"Everybody Thinking Differently" K-12 is a Leverage Point

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“So if we want to bring about the thoroughgoing restructuring of systems that is necessary to solve the world’s gravest problems – poverty, pollution, and war – the first step is to think differently.

Everybody thinking differently. ”

Donella Meadows

Reasons for Students to Study System Dynamics (Forrester)

- Cause and effect are not closely related in time or space
- Low leverage policies are usually ineffective
- High leverage policies are usually difficult to apply correctly
- The cause of the problem is within the system
- There is conflict between short-term and long-term goals
- There is a tendency for goals to spiral downward

Part I

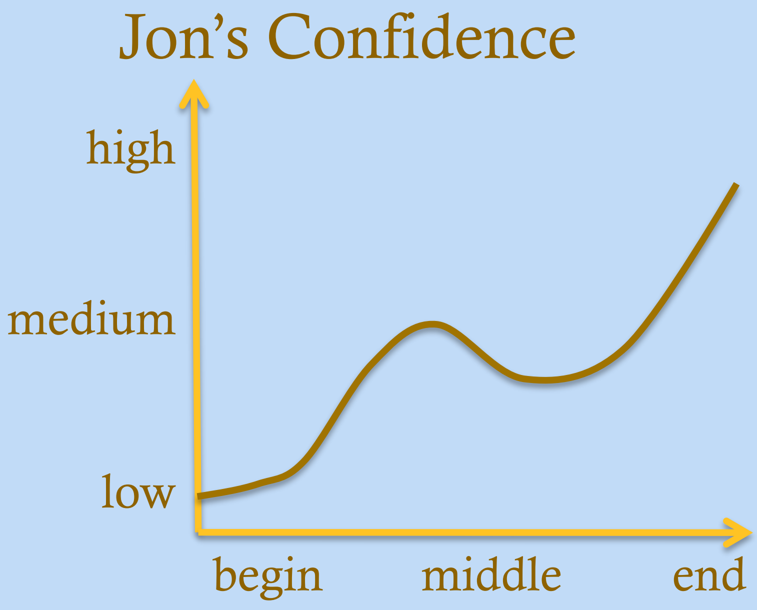
Systems Thinking Skills for K-12

Early School Years (7 – 10 years)

1. Surfacing mental model
2. Change over time
3. Simple interconnectedness
4. Circular causality
5. Reinforcing feedback
6. Balancing feedback
7. Unintended consequences
8. Accumulations and flows
9. Archetype: Escalation
10. Archetype: Fixes that fail
11. Time horizons and the general idea of delays
12. Looking at a problem from multiple perspectives

Some Instructional Strategies & Tools

- Stories
  - Waters Foundation website (www.watersfoundation.org)
  - Linda Booth Sweeney
- Behavior over time Graphs
- Causal loop diagrams
- Materials from The Creative Learning Exchange (www.clexchange.org)



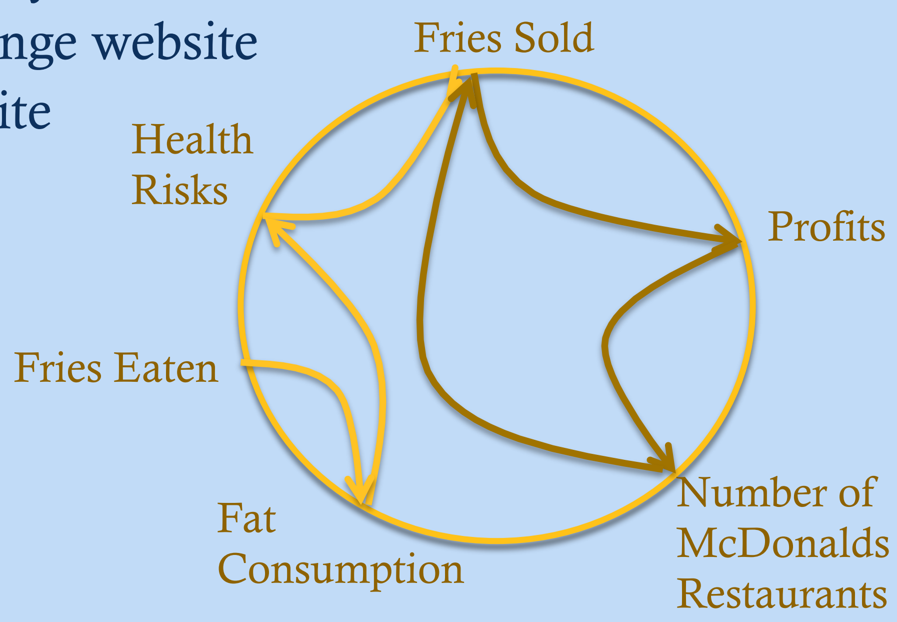
Middle School Years (11 – 14 years)

13. Drawing Stock/Flow diagrams
14. Small generic structures (linear, exponential)
15. Building simple system dynamics simulations
16. Exponential versus Linear growth/decay
17. Doubling time/halving time
18. Goal-seeking behavior, s-shaped growth
19. Multiple feedback loops
20. Loop dominance
21. Equilibrium
22. Boundaries
23. Limits to growth
24. Population dynamics
25. Infection dynamics
26. Leverage
27. Archetype: Tragedy of the Commons
28. Archetype: Success to the successful
29. Archetype: Drifting goals
30. Archetype: Shifting the burden (addiction)

Some Instructional Strategies & Tools

- Curriculum Lessons
  - The Shape of Change and
    The Shape of Change Stocks & Flows
    by Rob Quaden, Alan Ticotsky, with Debra Lyneis
  - The Systems Thinking Playbook
  - Creative Learning Exchange website
  - Waters Foundation website

- Connection Circles



Jay Forrester

Old mental models and decision habits are deeply ingrained; they do not change just because of a logical argument.

Coming to an understanding of systems must be a participative experience. Computer modeling allows an accelerated vicarious experience. … immersion in such active learning can change mental models.

