Simulations, Systems and Computational Literacy
Foundations of 21st Century STEM

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The Education Arcade
Not Just for Scientists Anymore...

- Current **public controversies**
  - Global climate change
  - Evolution and origins of life
  - Spread of emerging diseases
- Are these simulations to be believed?
- Understanding these and future issues in science and society require understanding systems and simulations
Our Primary Goal

• Enable/empower students to “think scientifically”

• Use the **tools of scientists**

• Develop the **habits of mind of scientists**

• Science is driven by **modeling** and **simulation**

• How do we make this accessible **conceptually & technically** to students?
Our Secondary Goal

- Increase interest/understanding of programming
  - Interest in **building careers** in much needed area
  - Understanding for **all users** of computers from macros to troubleshooting

- Yet, programming is on the decline
  - Programming **classes are disappearing** and relegated to those who are already interested
  - Outside of school opportunities are also scarce due to missing expertise and perceived interest
Beyond the Basics

- Opportunity to engage in fun, hard problems
Constructivist Computational Heritage

• Seymour Papert
  • Programming/Logo
    • Learning to think through programming
  • Hard fun
    • It is fun because it is hard
• Constructionism
  • Learning by creating
• New directions in a new millennium
The Last Decade at MIT

- Learning about simulations and Complex Systems
- Collaboration between MIT and the Santa Fe Institute since 1998
- NSF and Private Funding
- Learning by creating
- Input from research community
Simulations and Complexity Science

Complex Systems

The science of complex systems is the science of systems that are highly interconnected, have behaviors that are sensitive to initial conditions, and have outcomes that are hard to predict. Some examples of complex systems are cells, brains, ecologies, economies, and societies.

Agent-Based Modeling

Agent-based modeling is a way of studying complex systems. An agent-based model consists of a virtual world filled with agents. Agents are like creatures that follow simple rules. They can represent any kind of individual: people, cars, atoms, rabbits, cells etc. Complex systems can be modeled by giving the agents a set of rules for how to behave and interact. The results are often surprising.

The Termites Model

Here’s an example of an agent-based model of complex system: suppose you had a world consisting of termites, and chips of wood. The termites are the agents in this model. Their rules are as follows:

- Wander around randomly
- If you bump into a wood chip, pick it up
- If you’re carrying a wood chip, and you bump into another one, put it down

Given only this set of rules, what would you predict will happen to the wood chips over time?

Click next to test your predictions.
Complex Systems

• A way of thinking about and across systems
Islands of Science

- Science is traditionally thought of as islands of topics.
- We learn bits of facts within subjects, and few connections between subjects.
• Complex systems is a way of learning that transcends particular concepts and classes
• Understanding the common themes that arise in natural, artificial, and social systems
• Improve science understanding through CS

Complexity

ecology

genetics

molecular biology

osmosis

chemistry

energy
New Paradigms for New Ideas

• Traditional pedagogies and technologies make some ideas accessible
• But leave others unapproachable

“In this demonstration, the students have isolated the effect of single variables on the growth of a bean plant”

“In this experiment, the students have ignited a forest fire to study the effects of tree density on the spread of fires.”
Adventures in Modeling

- Designing, creating and studying simulations of Complex Systems on computers
  - **StarLogo**
- Enacting simulations of Complex Systems with and without technology
  - **Participatory Simulations**
  - **Role-Playing Activities**
StarLogo Models

- Ecology
- Evolution
- Epidemiology
- Engineering
- Chemical Reactions
- Social Systems
Off Computer Activities
EcoScienceWorks

- Foundation for Blood Research
  - (ScienceWorks for ME)
    - Walter Allan and Jeri Erickson
- SimBiotic Software
  - Eleanor Steinburg and Eli Meir
- MIT STEP
  - Eric Klopfer, Ricarose Roque, Daniel Wendel
- Maine Audubon
- Camp Kieve
- Maine Learning Tech Initiative
Combining field work and simulations to understand locally relevant ecological issues and learn core content
EcoScienceWorks Labs

Welcome to EcoBeaker Maine Explorer™ for Middle School Students

- Beaver Pond Succession
- Edgelands and Fractured Forests
- Keystone Predator
- Lake Invaders
- Runaway Runoff
- Program a Bunny
- Library

developed by SimBiotic Software
www.simbio.com
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Lab:
Lake Invaders
Choose an Exercise...

