Using systems thinking to attract more kids (and teachers!) to math and the scientific method

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Systems Thinking and Dynamic Modeling Conference for K-12 Education

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What is the systems lens?

Hint: Structure and behavior

Slinky photo ©istockphoto/difydave

Introduction from Meadows, D. H., & Wright, D. (2008). *Thinking in systems: A primer*. White River Junction, Vt: Chelsea Green Pub.

Agenda

- What is system dynamics?
- Change over time by grade & subject
- K-3 Example
- Potential grade-staging of system dynamics artifacts
- Description of a few of the artifacts
- Using system dynamics to think about drug-related crime
- Modeling Process: Connections to the scientific method
- Barry Richmond's systems thinking skills
- Really important outcomes of practicing systems thinking
- Connections to math
- Next steps

What is System Dynamics?

System dynamics [*systems thinking*] deals with how things change through time, which includes most of what most people find important.

It uses computer simulation [*systems thinking uses mental simulation instead*] to take the knowledge we already have about details in the world around us to show why our social and physical systems behave the way they do.

= 'strategies' = 'decision rules'

System dynamics demonstrates
how most of our own decision-making policies are the cause of the problems that we usually blame on others, and
how to identify policies we can follow to improve our situation.

System dynamics gets a lot of its power from a 'feedback' perspective -- the realization that tough dynamic problems arise in situations with lots of pressures and perceptions that interact to form loops of circular causality, rather than simple one-way causal chains.

See Reference 1 for an interesting article by Jay Forrester, entitled "Learning Through System Dynamics as Preparation for the 21st Century."

(above from 1997 system dynamics email list postings by Jay W. Forrester and George Richardson)

Change through time examples by age & subject (except math & science)

	Age Group			
Subject	Plant system K-3	4-6	7-9	10-12
Personal Life	Messy room – happy mom			
News				
Literature				
History				
Civics			Drug-related crime	
Economics				
Health & PE	Tired at bedtime – hours of sleep			

Using system dynamics to attract more kids (and teachers!) to math and the scientific method

A grades K-3 example from Nancy Roberts[2]

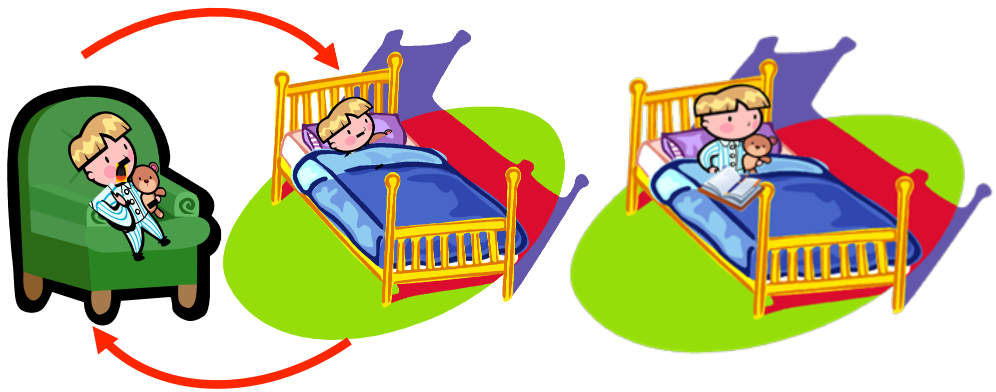
Integrating Model-Building Concepts in the Primary Grades Curriculum

"Using as a guide the Report of the National Council for the Social Studies Task Force on Scope and Sequence (*Social Education* 1984), the subject matter recommended for the primary grades focuses on the home, family, and local community. <u>Three key system dynamics concepts may be introduced at the primary grade level</u> in conjunction with these topics:

1. <u>*Causation and Feedback*</u> – a change in one element in a system will cause a change in another, eventually affecting the original element again

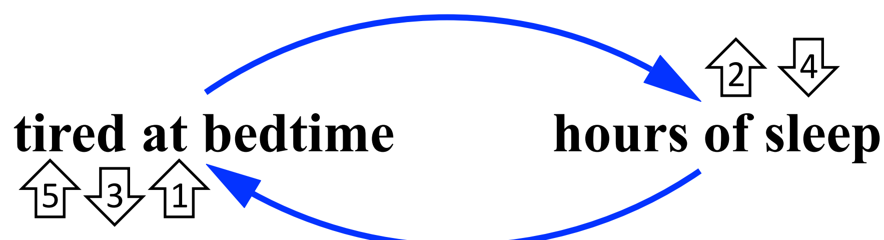
2. <u>*Change*</u> – focusing on behavior as it changes over time

3. <u>*System*</u> – encouraging the student to understand how all the parts of a system fit together (synthesis-level thinking). This way of thinking is quite natural for younger students but seems to disappear from the curriculum in the upper grades."



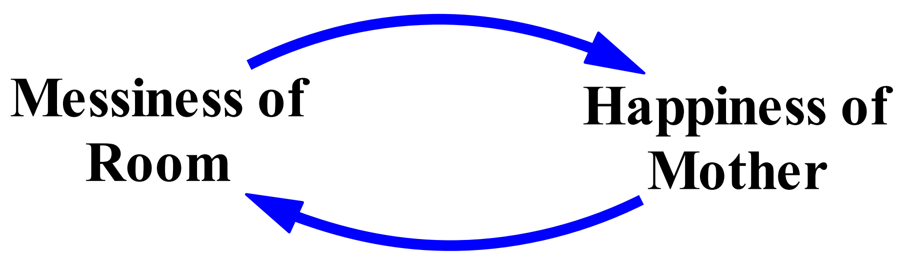
"Using these two pictures, a teacher can begin generating a "circle" story, such as:

Being tired at bedtime causes you to sleep. When you've had a good night's sleep, and you go to bed the next night, you probably feel less tired, *causing* you to stay up late and play. Staying up late playing will probably cause you to get less sleep and be tired again the next night at bedtime.

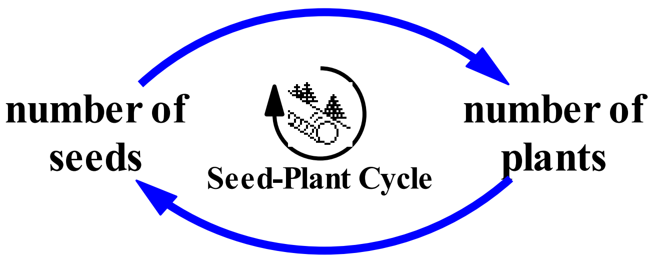


A second K-3 example from Nancy Roberts[2]

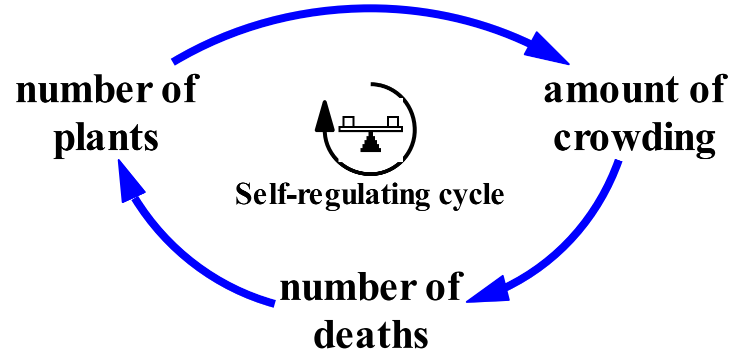
This series of pictures suggests that when a child leaves a room messy, it might cause the child's mother to be angry. An angry mother might cause the child to straighten up his or her room. When the mother notices the clean room, it might cause her to be happy and relaxed, perhaps causing the child, the next time at play, to forget and leave the room somewhat messy again.



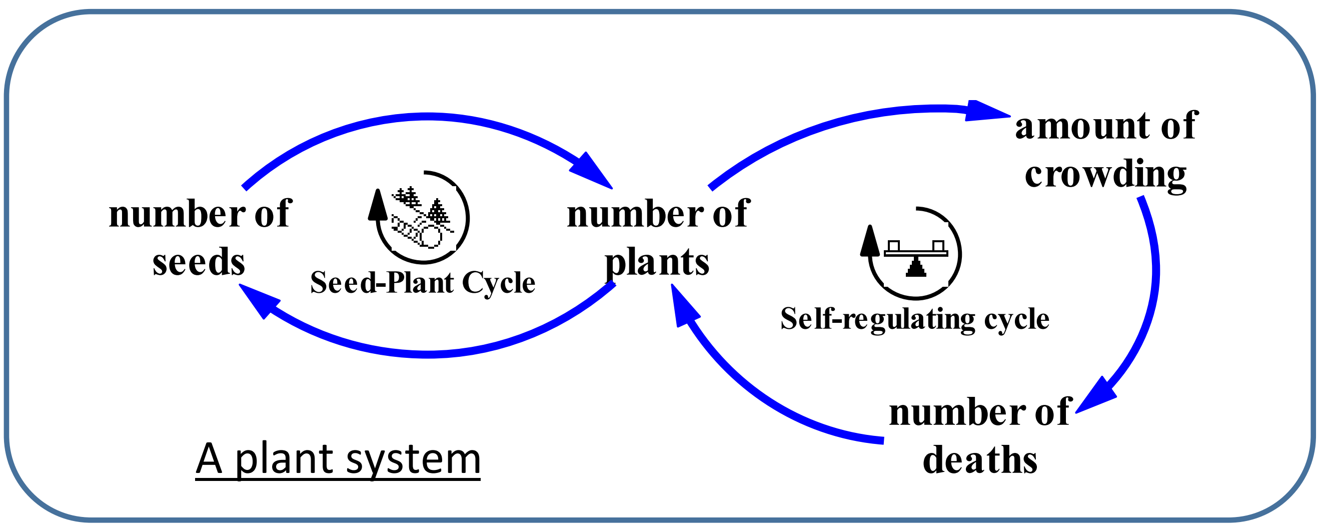
A third K-3 Example from Nancy Roberts[2]



<u>Seed-plant cycle</u>: The more seeds there are, the more plants there will be, producing even more seeds and plants.



<u>Self-regulating cycle</u>: The more plants there are, the more crowded they are, causing an increase in the number of deaths, eventually resulting in fewer plants and less crowding.