High School Years (15 – 18 years)

31. Structure generates behavior
32. Causal link polarity
33. Designing graphical functions for nonlinear effects
34. Overshoot and collapse
35. Oscillations
36. Shifting loop dominance & the role of nonlinearity
37. Tipping points
38. Modeling information and material delays
39. Instability from delays in balancing feedback
40. Transferability of structure
41. Analyzing systems in the news
42. Graphical integration

High School Years (15 – 18 years)

43. Formalizing relationship between accumulations, rates of change, and changes in rates of change
44. Shared vision and organizational change
45. Building & using more sophisticated system dynamics models
46. Sensitivity analysis with system dynamics models
47. Determining high leverage from system dynamics models
48. Testing potential policies using system dynamics models
49. Explaining learning/ insights from system dynamics models
50. Professional system dynamics involves items 45 to 49

Some Instructional Strategies

- Identify the difficult dynamic concepts within each discipline and focus on finding/designing models for those
- Three possible approaches for instruction
  - Students manipulate pre-made models
    - Need powerful experiences (i.e., Fish Banks)
  - Students add to/modify an inadequate model created in class
  - Students create original small models from scratch
- Combine methods as desired

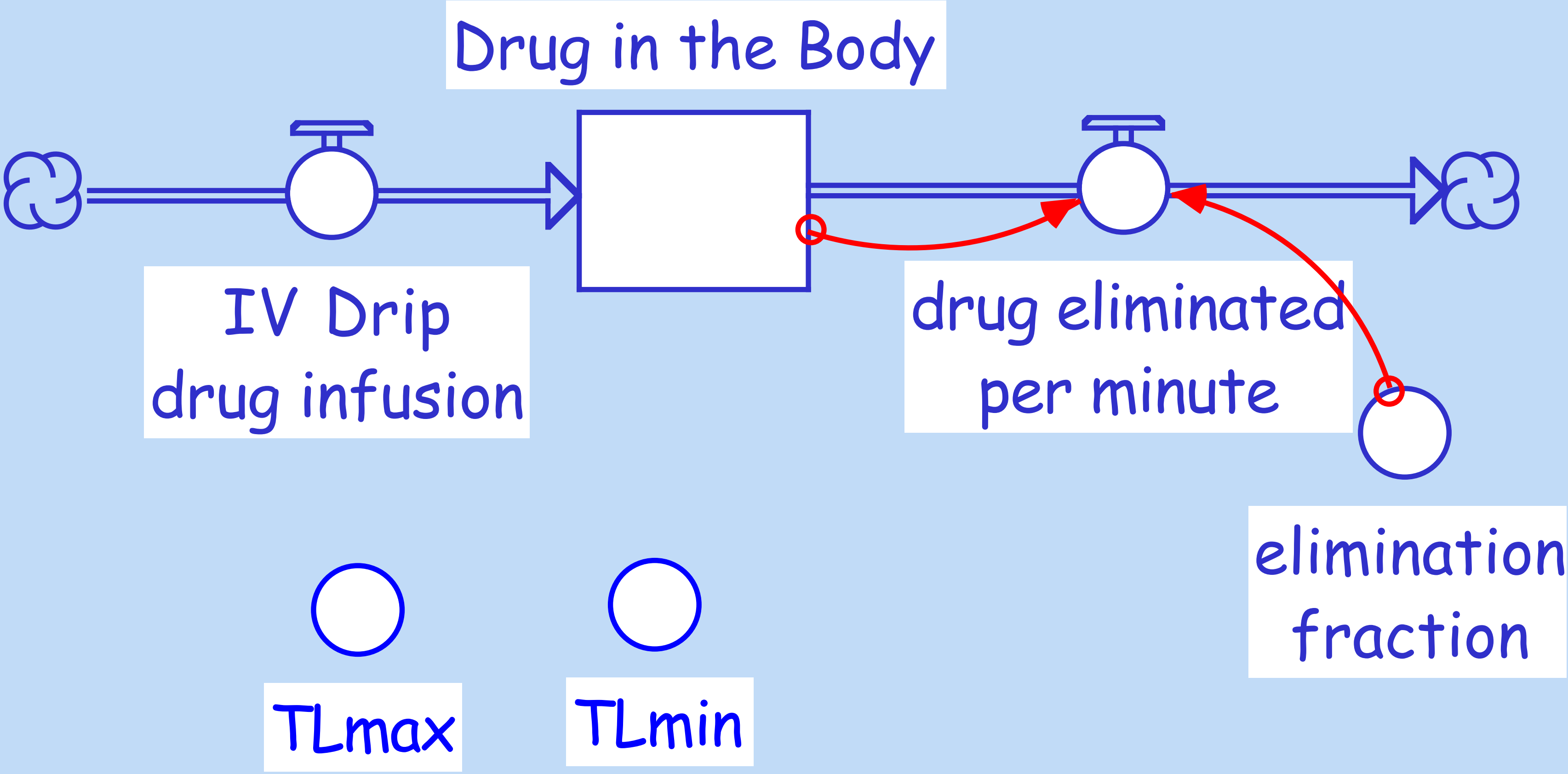
Part II

High School Mathematics Classes

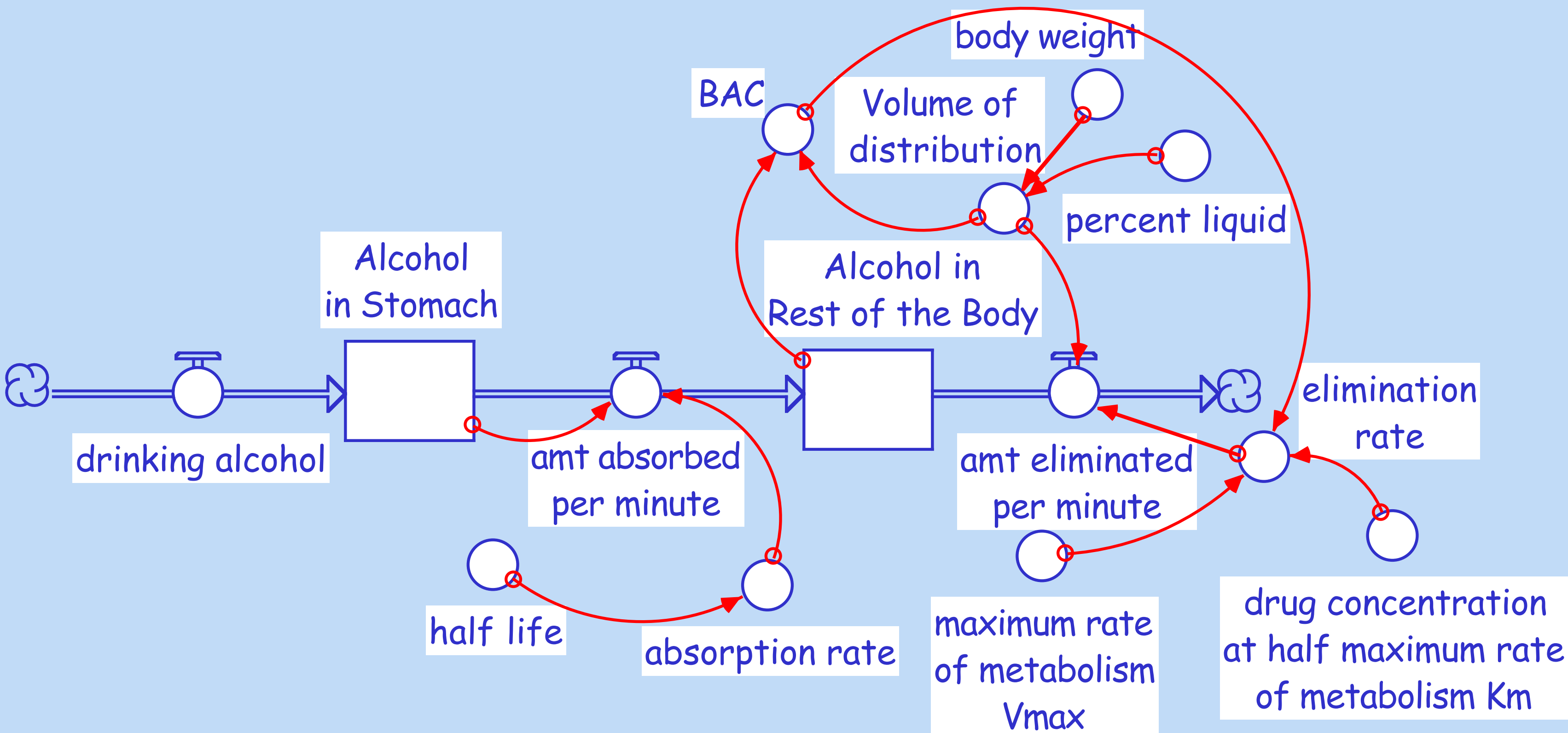
Three Stage Strategy

- Stage 1: Students design small system dynamics models to reproduce (many) typical functions found in algebra, pre-calculus, and calculus classes.
- Stage 2: Students combine one-function system dynamics models to study more sophisticated problems
  - Drug models, resource models, predator/prey models, etc.
  - Students predict behavior
  - Introduce simple feedback to explain behaviors
  - Trojan Horse approach

Second of Five Drug Model Sequence



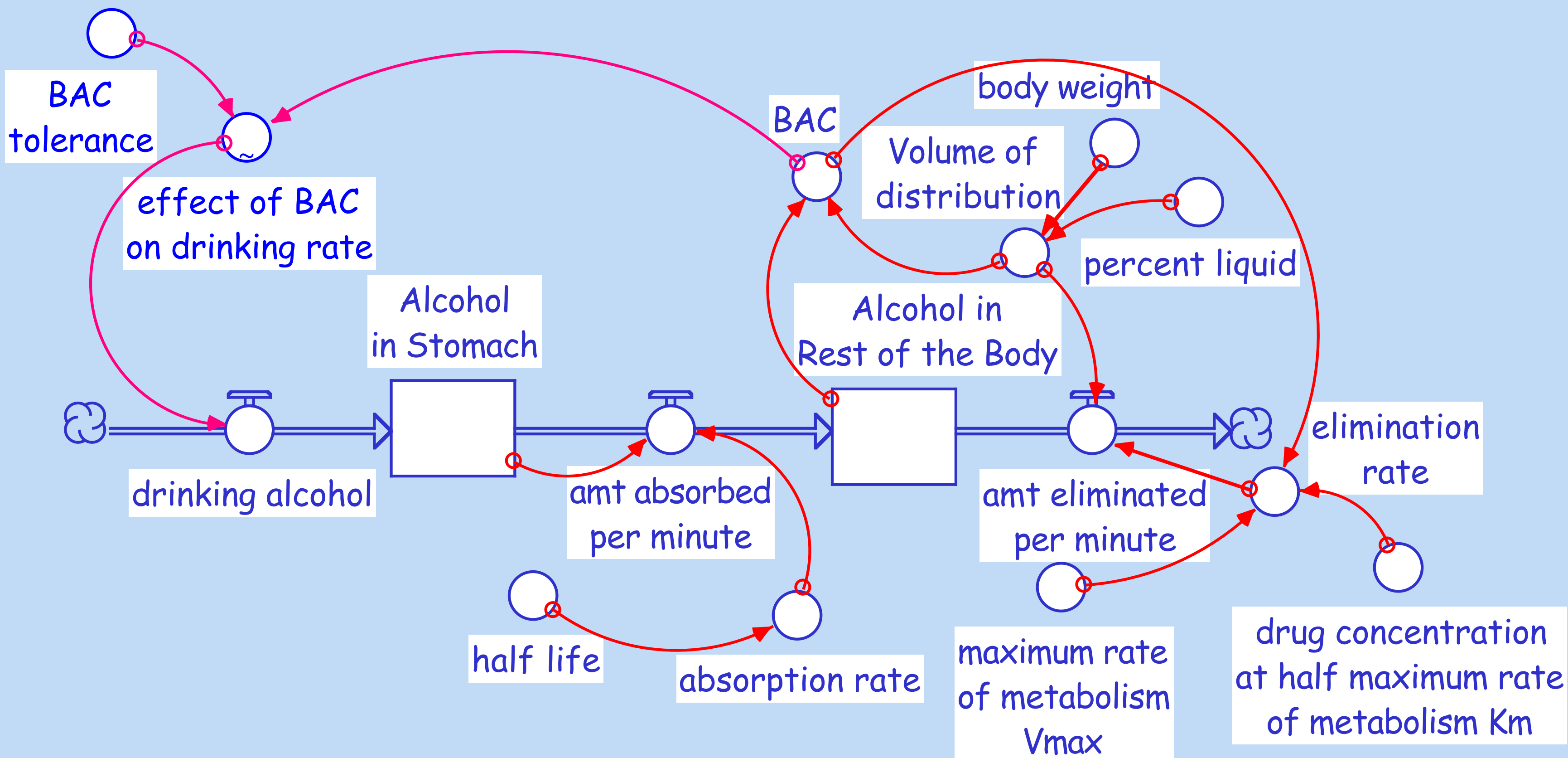
Fifth of Five Drug Model Sequence



Three Stage Strategy

- Stage 3:
  - Problems contain more feedback
  - Shifting loop dominance is presented
  - Graphical functions introducing nonlinear effects are used
  - Policy testing can become part of problem analysis

Revisiting Alcohol Model

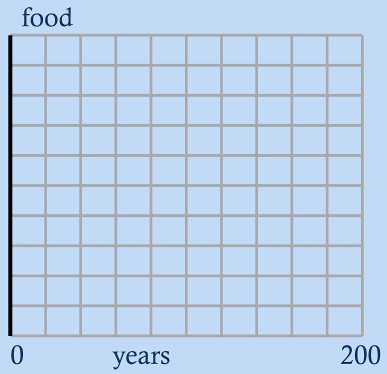


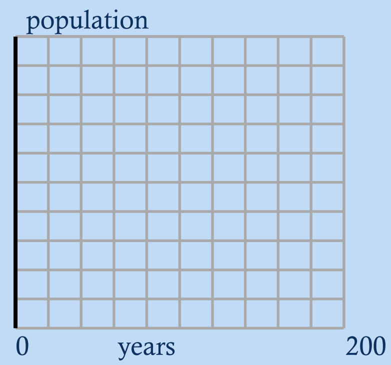
The Malthus Problem

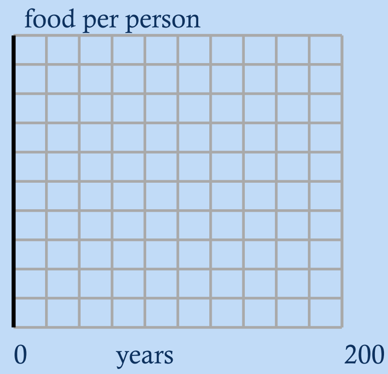
World population is increasing exponentially, while food production is increasing linearly. Why is this a problem? What can be done?

