Interactions Between Human Cognitive Architecture, the Challenges of Complex Causal Induction in Science Learning, and the Affordances of the Digital World

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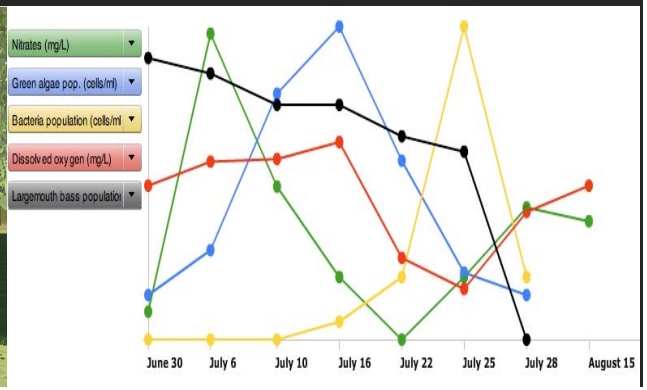

Causal Learning in the Classroom Project

EcoMOBILE Project

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EcoMUVE Project

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Overview

- The Cognitive Science of Everyday Causal Reasoning
- Three Modes of Causal Induction and How They Interact with Complex Problem Spaces Such as Ecosystems Dynamics Where Intervention is Difficult
- Affordances of Digital Media for Studying Perception, Attention, and Reasoning and for Supporting Learning

In the 1950s, malaria was a problem in Borneo. The World Health Organization sprayed large amounts of DDT to kill the mosquitoes that carried the malaria. The mosquitoes died and malaria declined. Soon, the thatched roofs of people's houses began to fall down on their heads. The DDT also killed a parasitic wasp that had previously controlled thatch-eating caterpillars. The DDT-poisoned insects were then eaten by geckoes, which in turn were eaten by cats. As cats started to die, rats flourished, and the people were threatened by outbreaks of sylvatic plague and typhus. To cope with this new set of problems, the World Health Organization parachuted live cats into Borneo.

“If you want to understand nature, you must be conversant with the language in which nature speaks to us.”

-Richard Feynman


DIVISION ONE HARDWOOD
BASKETBALL
LEAGUE

Environmental justice will be one of the defining issues of our time.

How do we discern the patterns of our world from the available information?

What enables us to engage in informed and morally thoughtful actions in a complex world?

Environmental reasoning depends largely on observational data—while we can take advantage of "natural experiments", our primary modes of understanding are not isolation and control of variables.

The Cognitive Science Story


DON'T DUMP
DRAINS TO
CHARLES RIVER

Humans as sense-makers: Tendencies that influence everyday causal reasoning…

- We notice co-variation and we sum across our experiences to seek out patterns or correlations between events. We may try to screen off experiences to disambiguate potential causes. (Shultz; Sigler; Gopnik & Schulz)

- We seek out plausible mechanisms and use our knowledge of particular mechanisms. (Keil; Atran; Leslie; Sobel)

- Agency plays a powerful role in causal cognition. (Carey; Meltzoff etc.)

Perception and Attention are Part of the Equation

- We necessarily filter stimuli and tend towards efficiency—impacting what we notice and where we draw boundaries. (Simon; Mack & Rock)

- Meaningful or familiar patterns are more salient to us and more likely to be noticed. We default towards meaningful, "well traveled" patterns. (Lamme; Most; Gagnepain et al.)

Grotzer, T.A., Miller, R.B., Lincoln, R.A. (2011). Perceptual, attentional, and cognitive heuristics that interact with the nature of science to complicate public understanding of science, in M.S. Khine (Ed.) (pp. 27-49) *Advances in the nature of science research: Concepts and methodologies*, New York: Springer Science and Business Media.