An educated guess for grade-staging of a few systems thinking concepts & artifacts*

K-3 4-6 7-9 10-12

Causation & feedback, change & system via simple causal loop diagrams (SCLDs)

Playing physical group games that introduce system concepts (Group Games)

Drawing simple stock and flow diagrams (SFDs)

Using simple pre-built simple simulation models & games (SIM Games)

Graphing simple behaviors-over-time (BOTGs)

Adding link & loop polarities to make complete CLDs

Building simple no-feedback simulation models (NFSIMs)

Building simple feedback SIMs (SFSIMs)

Completion of 1st Year Algebra

Building feedback SIMs (FSIMs)

* Based on curriculum units at http://clexchange.org/ & http://watersfoundation.org/

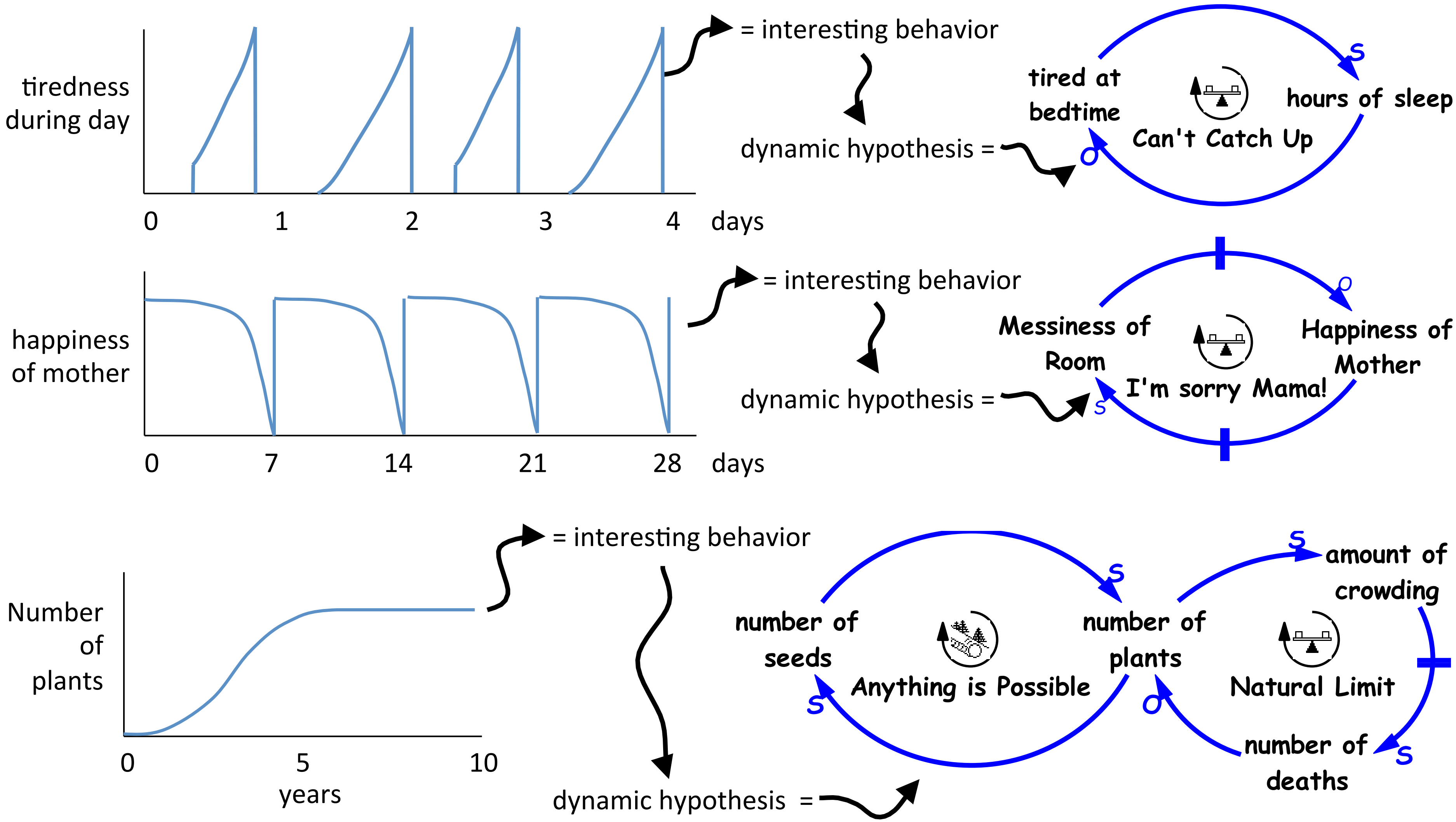
"It is amazing how far one can get in this world using a little first year algebra along with computer simulation!"

Paul Newton

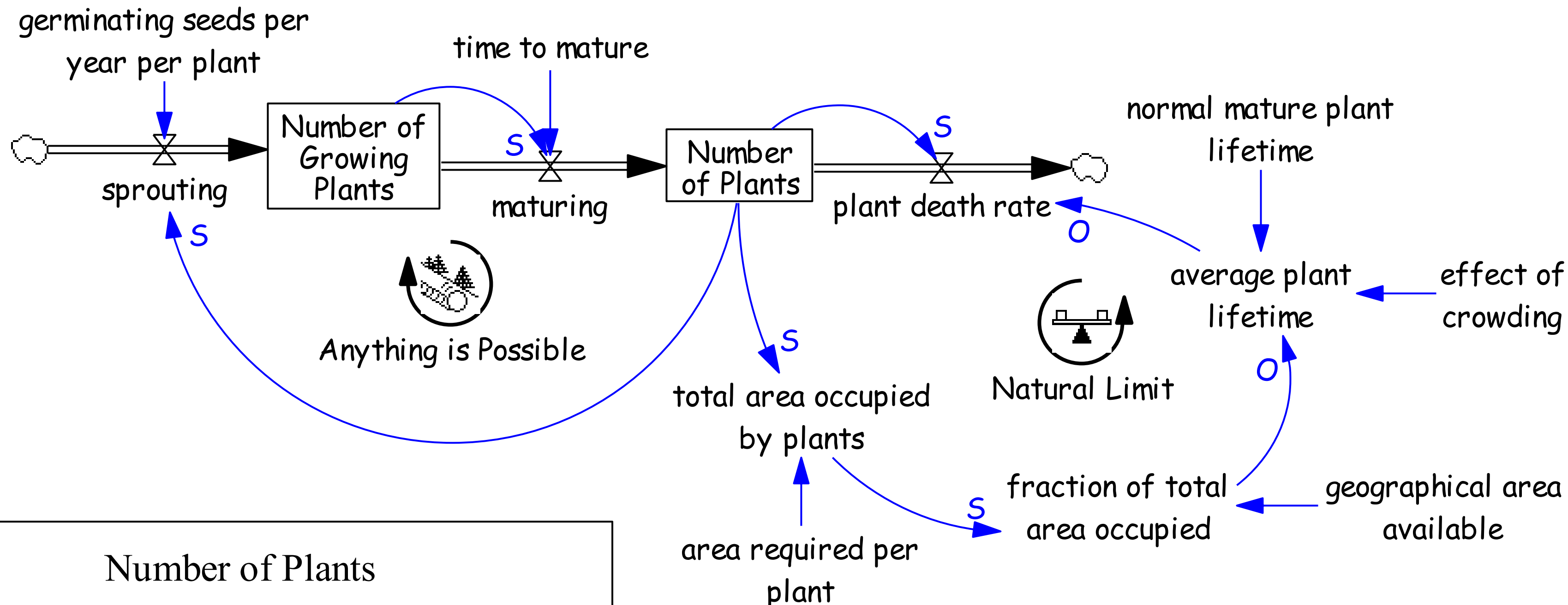
4 systems thinking artifacts we illustrate

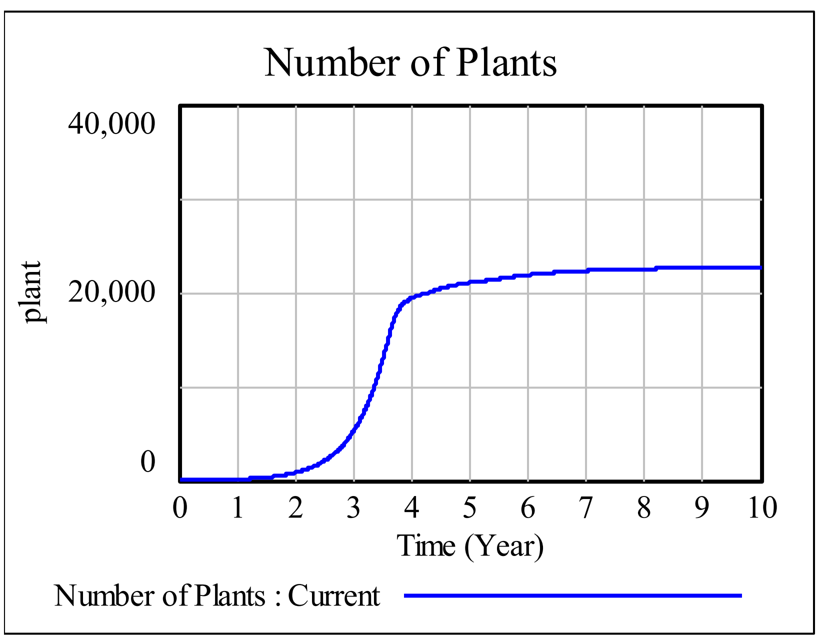
- BOTG (Behavior-over-time graph)
- CLD (Causal loop diagram)
- SFD (Stock-flow diagram)
- SIM (Simulation)

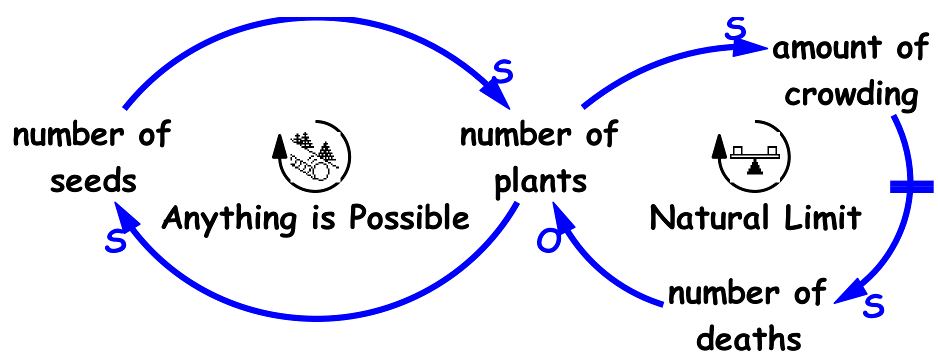
Systems Thinking Artifacts: BOTGs & CLDs