Predicting the Behavior

Students draw graphs of food production, world population, and food per person, (over 200 year time frame) based on understanding of linear and exponential growth.

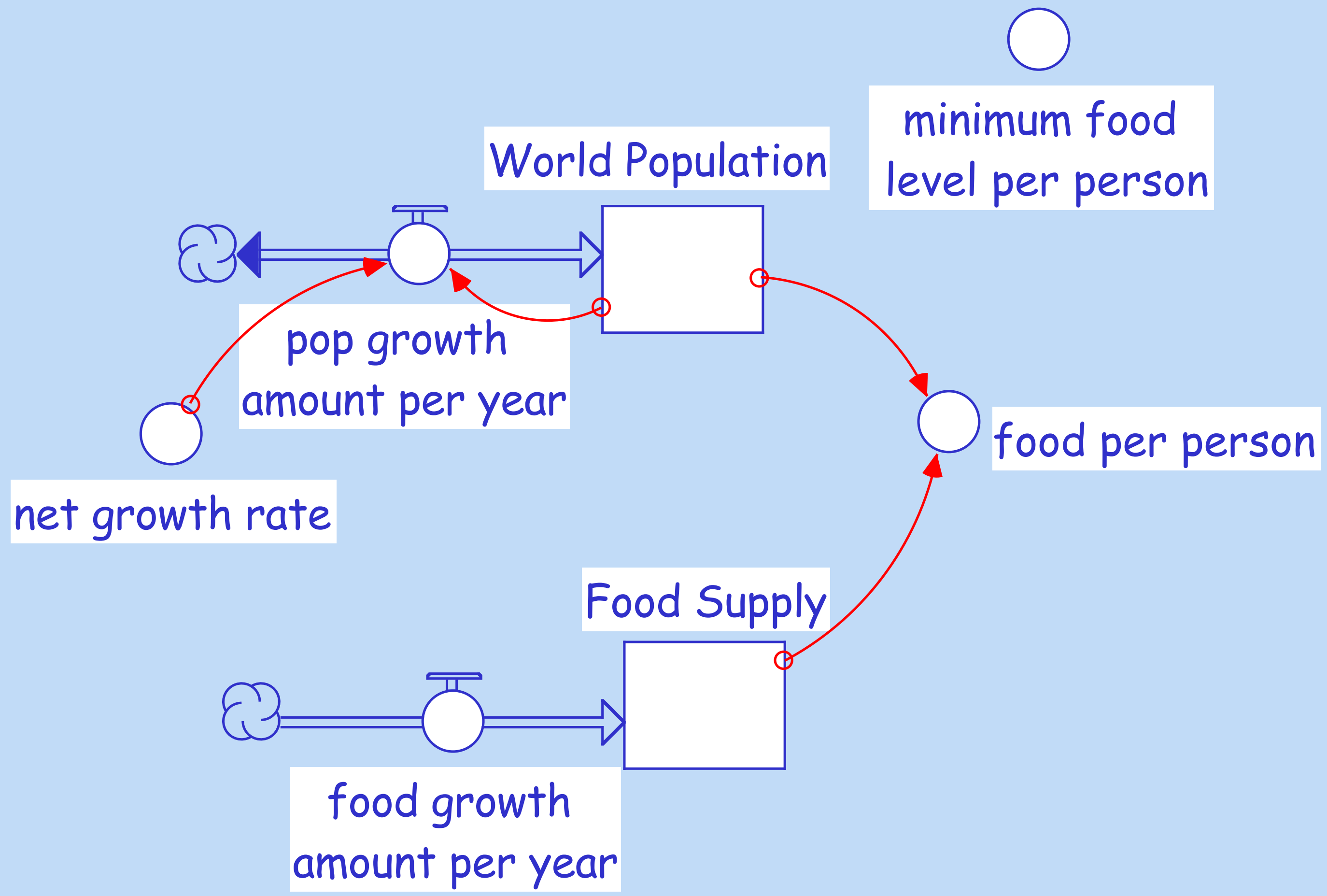






Students explain why they drew the food per person graph as they did on the grid above.