Causal Default Assumptions

1. linear (vs. non-linear)
2. direct (vs. indirect)
3. unidirectional (vs. bi-directional)
4. sequential (vs. simultaneous)
5. obvious (vs. non-obvious)
6. active, intentional agents (vs. passive, non-agentive)
7. event-based (vs. processes or steady states)
8. deterministic (vs. probabilistic)
9. local (vs. spatially distant)
10. immediate (vs. delayed)
11. centralized (vs. decentralized/distributed)

Lake Nyos, Cameroon

http://pagesperso-orange.fr/mhalb/nyos/webcam.htm

Modes of Causal Induction

Causal Bayes Nets

- People attend to co-variation between cause and effect…
- Summing across instances…
- Humans connect across statistically probabilities that a cause and effect are linked….
- Intervening and screening off as needed…

What about…

- The cognitive load of complex causality?
- Observational data rather than that which can be easily manipulated (natural experiments)?
- The “noise” in messy real world environments (the ontological problem…)?
- Causes and effects in different attentional spaces?
- Complex patterns of interactions (not Directed Acyclic Graphs (DAGs))?

Kindergarten Funny Bunny Study

Students were from Boston and Cambridge and are primarily Black and Latino with less than 1% Caucasian and 78% on "Free or Reduced Lunch."

Specific Generative Mechanisms

- Children amass considerable mechanism knowledge over time.
- The challenge of non-obvious mechanisms is not that we can't understand them but that they often compete with salient obvious mechanisms.
- Mechanisms can be defined at different levels.

Trust in Testimony (Paul Harris)

- How can testimony support complex causal connection-making?
- How does testimony interact with mechanism knowledge?
- What happens when testimony comes in the form of compelling narratives? (Availability Heuristic, Kahneman) How easily can people override it in their reasoning?
- Is it an answer to the Bayesian cognitive load problem? Adaptive? (Damasio; LeDoux)

How Might these Modes of Causal Induction Interact to Support Complex Causal Understanding?

Expert Reasoning About Ecosystems Involves Reasoning About:

- spatial scales involving action at a distance, where impacts are felt far from their causes.
- time delays between causes and their effects.
- causes that can be non-obvious or act in concert with obvious causes.
- processes and steady states in addition to event-based reasoning.

Spatial Gaps
Action at a Distance

- Infants expect physical contact between causes and effects and show puzzlement to "action at a distance" --Shadow Research by Spelke and colleagues.

- Students tend to expect causes and effects that are close together in space and time (but knowledge of mechanisms also plays a role.)

“Action at an *Attentional* Distance”

Even if we realize that causes and effects can be separate in space and time, we have to overcome the attentional gap.

We tend to miss effects that happen at a distance from their causes. We may not realize that they are linked and even if we do, we find it difficult to attend to them.

What are MUVEs?

Multi-User Simulated Virtual Environments

- Immersive microworlds
- Avatars move around and interact.
- Multiple linked representations of a phenomenon (graphs, equations, behavioral dynamics)
- Embedded hints and tutoring
- Distributed teams are possible.
- Can impose visualizations and other aids to facilitate understanding of complex phenomena.

Causal Patterns in Ecosystems

Lessons to Infuse into Ecosystems Units to Enable Deeper Understanding

The Understandings of Consequence Project
Project Zero, Harvard Graduate School of Education

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Black's Nook

EcoMUVE

Supported by the Institute of Education Sciences, U.S. Department of Education, Grant No. R305A080514 to Chris Dede and Tina Grotzer.