Systems Thinking Artifacts: SFD & SIM

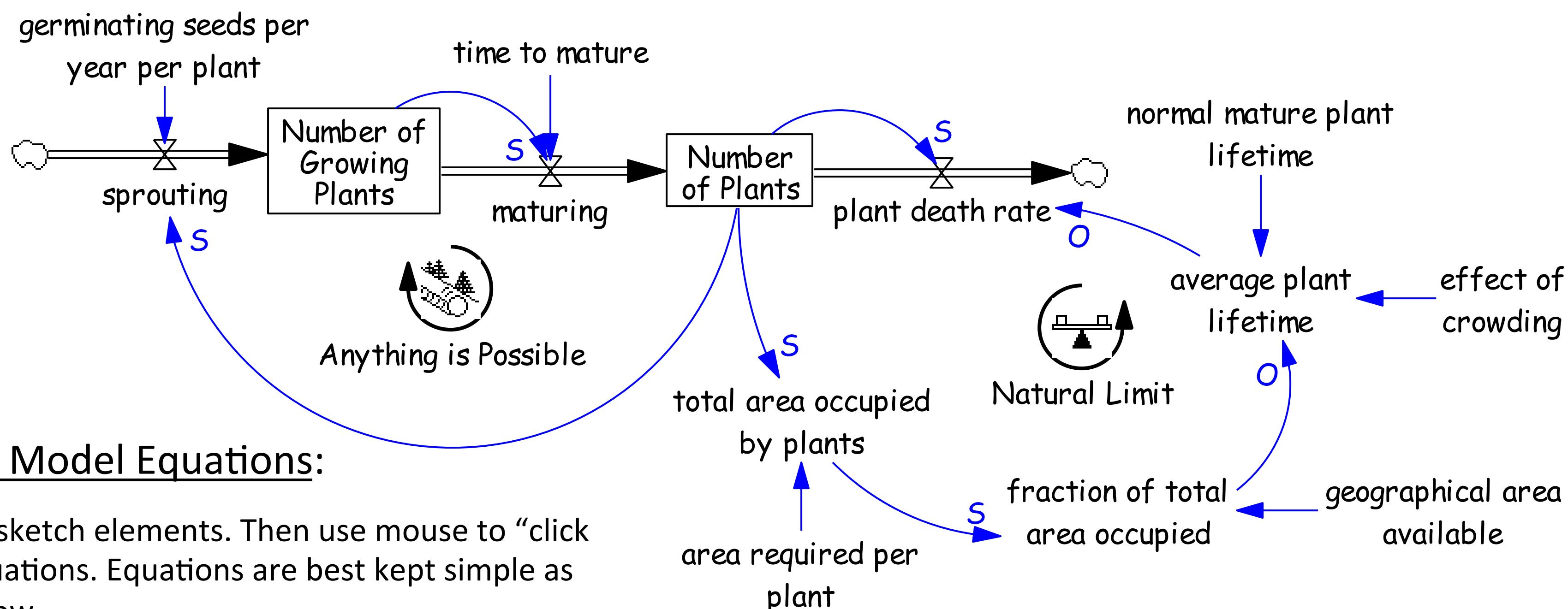






20100801b_AddDeathRate_SimOfFigure5pt9APlantSystem.mdl

Systems Thinking Artifacts: SIM cont'd



Creating Model Equations:

First draw sketch elements. Then use mouse to "click in" the equations. Equations are best kept simple as shown below…

Number of Plants = INTEG (maturing - plant death rate , initial number of plants)
Units: plant

"INTEG" equations are created automatically by the software from your drawing. You do not write them.

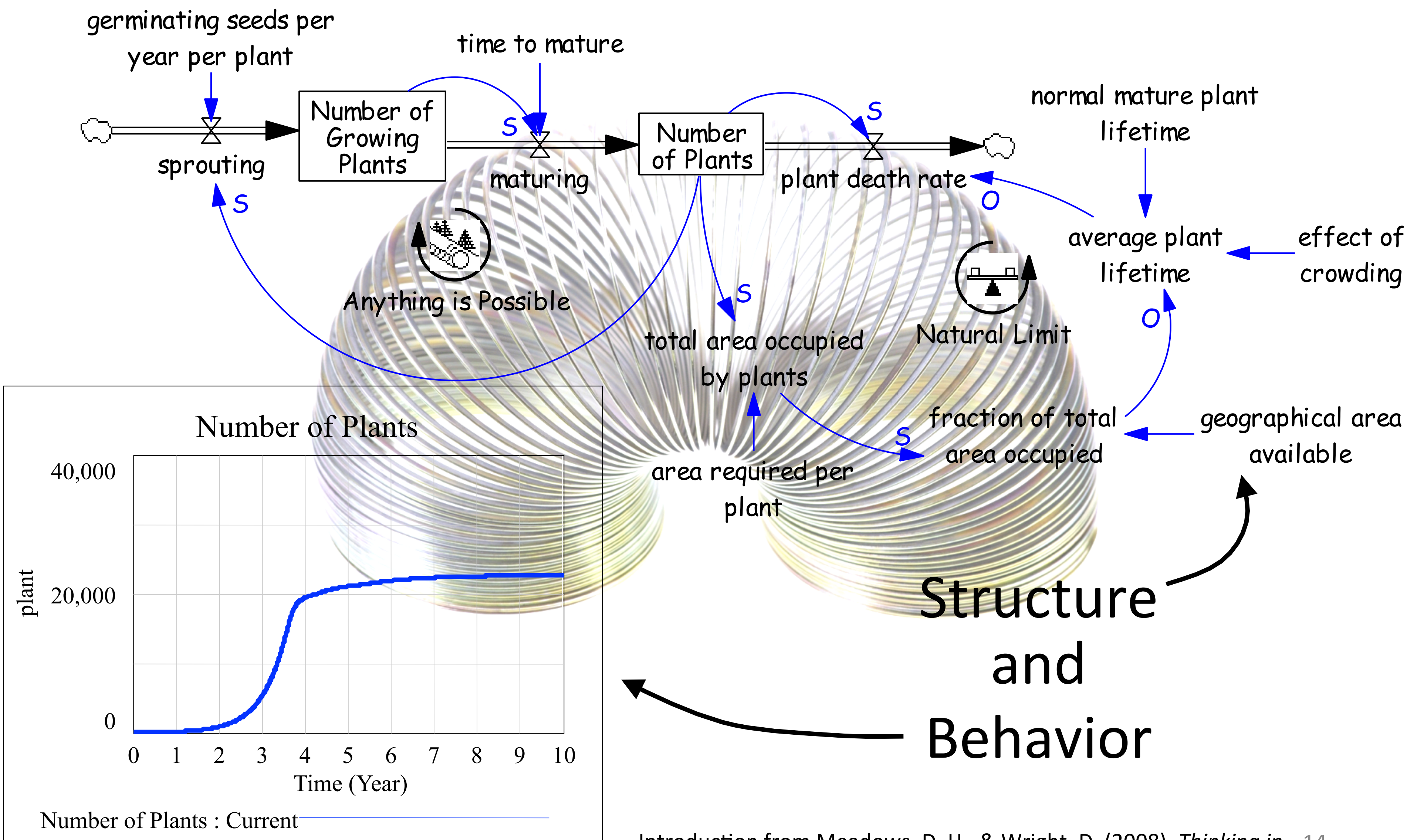
total area occupied by plants = Number of Plants * area required per plant
Units: feet * feet

Sprouting = Number of Plants * germinating seeds per year per plant
Units: plant / Year

This section of the equation is like "f(x)" where the function "f" is "effect of crowding." Although "effect of crowding" is a function, you don't have to write an equation; instead you just "click in" the function shape you want!

average plant lifetime = normal mature plant lifetime * effect of crowding (fraction of total area occupied)
Units: Year

What is the systems lens?

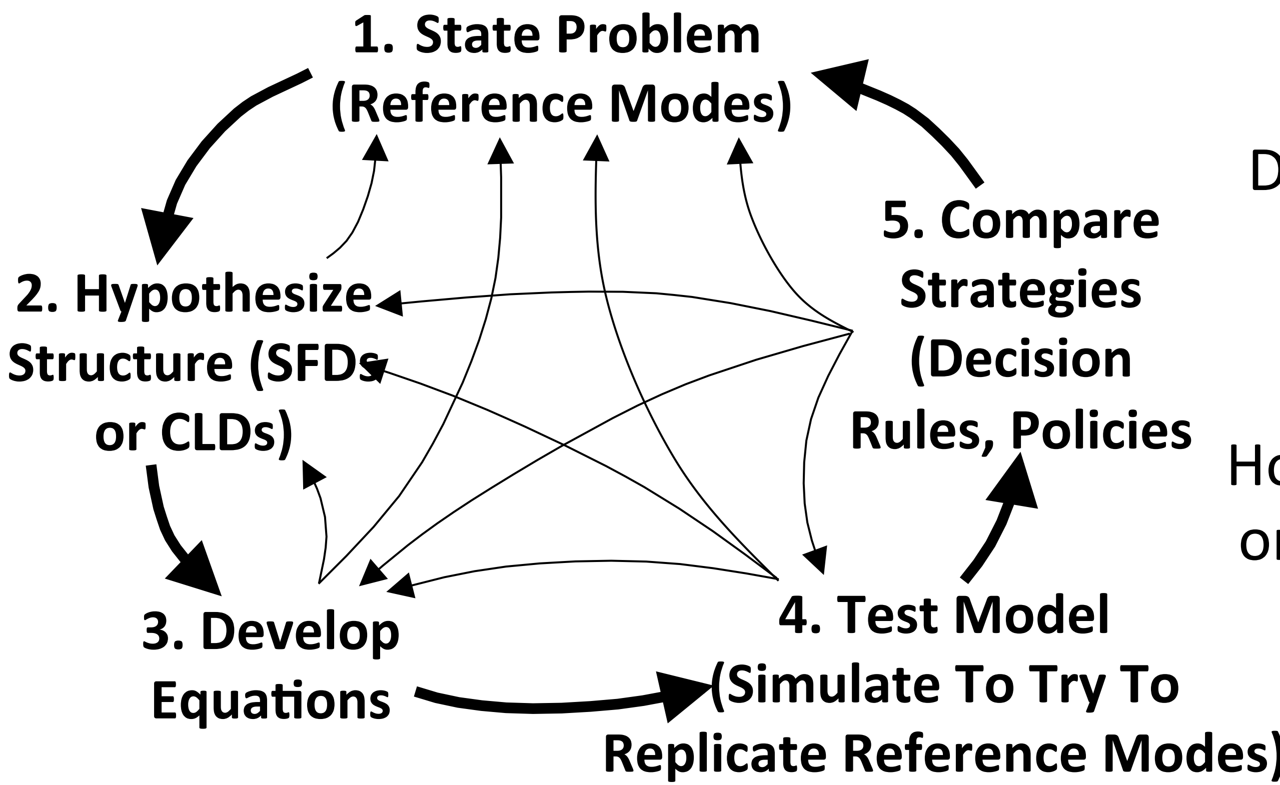


Slinky photo ©istockphoto/difydave

Introduction from Meadows, D. H., & Wright, D. (2008). *Thinking in systems: A primer*. White River Junction, Vt: Chelsea Green Pub.

System dynamics' iterative modeling process

Connections to the Scientific Method



Does this look familiar?

How would you compare or contrast this with the scientific method?

Results of any step can yield insights that lead to revisions in any earlier step (indicated by the links in the center of the diagram).

Using systems thinking to attract more kids (and teachers!) to math and the scientific method!