The Malthus Model



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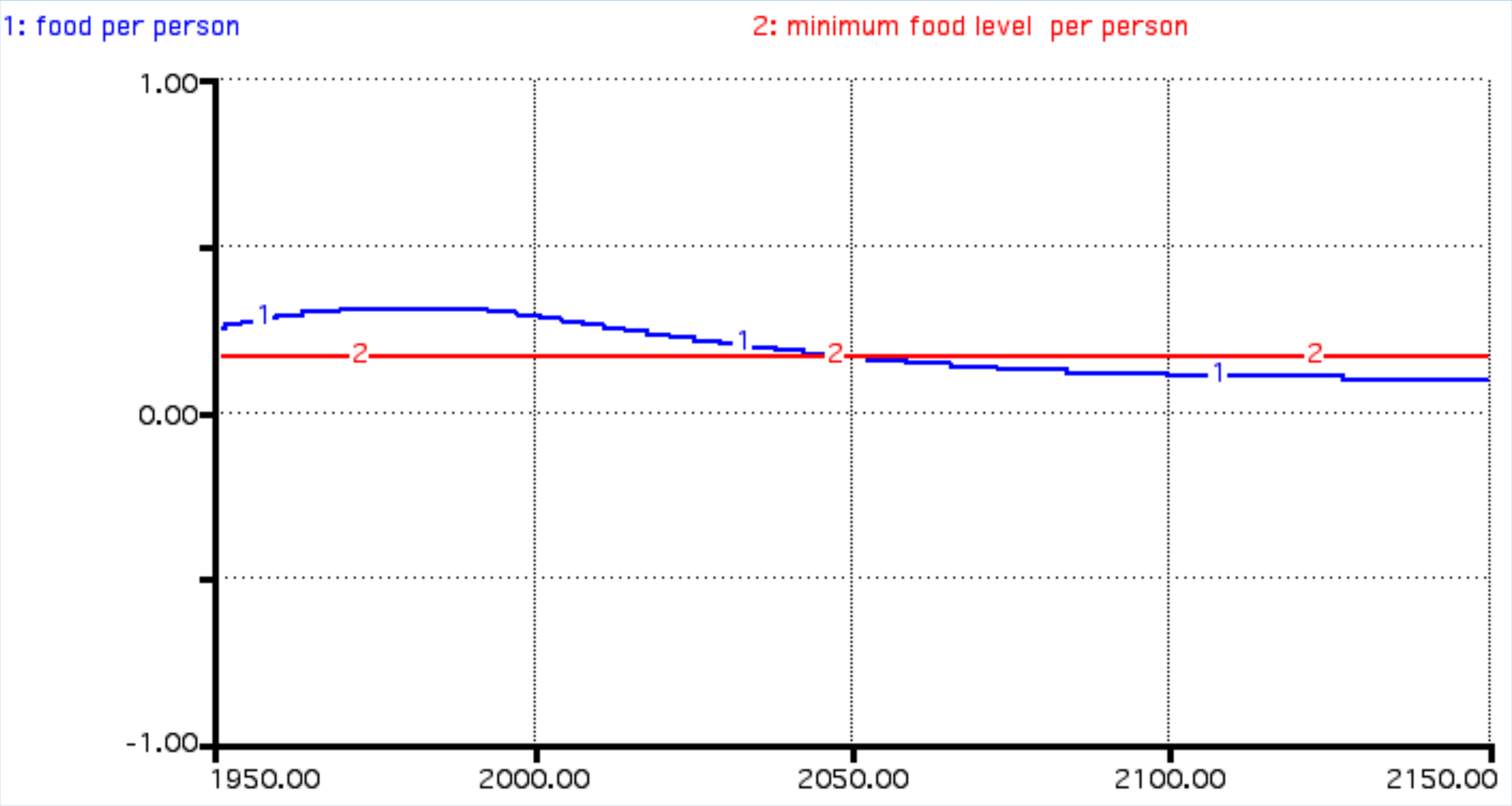
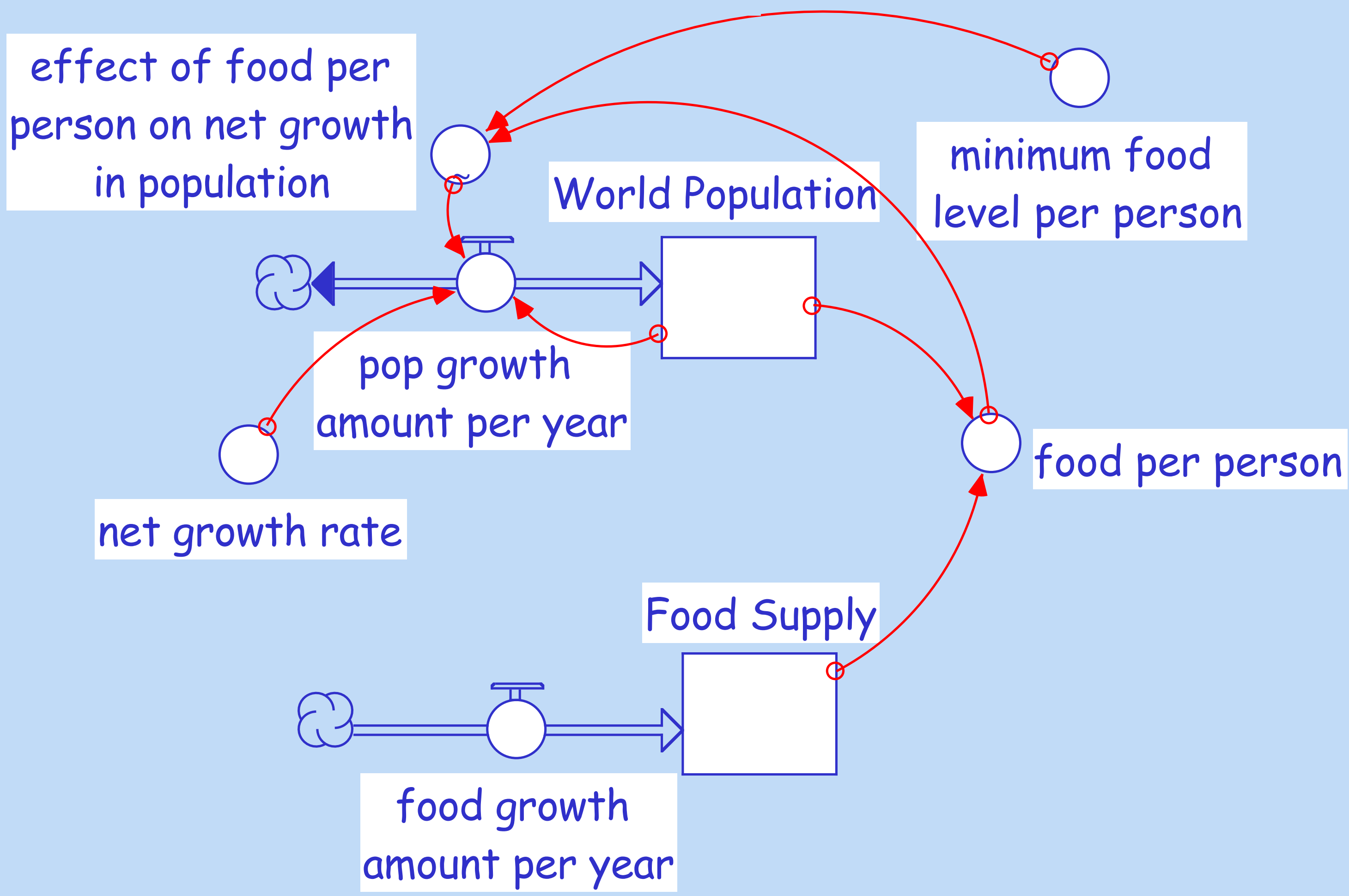


The Malthus Model



Analysis

- Is it possible to solve this problem?
- Issues to discuss
  - Consuming grain based diet rather than meat based
  - Food is not distributed evenly around the world
  - Food production cannot grow forever
- Determine a policy
  - Test the policy
  - Who will fight the policy?
  - How will you convince these people?

Why System Dynamics for Math?

- It is easier (than using equations) to connect the real world to system dynamics modeling representation
- It is possible to combine core functions to study more relevant and rich real world dynamics
- The icon-based format allows a conceptual introduction to the core concepts of calculus (stocks = integrals, flows = derivatives)
- Math is about building representations to capture and analyze real world patterns of behavior. Building simulations should be part of this experience.

Why System Dynamics for Math?

- The icon-based symbolic representation makes math concepts more transferable/available to other disciplines.
- The system dynamics model representation gives visual clues about the system (flows and dependencies) and uses full words and/or phrases to identify each component, allowing a broader audience of students to learn to use math to study world issues.
- Understanding the importance of feedback is critical to understanding why complex systems behave as they do. Students need to make decisions involving complex systems.
- Students are empowered to test hypotheses and potential policies on problems they study.