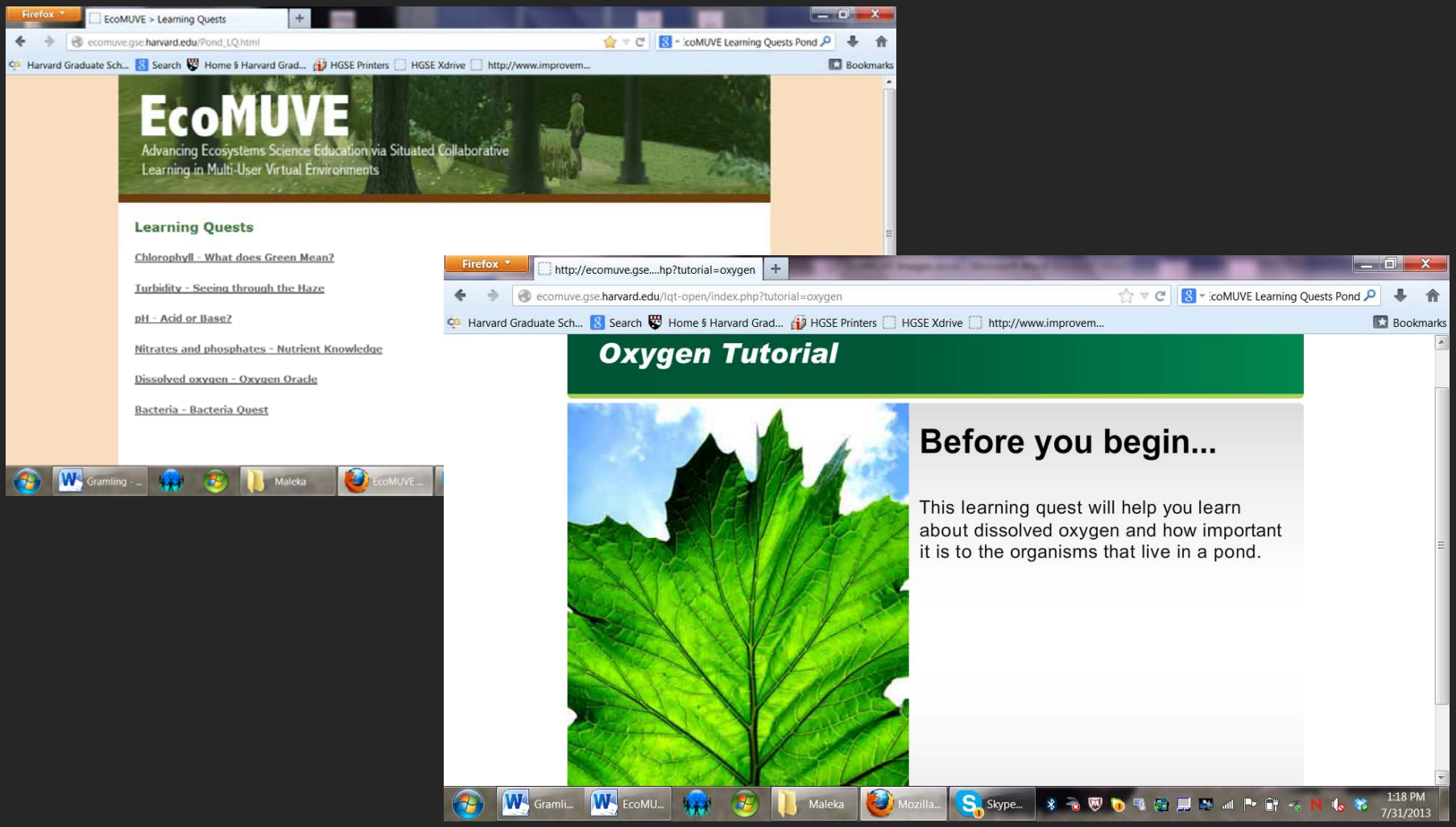
-EcoMUVE is promising for studying what students attend to and for teaching complex causal reasoning—sensitivity; ability, and inclination.

-EcoMUVE has built in affordances to help students reflect upon their own cognitive tendencies—the importance of metacognition and higher order reflection.

