structure and dynamics
  • Grounds system insights

• Building models
  • Probably essential training for students who may head toward STEM-related careers.
  • May not be essential for others.
Why systems thinking and modeling for excellence in education?

• Better thinking at every level, K to 12
• More understanding at every level
• More engagement at every level
• “Learner-directed” learning
• Better preparation for “systems citizenship”
  • *Delays in policy outcomes*: the right things take a long time
  • *Worse-before-better, better before worse*, the long-term is sure to be different from the short-term
  • *Compensating feedback* leading to policy resistance or outright defeat of favorite policies