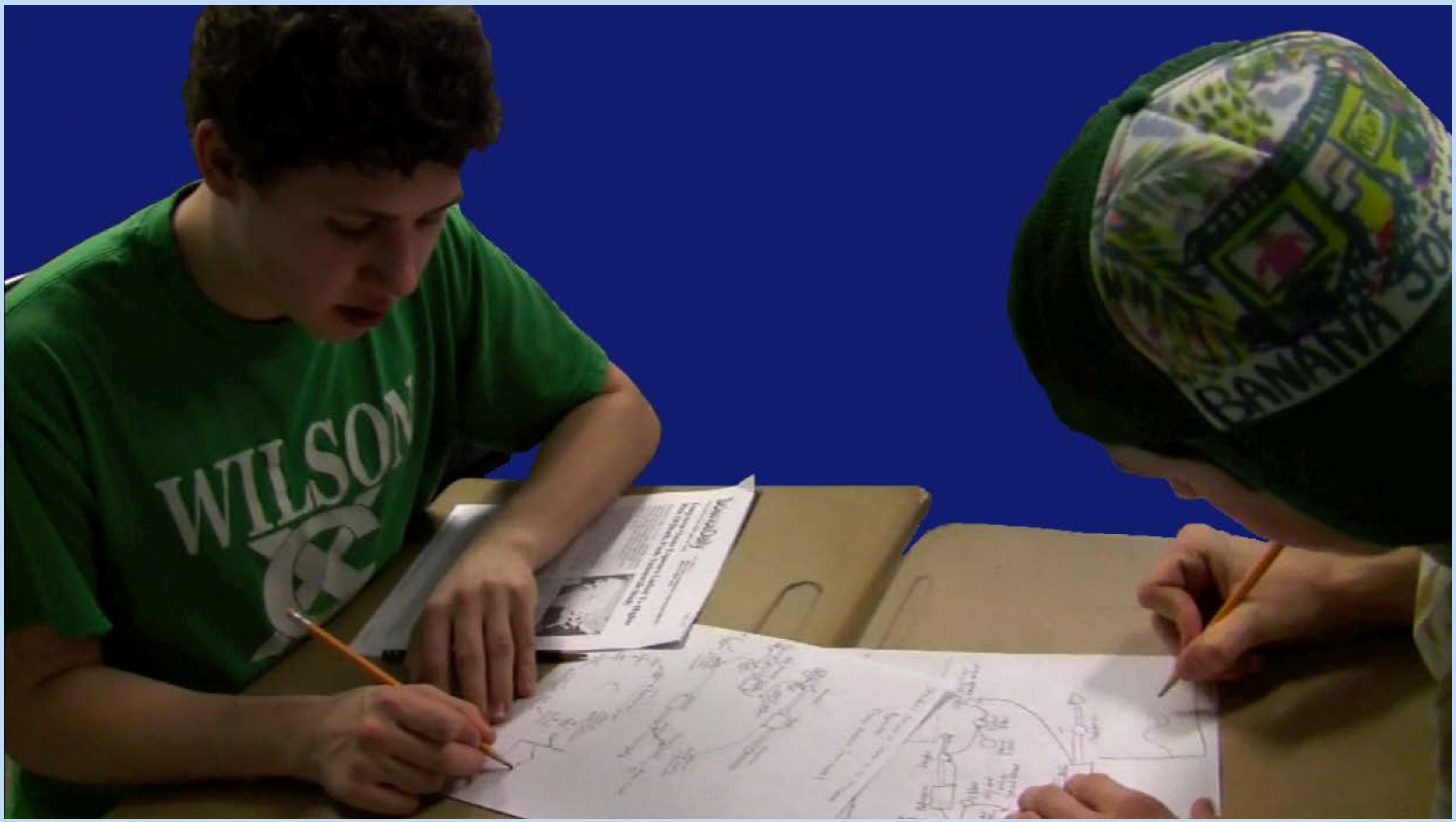
Part II

High School System Dynamics Modeling Class

The Design of the Course

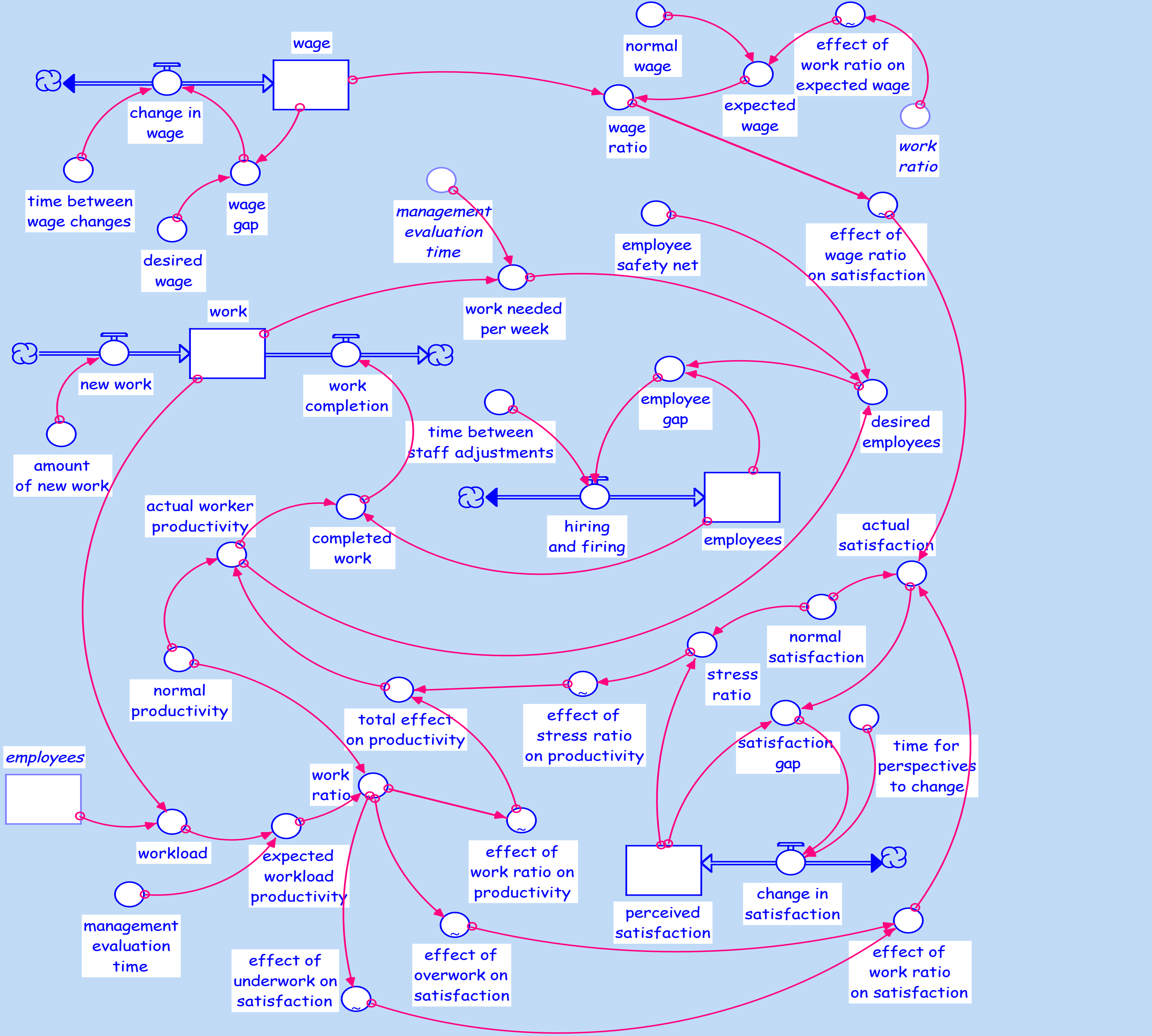
- The first three quarters students build modeling skill
  - Predicting behavior, explaining discrepancies
  - Defining units, checking for unit consistency
  - Learning how to explain a feedback loop
  - Designing a graphical function
  - Incorporating material and information delays
  - Recognizing instability from delays in balancing feedback loops
  - Students design dynamic hypothesis from news article
- Last quarter (10 weeks)
  - Students select and research topic of their choice, create simulation, write technical paper, present model