From Chapter 3, pages 83 – 105 in Sterman, John (2000) Business Dynamics: Systems Thinking and Modeling for a Complex World. Irwin McGraw-Hill

The Modeling Process
"Systems Thinking" vs. "System Dynamics"

perspective and a *set of conceptual tools*

1) Problem articulation
   - Theme selection
   - Key variables
   - **Time horizon**
   - Dynamic problem definition (**reference modes**)
2) Formulation of dynamic hypothesis
   - Initial hypothesis generation
   - **Endogenous focus**
   - **Mapping (CLDs, SFDs, HDs)**
3) Formulation of a simulation model
   - Specification
   - Estimation
   - Tests
4) Testing
   - **Comparison to reference modes**
   - Robustness under extreme conditions
   - Sensitivity
   - Many other tests… (see chap 21)
5) Policy design and evaluation
   - Scenario specification
   - Policy design
   - "What if…" analysis.
   - Sensitivity analysis
   - Interactions of policies

rigorous modeling method

Systems Thinking
- Everyone agrees that "systems thinking" includes these.
- Some people say system thinking encompasses these too, Policy design is best with the aid of simulation, but, in the absence of simulation, is certainly better with the feedback-rich systems thinking view than without.

[Chapter 3 of Sterman (2000)]

Systems thinking & dynamic modeling of a social problem: Drug-related Crime

"Drugs are a big worry for me, not least because of the crimes that people commit to fund their dependency. We want the police to bust these rings and destroy the drugs. They say they're doing it and they keep showing us sacks of cocaine that they've seized, but the crime problem seems to be getting worse".

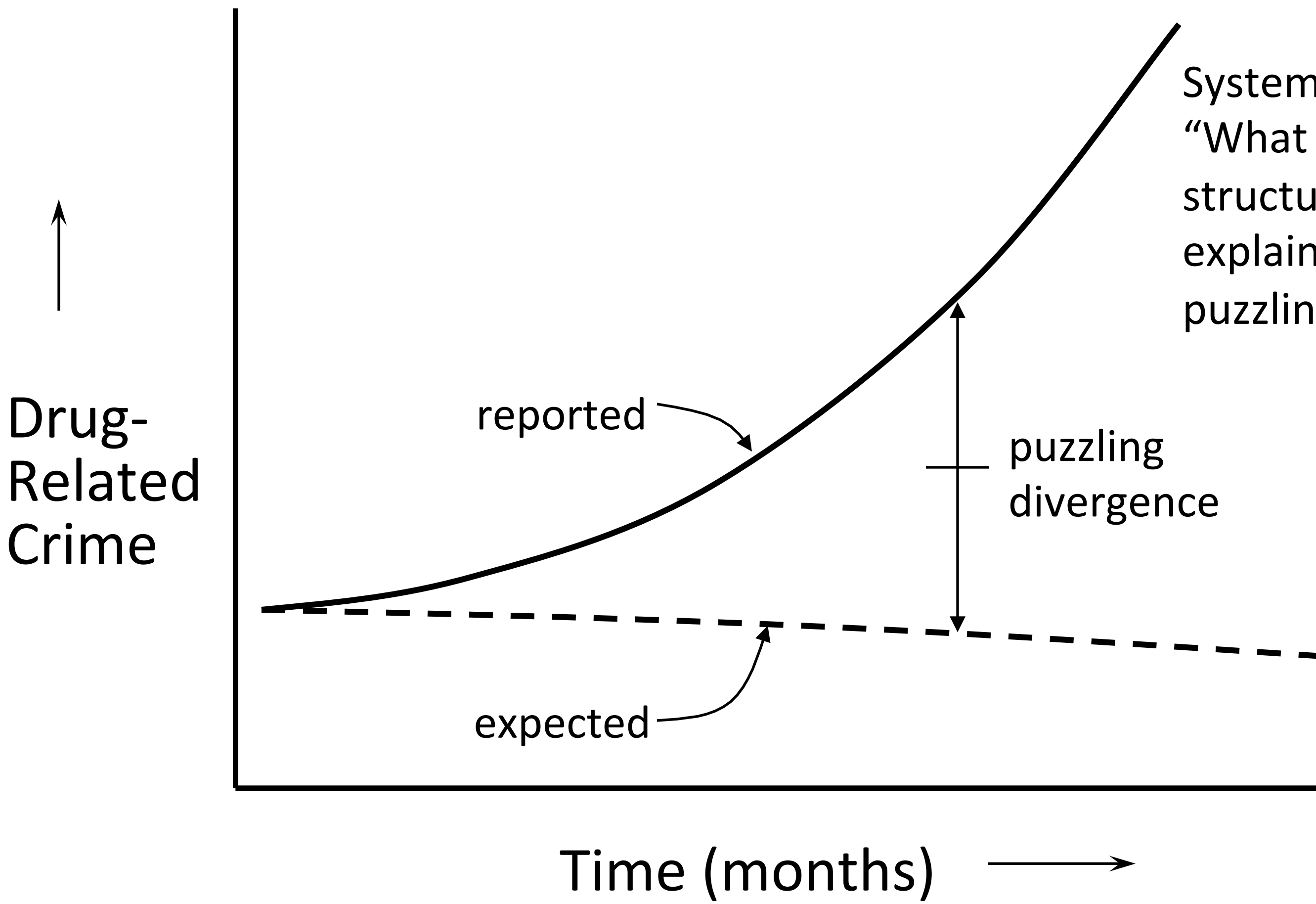
Typical description of the problem
by the victims of drug-related crime

Our hunch is that using systems thinking and dynamic modeling on such problems as this will attract more students and teachers to mathematics and the scientific method.

[page 46 of Morecroft, John (2007) Strategic Modelling and Business Dynamics. Wiley]

Unintended Dynamics of Drug-Related Crime

Graph the behavior-over-time described on the previous slide…

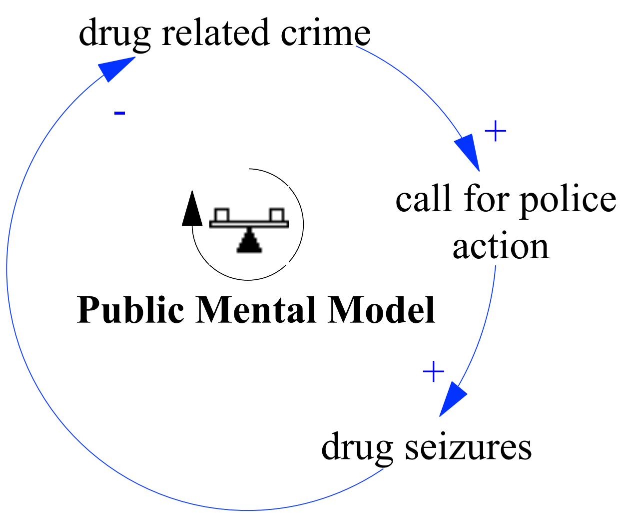


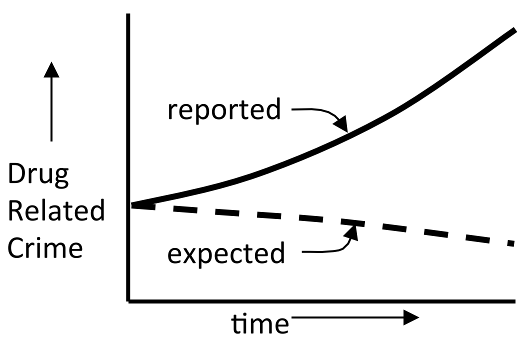
Systems thinkers ask: “What feedback structure could explain this puzzling divergence?”

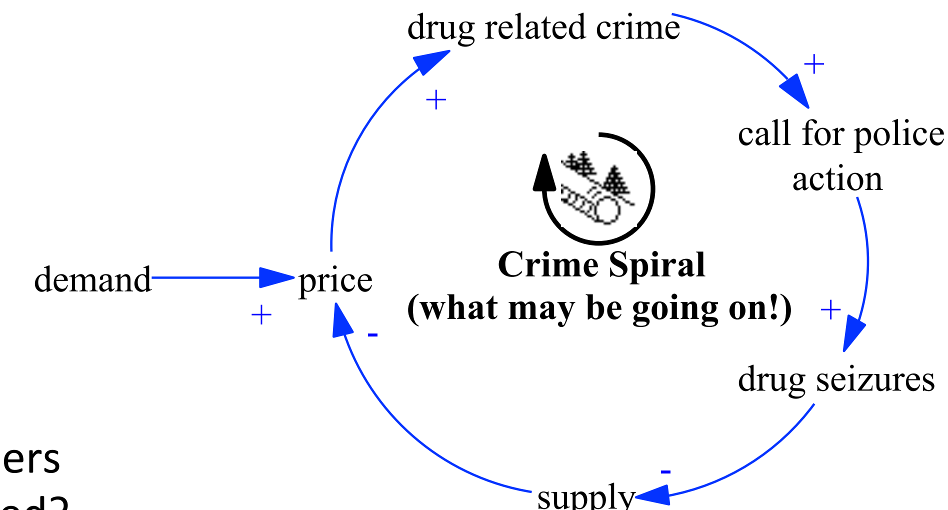
[Morecroft (2007) p 47, Fig 2.10]

Causal Loop Diagram (CLD) for Drug-Related Crime

"What feedback structure could explain this puzzling divergence between reported crime and expected crime? Systems thinkers would say that the persistence of unwanted growth in crime suggests a feedback loop that weaves its way around society, and by doing so it goes unnoticed."