Lab Instructions

Exercise 3: Big Fish Little Fish

Fishing for trout is fun, but fishing for pike is MORE FUN! Pike are large predatory fish that are often referred to as the "shark of freshwater" - sometimes even as the "waterwolf of the aquatic jungle". Pike are not native to Maine. To read more about pike, click here.

Because pike are so fun to catch, people who fish often like to introduce them to previously pike-free rivers and lakes. But this can have a serious impact on those rivers and lakes. In this exercise, you will add pike to the lake and see what happens.

Pike in the simulation look like this:

Graphs
Algae
Zooplankton
Trout
Pike

Data

Next ➤
What Color is Your Box?

- Black Box

- Understanding the model from the inside

- Glass Box

to setup
cat

crt number
ask-turtles [width]
Challenges in Practice

- Kids and instructors worry about **syntax**
- More *using* programs than *building* programs

```plaintext
count-with-turtles [color = red]?
count-turtles-with (color = red)?
{count-turtles} with (color = red)?
(count-turtles) [with color = red]?
```
Breaking the Syntax Barrier

- Visual programming language specifies syntax
- Commands are defined in the interface
- Allows focusing on the “good” challenges (i.e. models) instead of the language
Program a Bunny

![Image of a bunny programming environment]

- Code Blocks
- Workspace Demo
- Return To Bunny Land
- EvoBeaker
- Lab: Logo Bunnies
- Exercise: Scenario 7
- Bunny's Current Energy: 99

Notes:
- Program logic for a bunny action:
  1. Hop
  2. Eat
  3. Turn
  4. Nibble
  5. With Percent Chance

- Bunny Land

- Control Panel
- Go
- Step
- Time
- Days
Is it Correct?

Suprematism
Kasimir Malevich

Courtesy of James Clayton
30,000 Foot View
Variations on a Theme
How Might a Bunny...
StarLogo TNG

- More extended opportunities for programming and complex systems
- Provides rich 3D environment and intuitive visual programming
- Creating embodied understanding of complex systems
Example - Forest Fire

• Practice controlled forest clearing to study spread of forest fires
• Vary conditions of wind, density and clearing patterns
TNG Implementations

• After school - TNG Games
  • Current after school program 1x per week
  • Middle school

• The Bridge - **Project GUTS** (Growing Up Thinking Scientifically - PI, Irene Lee)
  • Middle school students
  • In and out of school
  • Centered on locally relevant scientific problems

• In School - **Introductory Physics**
  • High School (11th and 12th graders)
  • Replacement curriculum on mechanics and vectors
  • Learn physics AND programming AND problem solving AND enjoy it
TNG Games

- Started this winter in urban district in MA
- After school for 1.5 hours/week in urban district
- Get students interested in programming, technology, games, STEM...

Sample Curriculum

- 0 degrees
- 45 degrees
- 90 degrees
- 180 degrees
- 270 degrees
Project GUTS

- Modeling of locally relevant scientific issues
- Learn modeling and programming through summer game development workshop
- During the school year students are the conduits to in-class work
  - Students mentor and teach other students
  - Work with trained teacher
Introductory Physics

- Need to add your own physics to make games
  - Acceleration and deceleration
  - Gravity
  - Vectors
Teacher Reactions

TNG has really changed the environment in the classroom. My students have a sense of **empowerment and a self-motivation**. It’s **changed my role** as a teacher, as a disseminator of information. When they come into class, they go straight to the computer - they don’t wait for me.

They care about making a really cool game. For kids who are not going to be physicists, it’s a super motivational tool.

-Physics teacher of “conceptual physics” class
Student Reactions

- It was fun and challenging
- Better understanding of how games work
- More confident with technology
- Many more likely to try programming again.
For More Information

- EcoScienceWorks

- StarLogo
  - http://education.mit.edu/starlogo
  - http://education.mit.edu/openstarlogo
    - (new “open source” version)

- StarLogo TNG
  - http://education.mit.edu/starlogo-tng

- klopfers@mit.edu