Analyzing the News



Workforce Pressure

by Harry Cassady (age 18)



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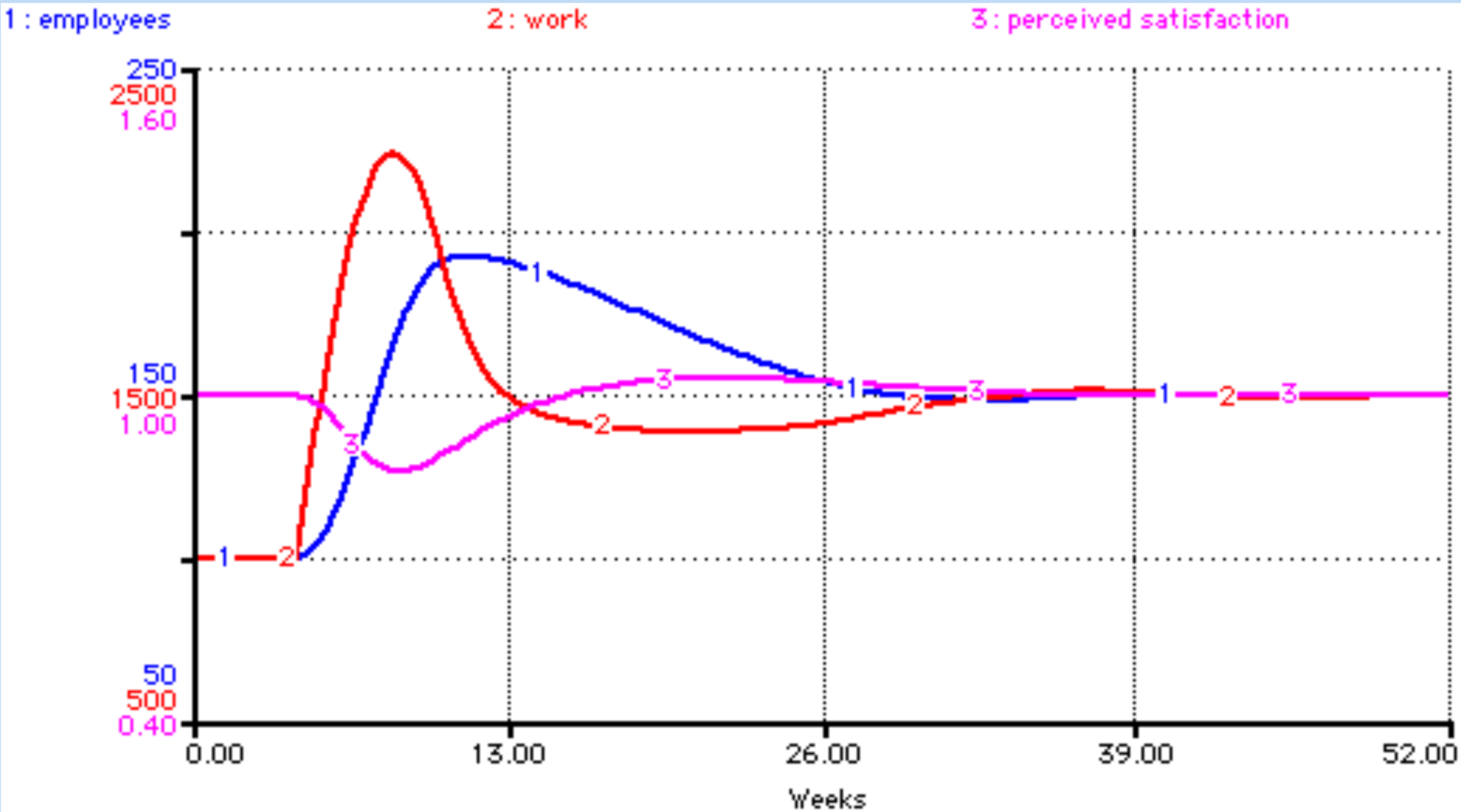