Stakeholders <u>represented?</u>

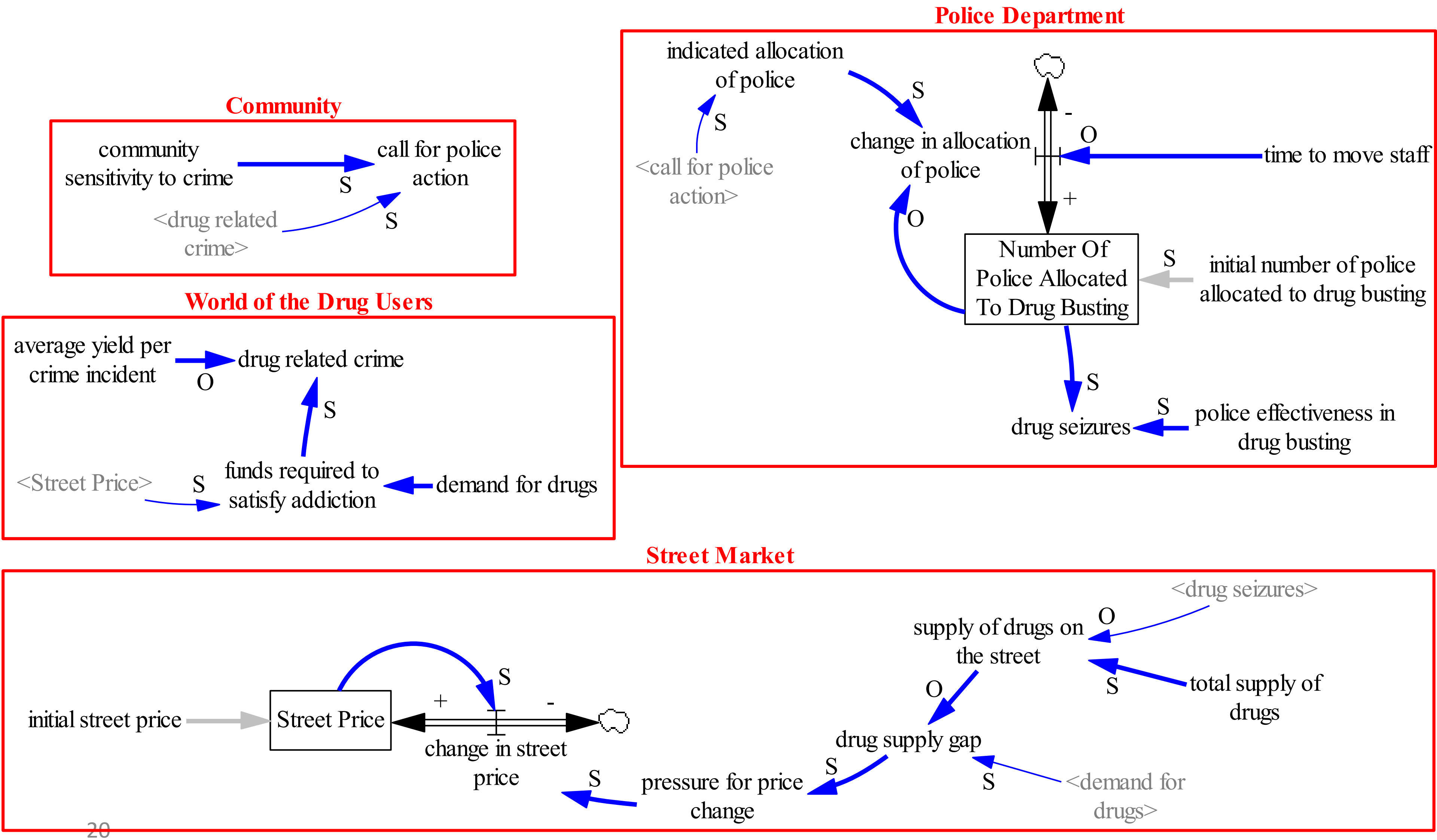
- Community
- Police
- Drug users
- Drug dealers

<u>Systems Thinking</u>

- a 'shift of mind' from 'event-oriented' to 'feedback systems' thinking
- expanded thinking boundaries
- tells 'the rest of the story'

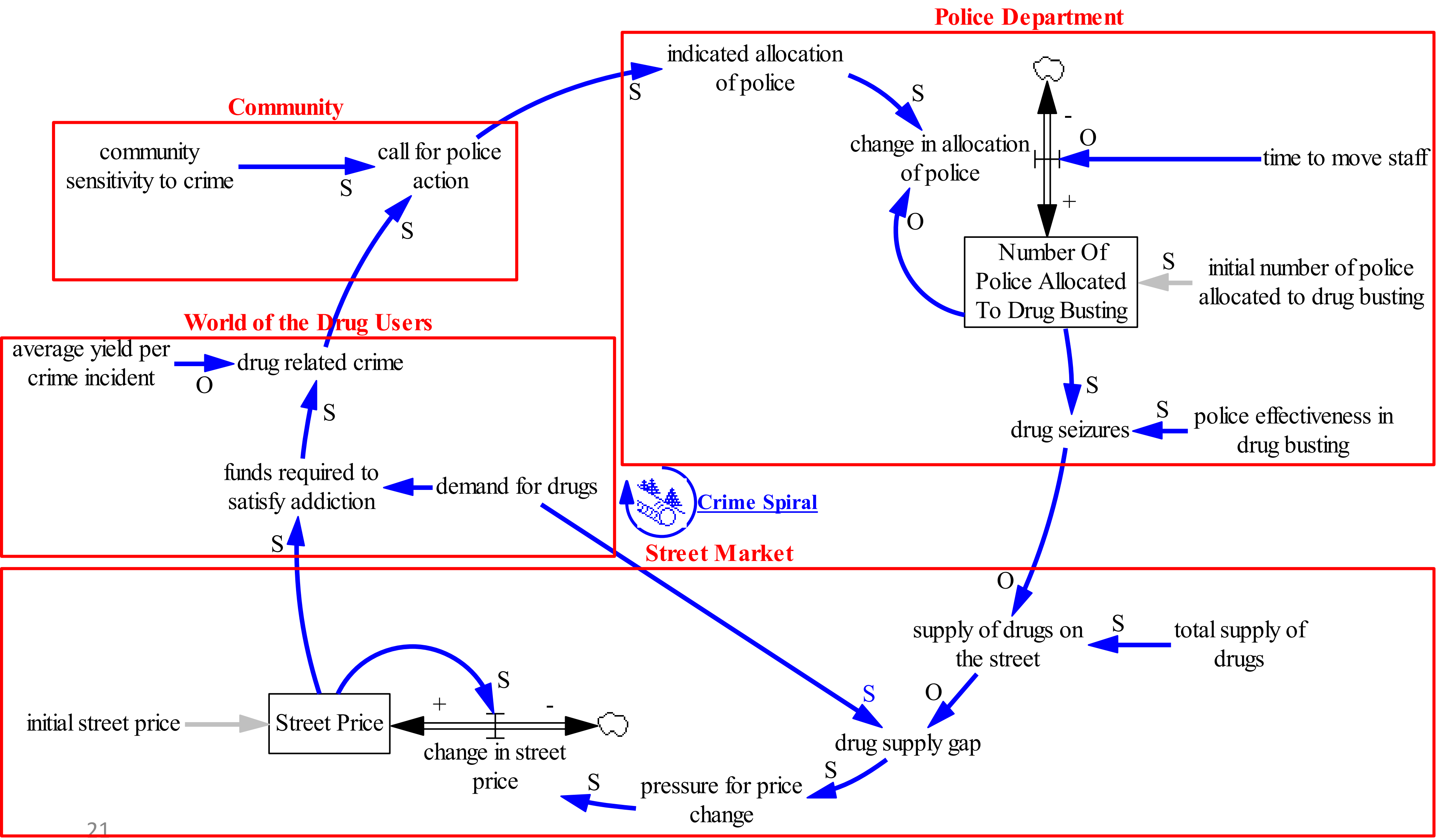
[Morecroft (2007) p 47-48]

Individual Stakeholder Views



20120317a_DrugRelatedCrimeReplication.mdl

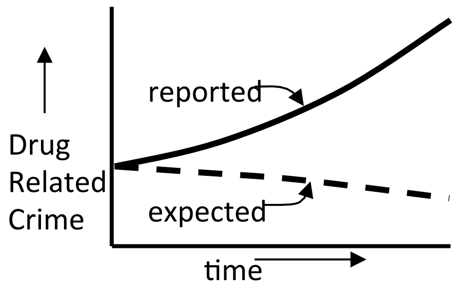
Feedback loop that wends its way around society, and by so doing, goes unnoticed!



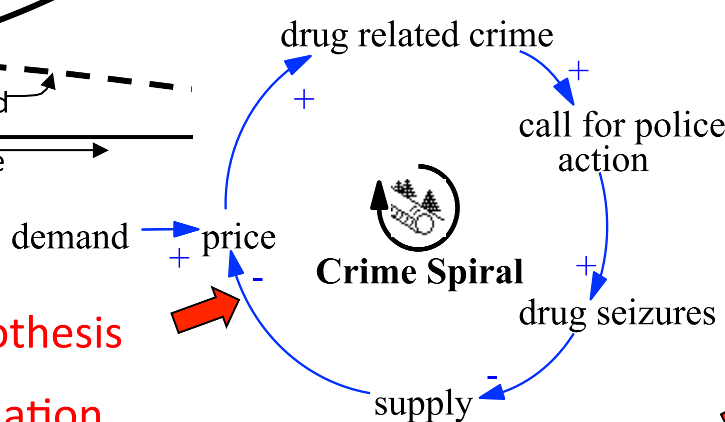
20120317a_DrugRelatedCrimeReplication.mdl

SD Process with BOTG, CLD, SFD & Sim Tools

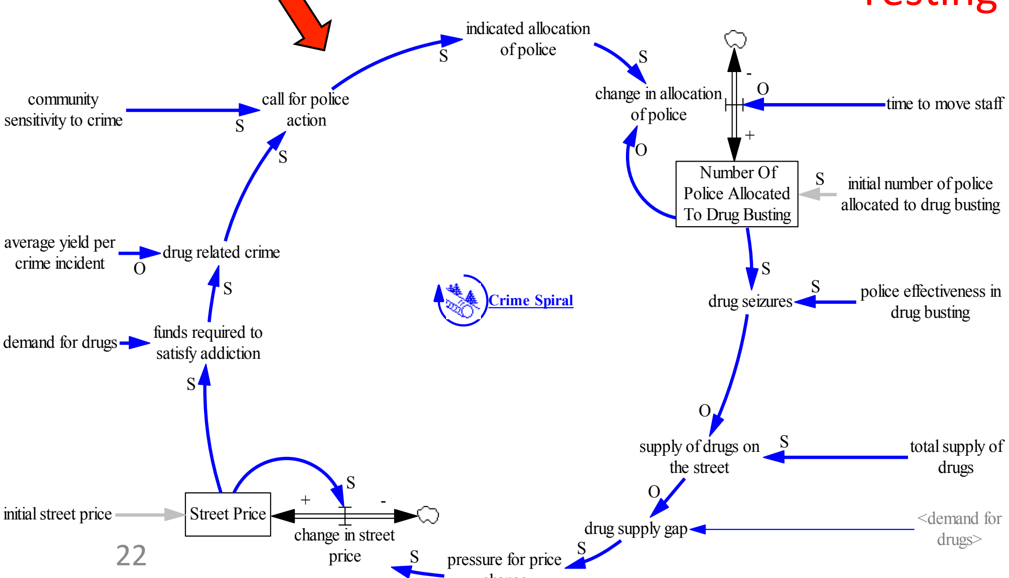
1) Problem Articulation
Reference Modes



Dynamic Hypothesis



Model Formulation



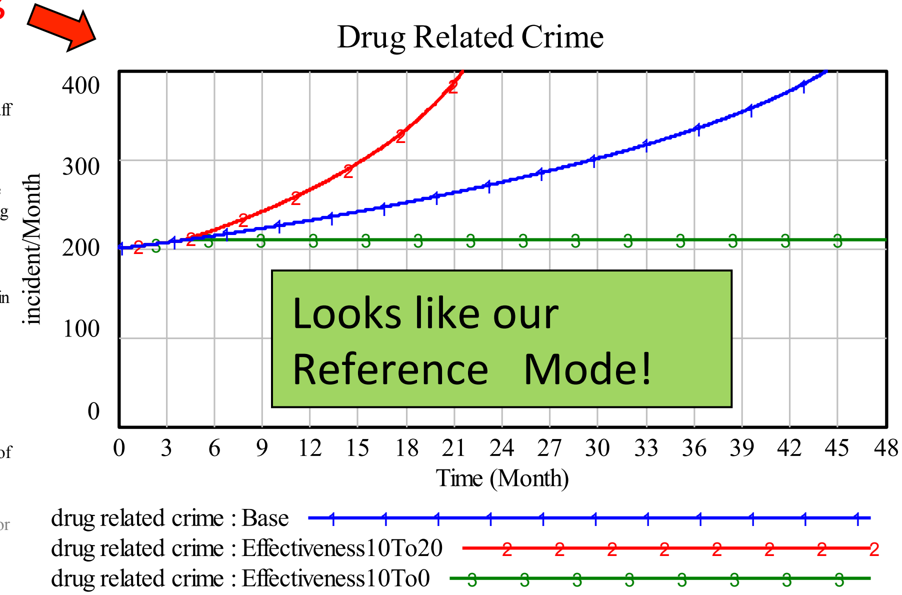
20120317a_DrugRelatedCrimeReplication.mdl