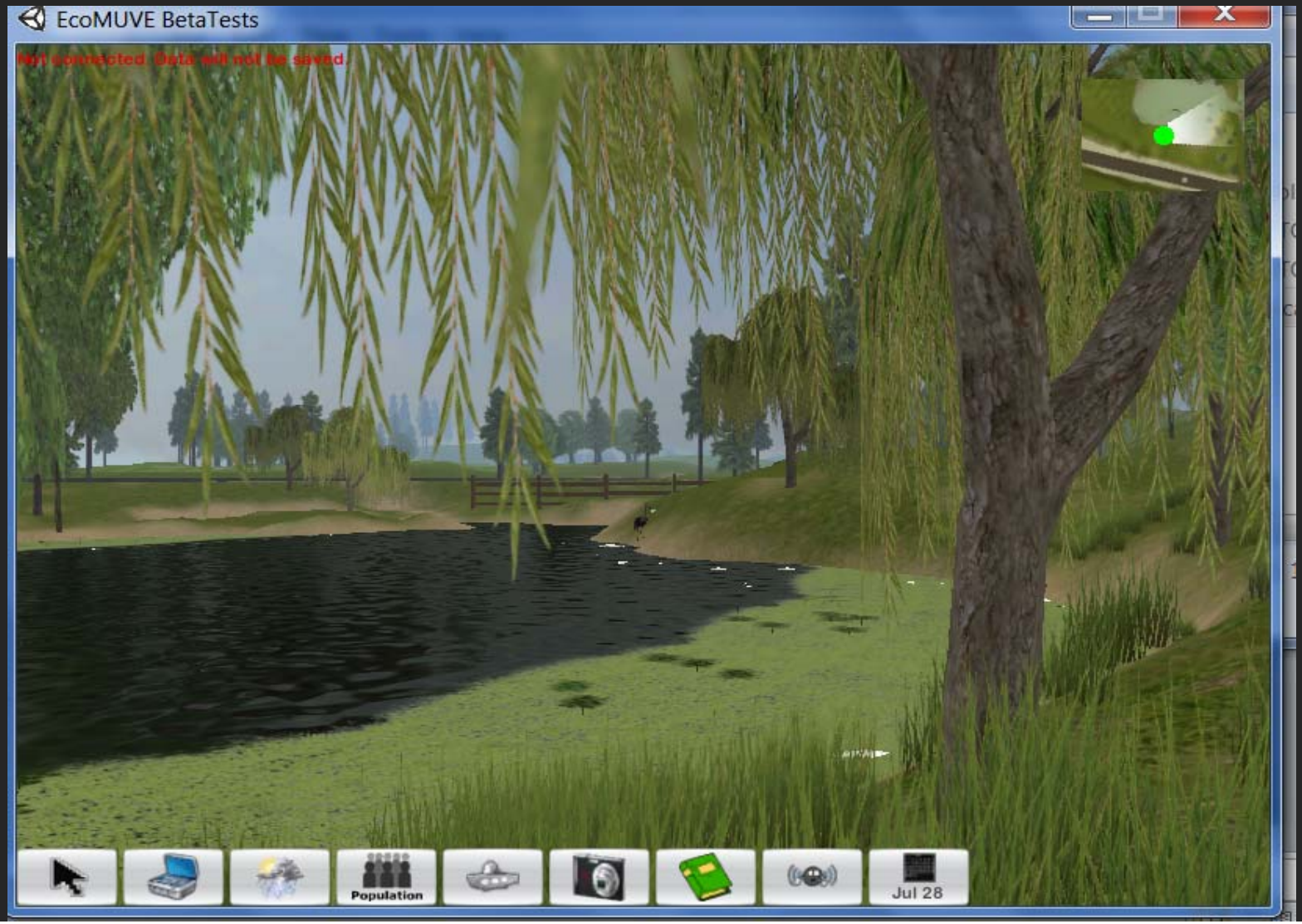
Features of EcoMUVE

- Zoom-in to the microbial world or out to macro-views (such as a population view).
- Ability to move to different points in the past or future. Ability to monitor the on-going state of systems.
- Testimony information is given by non-player characters.
- Ability to see the extended terrain, to reason about distant drivers to change in the ecosystem.
- Graphical representations can be contrasted to observations made in the world.