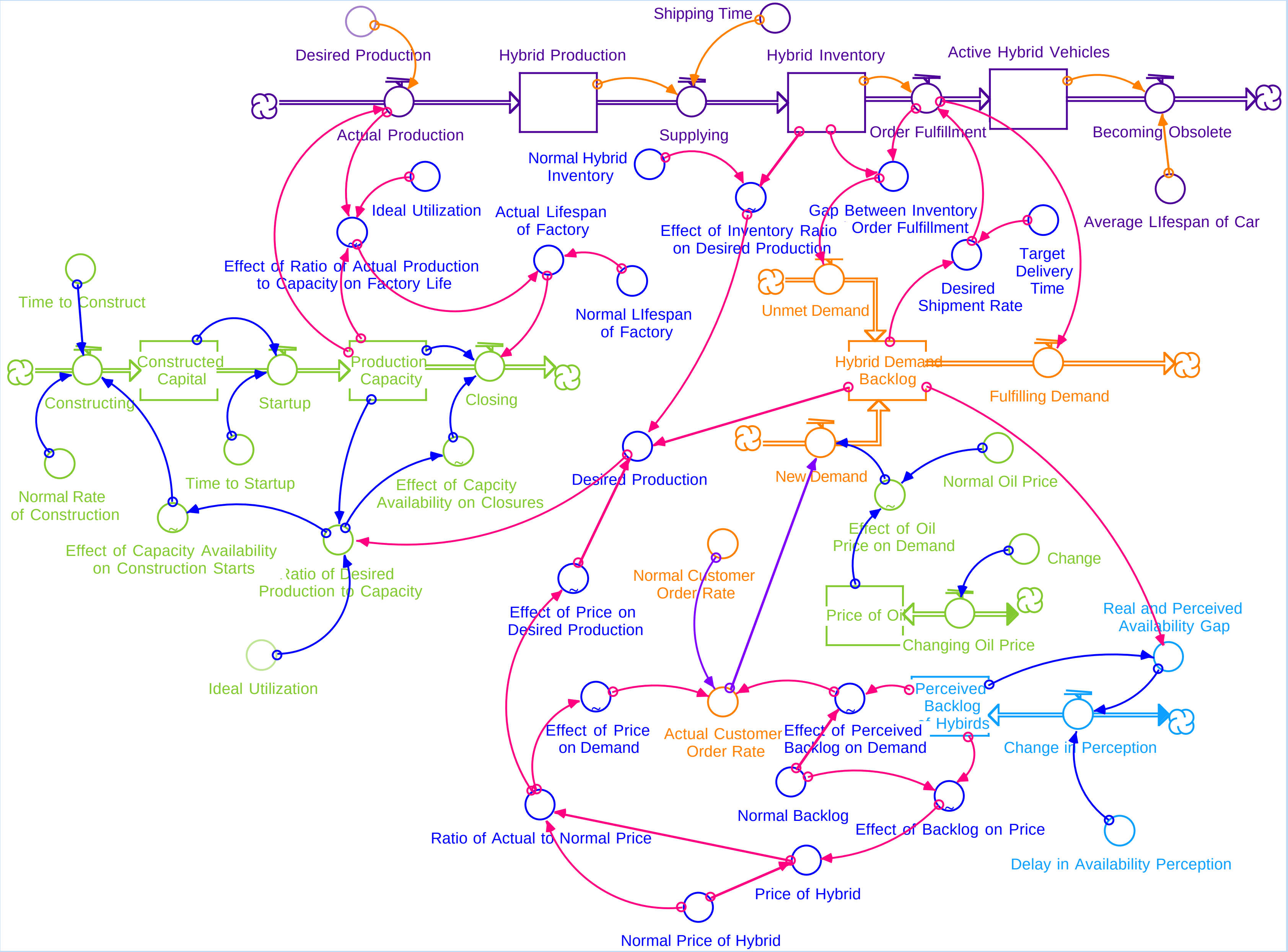
Work increases by 50% in week 4

Learning from/about the Modeling Process

- It is easy to become overly concerned with small details in the model, without looking at the model as a whole. It is easy to becoming very obsessed with the exact shape of a graphical converter, or be overly concerned with adding fairly insignificant details. Sometimes these small details are unimportant, and you need to step back; making sure you are still heading in the direction of answering the original question posed.

- I also learned how a model is really a large number of delays and feedback all working together to bring things back into equilibrium. By studying these delays and the feedback you can really begin to understand not only how things work within your model, but also how almost everything in the world interrelates through countless numbers of feedback loops.

Hybrid Car Production by Joseph Kibe (age 18)



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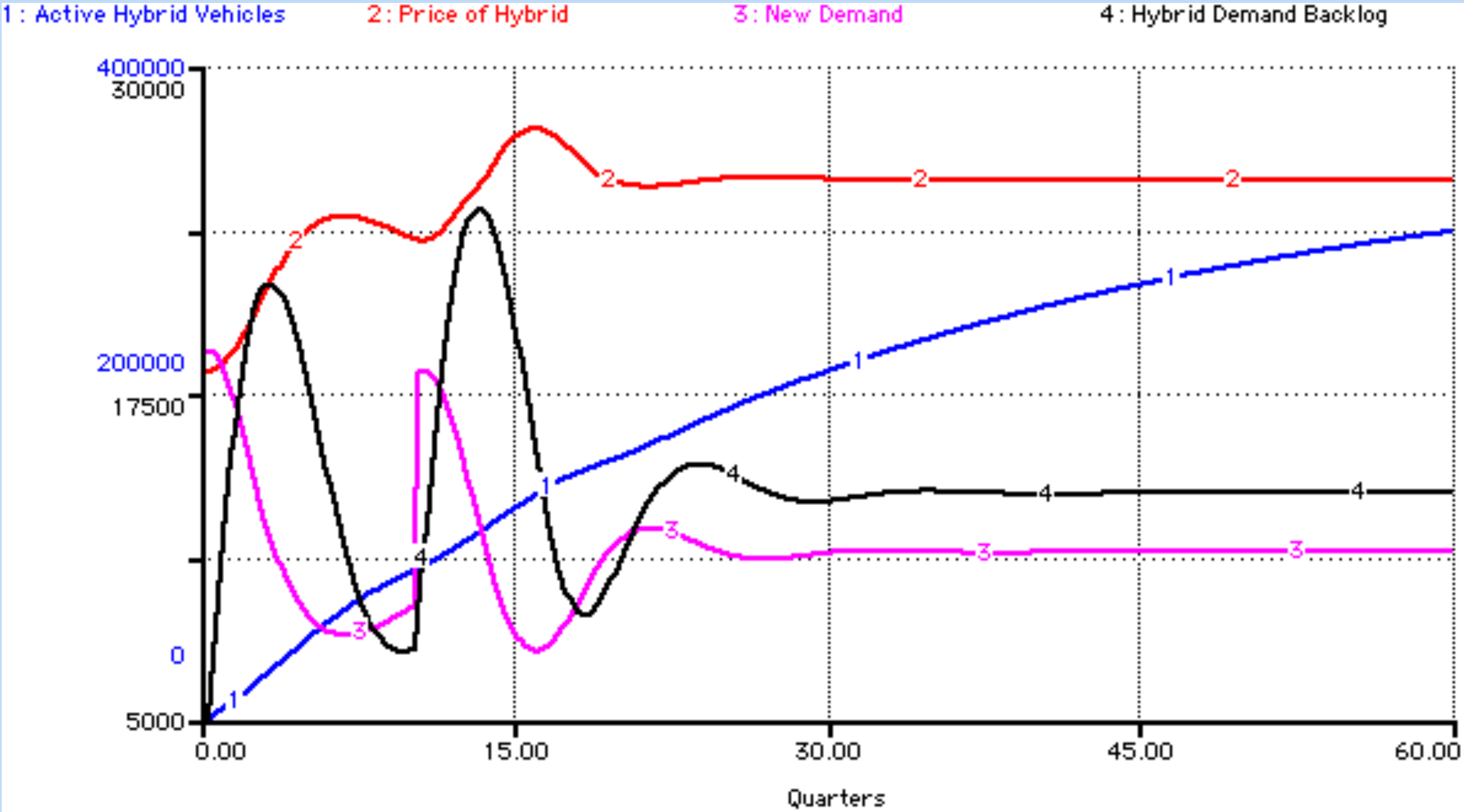

Oil Prices increase in Quarter 10

Learning from/about the Modeling Process

When I began this model I thought it would be fairly straight forward. But I encountered many unexpected behaviors that forced me to make the model more and more complicated to reflect the industry's true nature. *And it was particularly interesting to see the way that combining the different components, which all have predictable behaviors on their own, can come together to reveal some unexpected results.* The model also demonstrated how important delays, or the time it takes a company to react to changes, are to their operation. I always had some idea why companies spent millions of dollars to streamline their supply chain, but this model really illustrates how that can have an impact.

Learning from Modeling Process
by Tommy H. (age 17)

"In other classes, I am often asked to posit logical solutions to problems or am given the solutions reached by other people. Using models of complex systems I can test out my own theories and confirm those of others instead of faithfully accepting them as fact. *Where other classes ask me to memorize, this one dares me to explore*."

More Student Models, Videos, Technical Papers

CC MODELING SYSTEMS

modeling real world challenges

Going Forward

We, in the system dynamics community, feel that the system dynamics process is an essential tool in understanding and addressing the complex problems we face as a nation and as a global community.

Going Forward

Why are we not teaching
system dynamics
to our children?