Testing

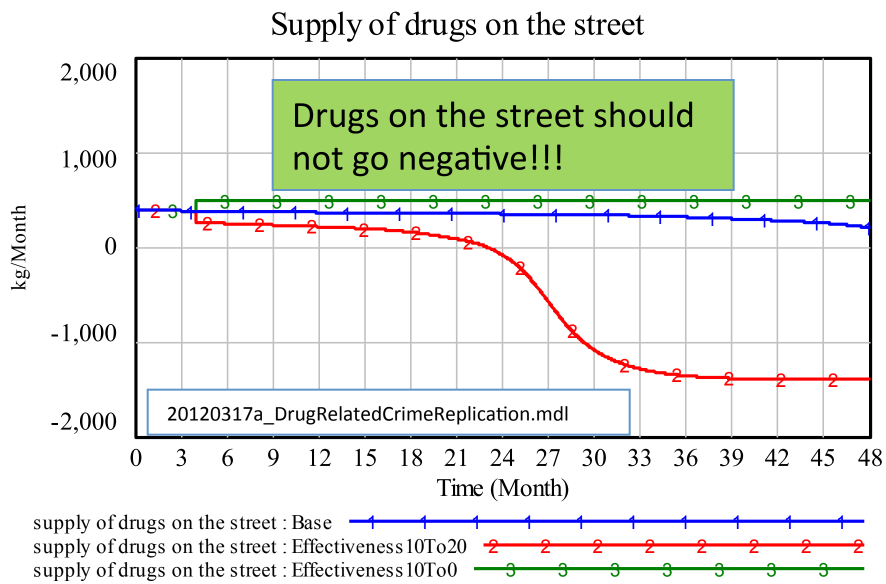
Parameter settings for the three simulation runs

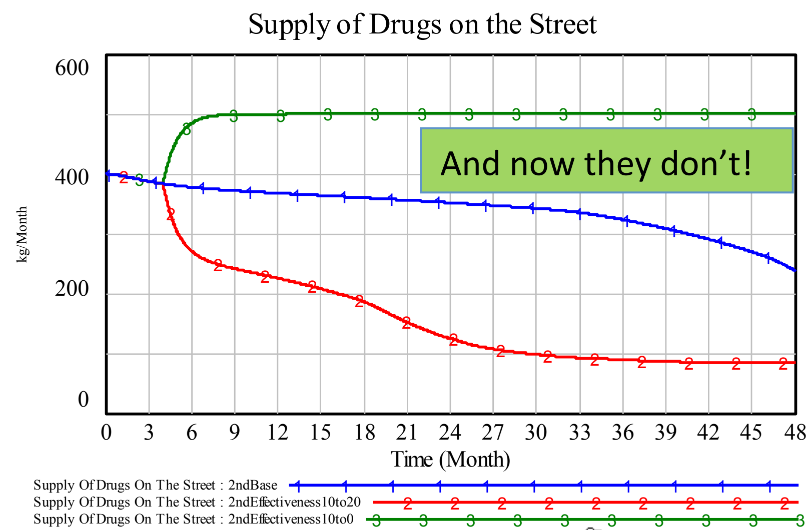
Parameter: "police effectiveness in drug busting"

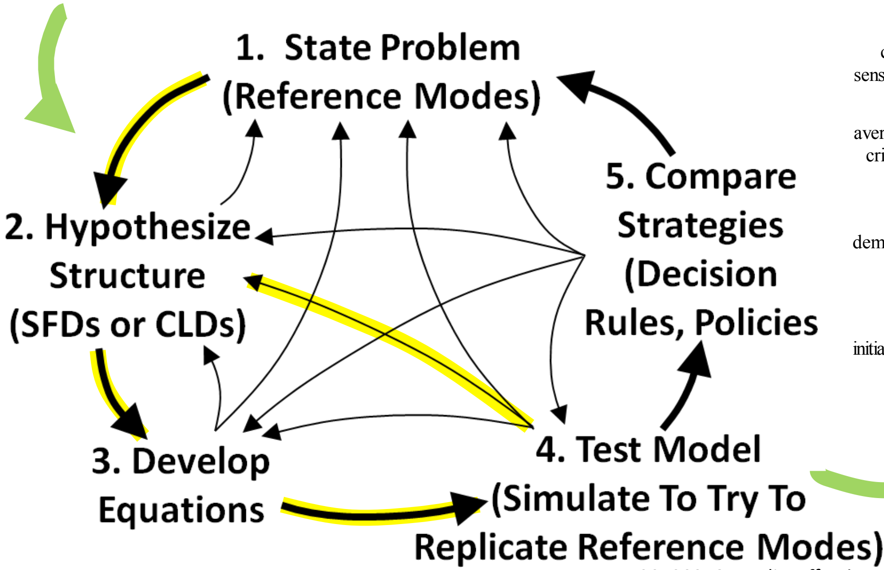
Simulation Run Name	Value (stepped at 4 months)
Effectiveness10To20	10 to 20 kg/officer per month
Base	10 kg/officer per month (no step)
Effectiveness10To0	10 to 0 kg/officer per month