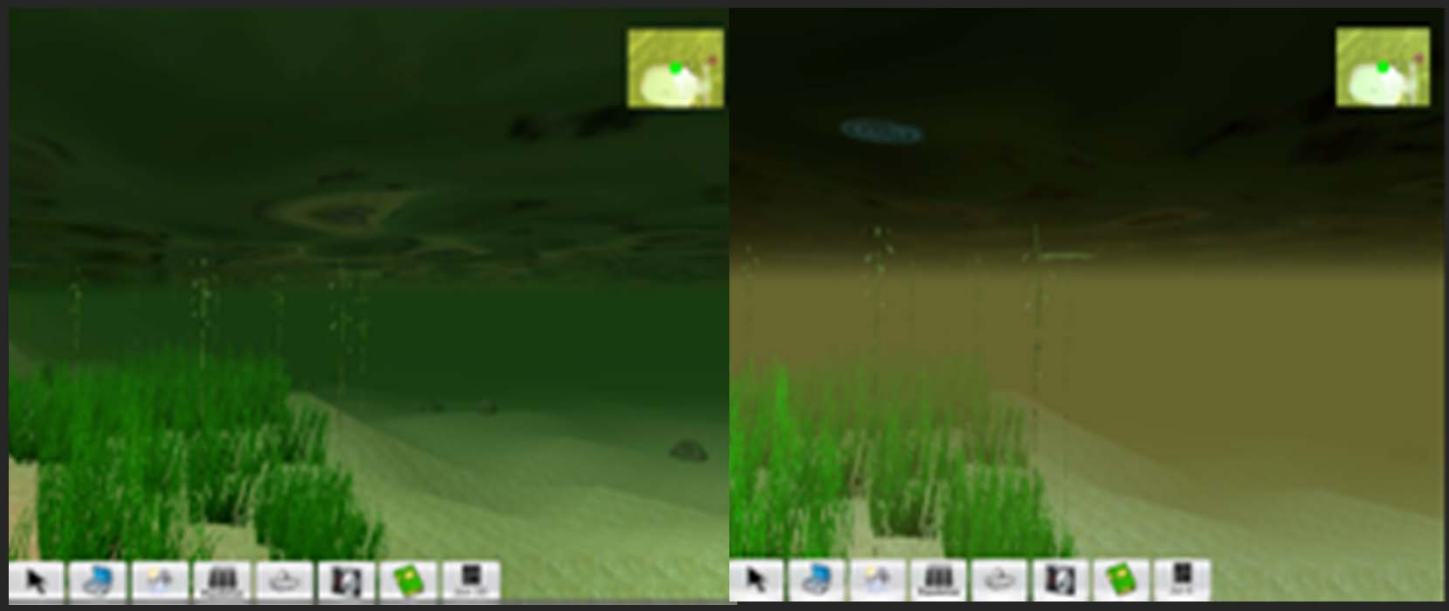
Learning About Variables That Might Be involved in the Mechanism



Problem-based but they have to discover the problem: An event grabs their attention…