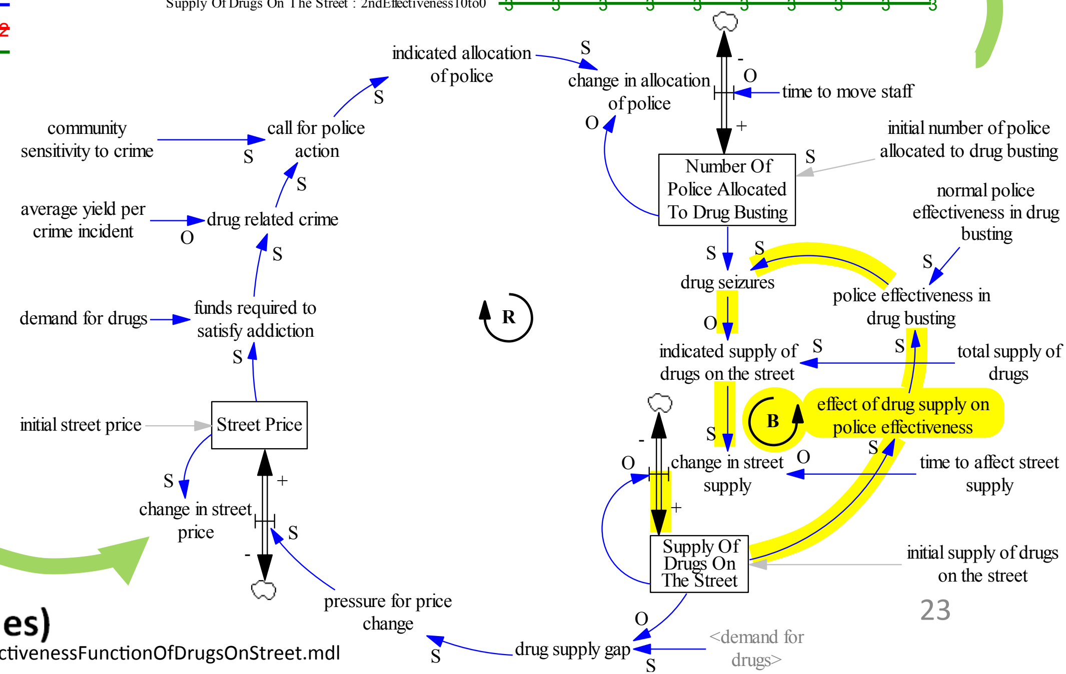


Behavior on previous slide is like our reference mode…but there's a problem…



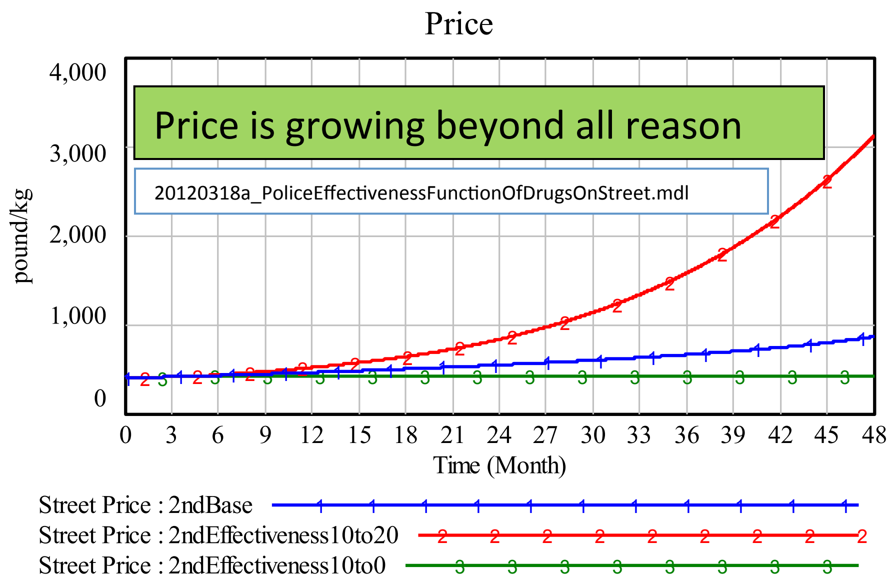


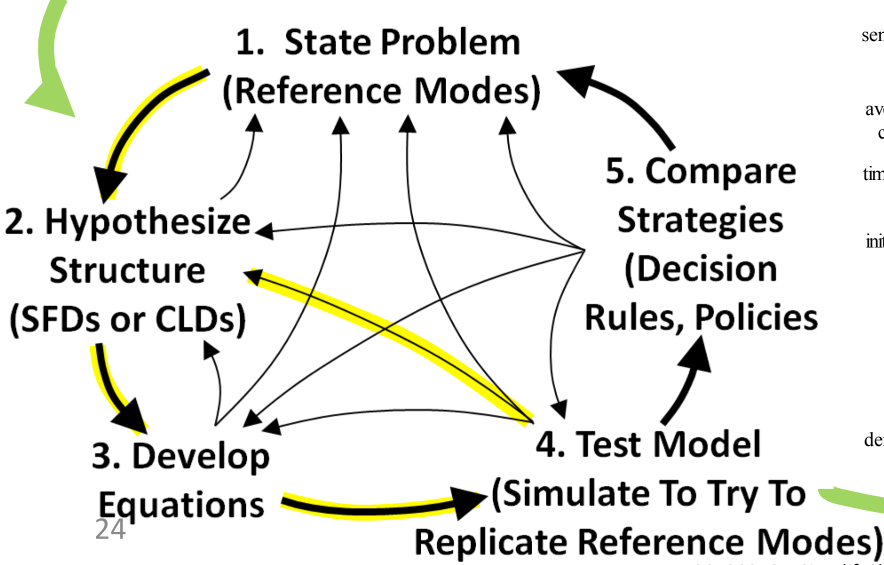


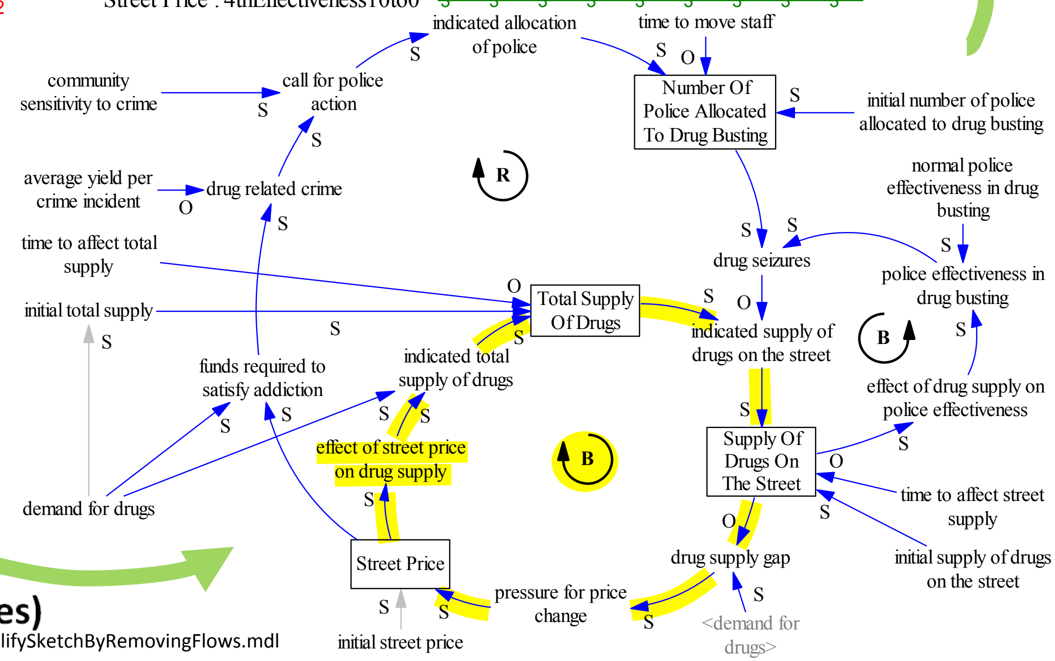


20120318a_PoliceEffectivenessFunctionOfDrugsOnStreet.mdl

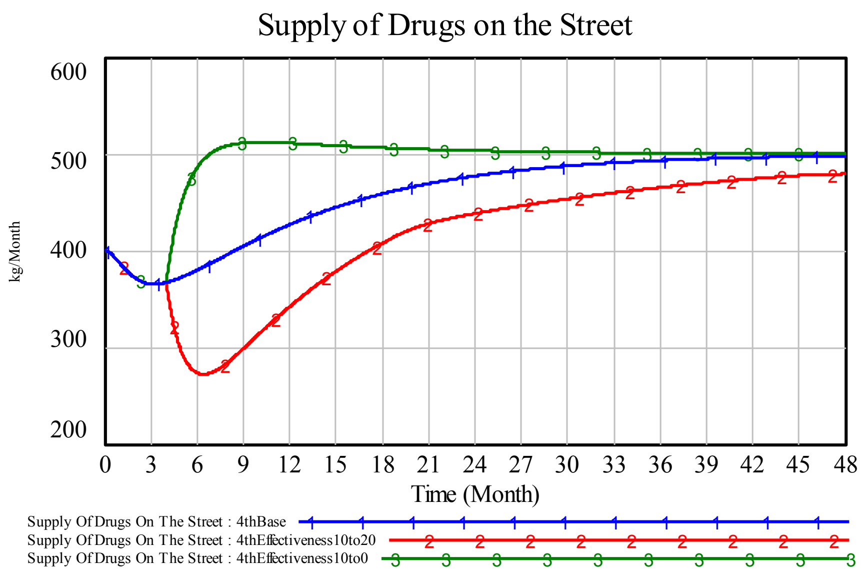
Continuing to use the Model to Improve Our Thinking

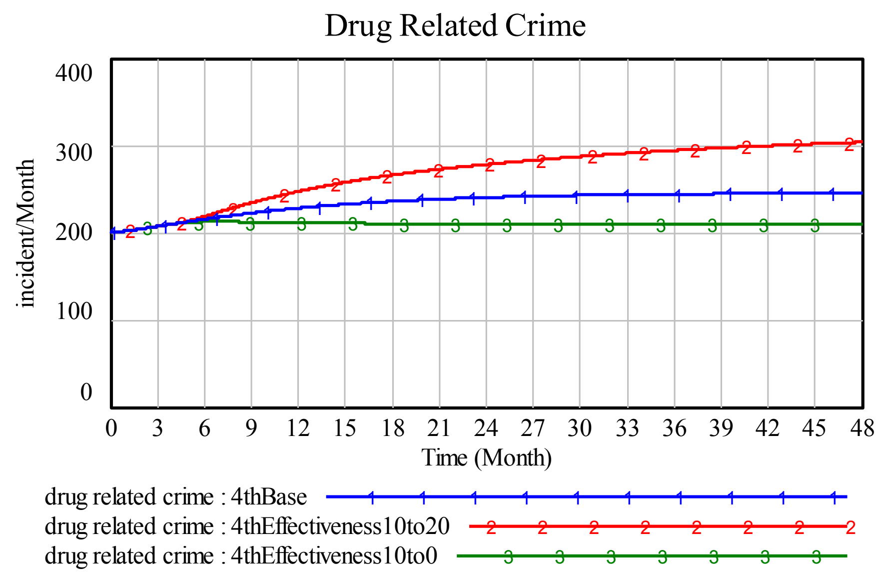


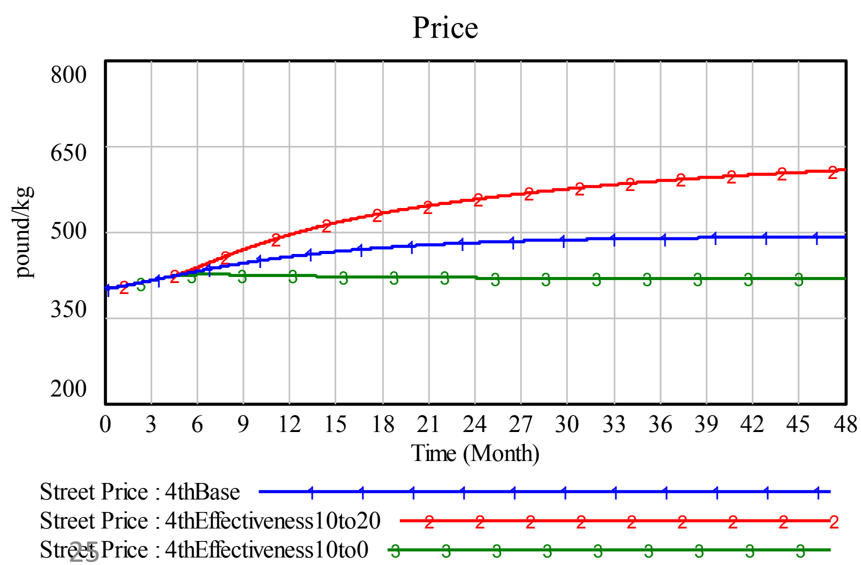


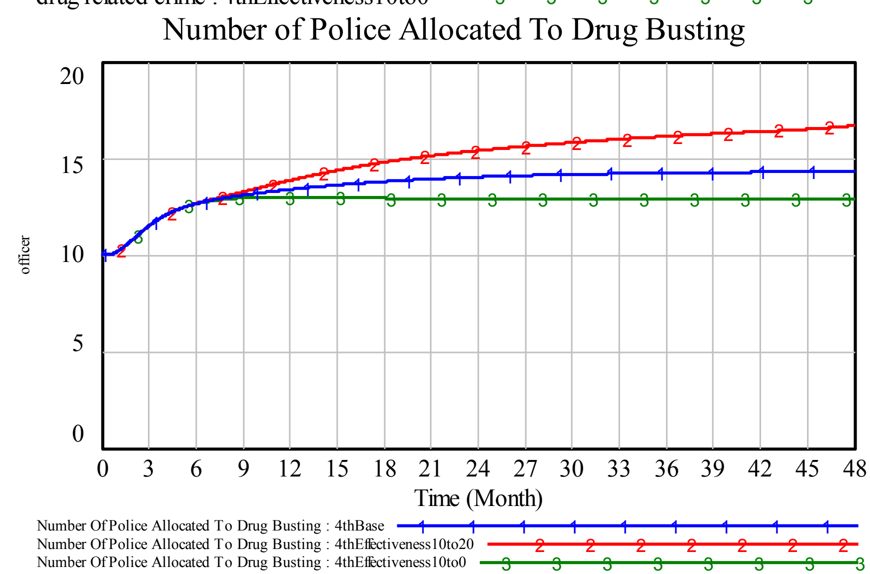


Final Model Simulation Behavior





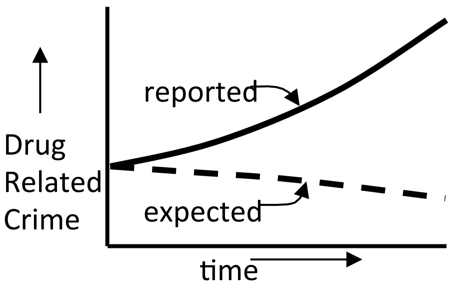


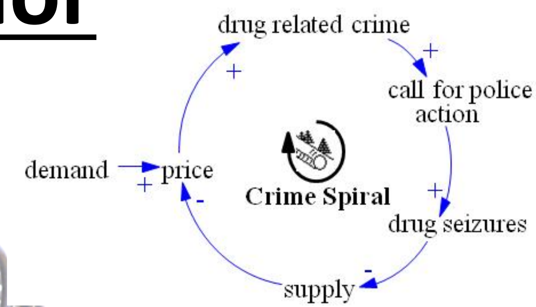


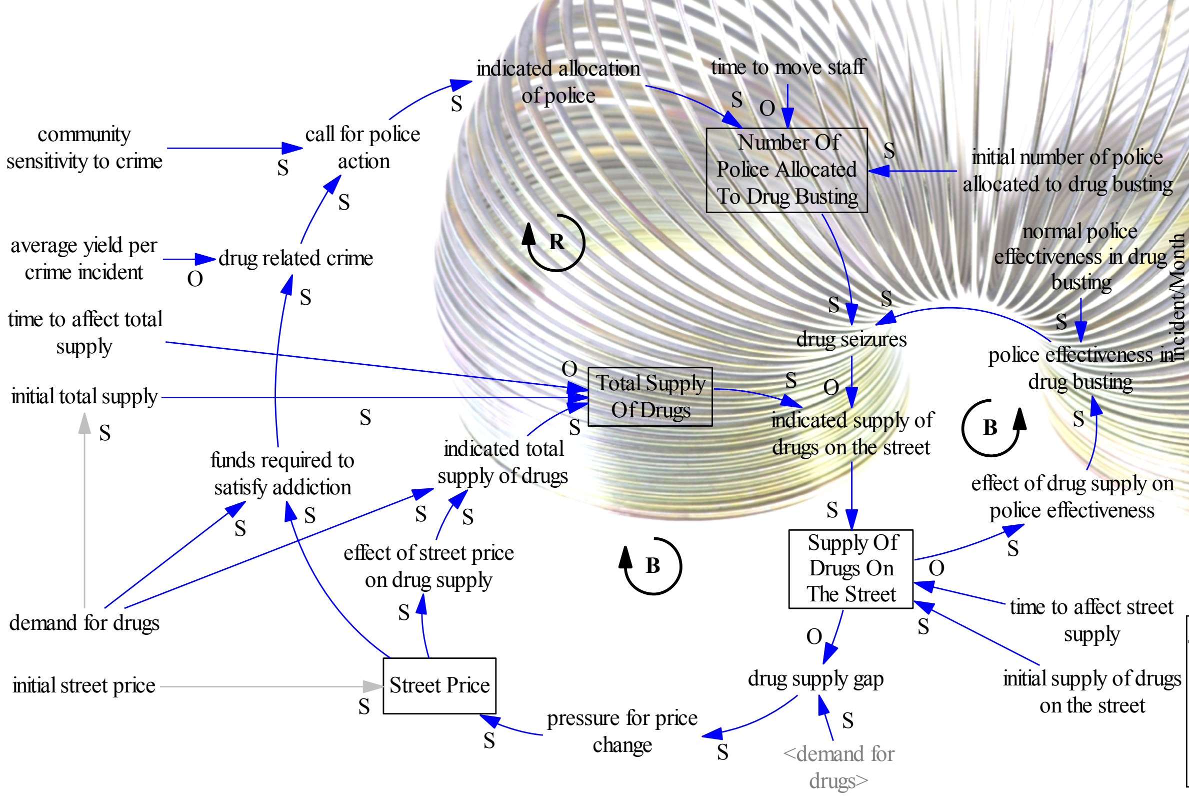
20120318c_SimplifySketchByRemovingFlows.mdl

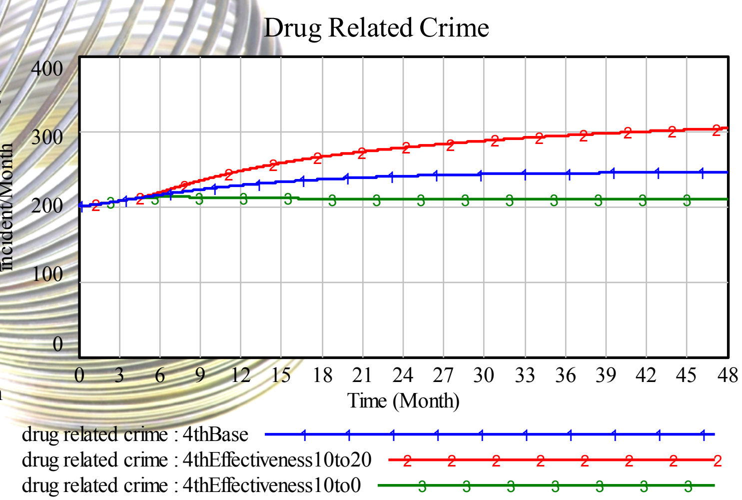
What is the Systems Lens?

Structure & Behavior









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Systems Thinking Skills

- 10,000 meter thinking[1]
- System as cause thinking[1]
- Dynamic thinking[1,2]
- Operational thinking[1,2]
- Closed-loop thinking[1,2]
- Non-linear thinking[1]
- Scientific thinking[1,2]
- Empathic thinking[1]
- Continuum thinking[2]
- Generic thinking[2]
- Structural thinking[2]
- Quantitative Thinking[3]

1) Richmond, Barry (2001) Systems Thinking and the Stella Software: Thinking, Communicating, Learning, and Acting More Effectively in the New Millenium, Chapter 1 in Richmond, Barry (2001) An Introduction to Systems Thinking. http://www.iseesystems.com/resources/Articles/STELLA%20IST%20-%20Chapter%201.pdf
2) Richmond, Barry (1993) Systems thinking: critical thinking skills for the 1990s and beyond. System Dynamics Review Vol. 9 No 2. (Summer 1993) 113-133. http://clexchange.org/ftp/documents/whyk12sd/Y_1993-05STCriticalThinking.pdf
3) Richmond, Barry (2002) In Search of a Clear Picture for Unifying our Community of Practice. Creative Learning Exchange's 2002 Systems Thinking and Dynamic Modeling Conference in Durham, NH. http://www.clexchange.org/ftp/conference/cle_2002/Richmond%20keynote.pdf

What distinguishes/defines Systems Thinking is a unique collection of thinking skills[4]

10,000 Meters Thinking System as Cause Thinking Dynamic Thinking	Filtering Skills (what to include, what to omit; and at what level of aggregation?)
Operational Thinking Closed-loop Thinking Continuum Thinking Nonlinear Thinking	Representing Skills (stocks, flows, converters, feedback loops)
Quantitative Thinking Scientific Thinking	Simulating Skills (internally-consistent numbers; controlled experiments)

4) This slide copied from Richmond, Barry (2002) In Search of a Clear Picture for Unifying our Community of Practice. Creative Learning Exchange's 2002 Systems Thinking and Dynamic Modeling Conference in Durham, NH. http://www.clexchange.org/ftp/conference/cle_2002/Richmond%20keynote.pdf

The REALLY IMPORTANT outcomes of practicing systems thinking

from

http://watersfoundation.org/

Systems thinking connections to math

Mathematical Thinking[12]

- Change over time
- Causation
- Continuous vs. discrete time
- Integration & differentiation
- Layers of causation (loops as well as links)
- Aggregation
- Problem formulation: setting time & space boundaries
- Modeling

Math content & techniques[12]

- Graphing over time
- Better solve word problems
- Making algebra concrete
- Causation vs. correlation
- Importance of units
- Notion of a limit
- Functions
- Numerical integration
- Nonlinear relationships
- Exponential growth & decay
- Sigmoidal growth
- Oscillations

Using systems thinking to attract more kids (and teachers!) to math and the scientific method

Next Steps

- Does it now seem to you that there might be potential for systems thinking to attract more students (& teachers) to math and the scientific method?
  - If so, we need to think together about how to help you learn more about this….
- If we decide systems thinking can attract more students and teachers to math and the scientific method (to STEM), then
  - We need to figure out how to help both in and pre-service teachers gain adequate systems thinking skills, and
  - We need to set up a system of coaching for these teachers, e.g. perhaps retirees & volunteer engineers from Boeing & other companies.

Systems thinking curriculum unit examples by age & subject [(#)s are references]

	Grade Levels			
Subject	K-3	4-6	7-9	10-12
Personal Life		The Friendship Game (9)	Schoolwork, homework and grades (11)	
News				
Literature				
History		causes of the Civil War in the U.S.(4)	Search & Destroy Policy in Vietnam (10)	New Deal - FDR 1932-1940 (7)
Civics			Civil rights: allowed vs perceived (8)	
Economics		bank balance with interest rates (3)	mortgage financing (3)	managing a retail store (6)
Health & PE				drinking and driving (5)

Using systems thinking to attract more kids (and teachers!) to math and the scientific method

References numbered on slides

1. Paper "Learning Through System Dynamics as Preparation for the 21st Century" at http://sysdyn.clexchange.org/people/jay-forrester.html
2. Roberts, Nancy; Susan Friel; & Thomas Ladenburg (1988). Computers and the Social Studies: Educating for the Future. Addison-Wesley, Chapter 5
3. http://clexchange.org/ftp/documents/social-studies/SS2004-01Econ&SDForYoungStu.pdf
4. http://clexchange.org/ftp/documents/social-studies/SS1996-11CausesTheCivilWar.pdf
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12. Burton, Leone (1984) Mathematical Thinking: The Struggle for Meaning, in *Journal for Research in Mathematical Education*, Vol 15, No. 1 (Jan. 1984) pp. 35-49.

Introductory Books & Software for Teachers

- Books
  - Systems thinking group activities & games
    - Quaden, Rob and Allen Ticotsky (2008) The Shape of Change
    - Sweeney, Linda Booth and Dennis Meadows (2010) The Systems Thinking Playbook.
  - Introduction to systems thinking
    - Richmond, Barry (2010) An Introduction to Systems Thinking with Stella. (book is great, even if you don't buy the Stella software)
  - Introduction to simulation modeling
    - Ford, Andrew (2009) Modeling the Environment, 2nd edition.
    - Fisher, Diana (2011) Modeling Dynamic Systems: Lessons for a First Course, 3rd Edition
- Software
  - Vensim PLE (Personal Learning Edition - free for educational use, including personal educational use)
  - STELLA (most K-12 education models have been built in STELLA)

Introductory Books & Software for Business

- Education
  - IseeSystems Short course
  - Online courses: Worcester Polytechnic Institute
  - Free online self-study courses: Roadmaps or Guided Study Program or Dept of Energy
  - Courses around the world
- Books
  - Business Dynamics: Systems Thinking and Modeling for a Complex World, by John Sterman
  - Strategic Modelling and Business Dynamics: A Feedback Systems Approach, by John Morecroft
  - An Introduction to Systems Thinking, by Barry Richmond and IseeSystems
  - Process Improvement Manual, by IseeSystems
- Software
  - Vensim
  - iThink