Changes in Turbidity Over Time: Noticing Processes/ Change Over Time

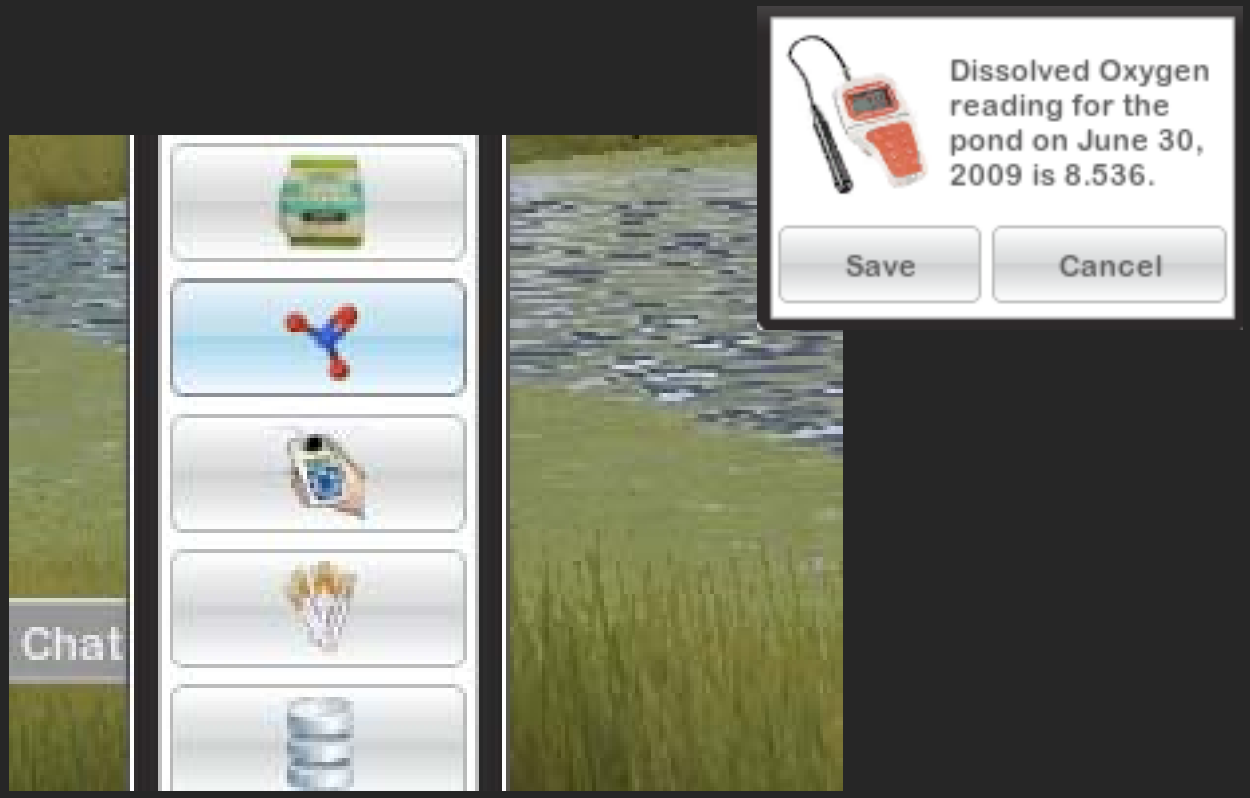


One can move back and forth in time.

Non-Obvious Causes

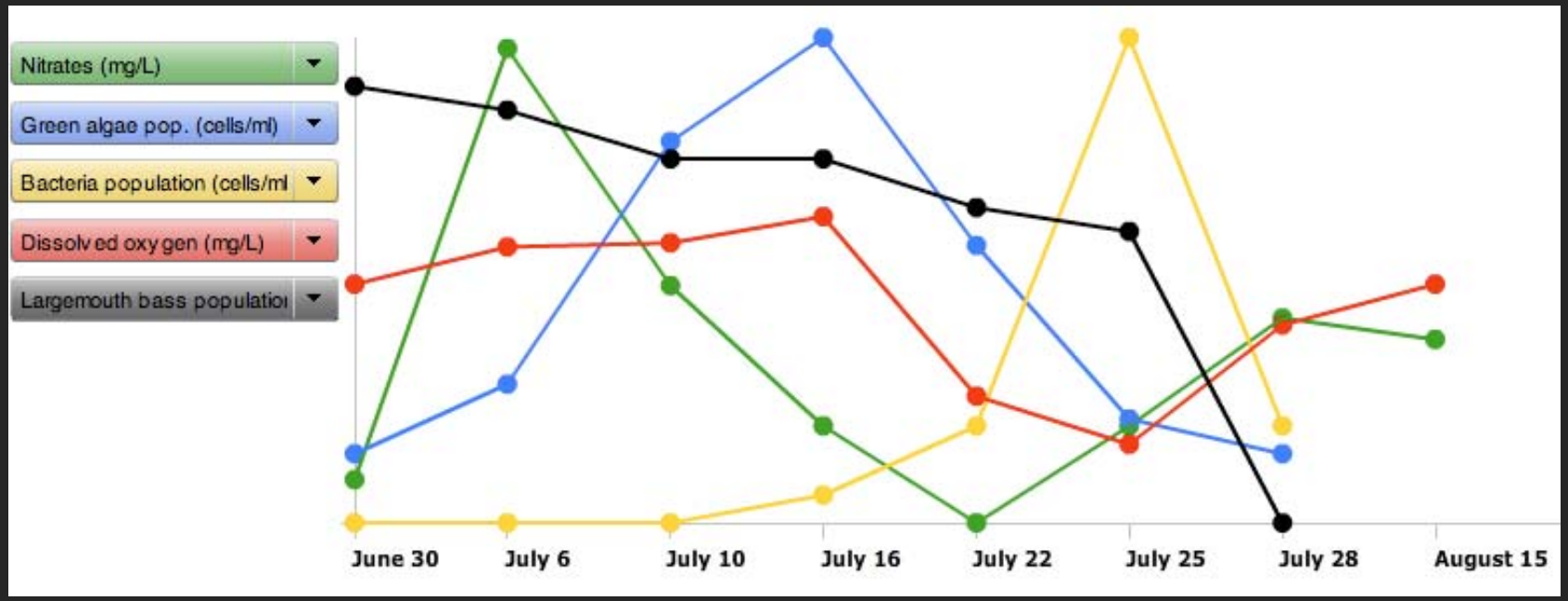
A submarine tool explores the microscopic organisms in the pond, helping students understand that organisms that they cannot see play a critical role in the pond ecosystem

Measurement and Monitoring



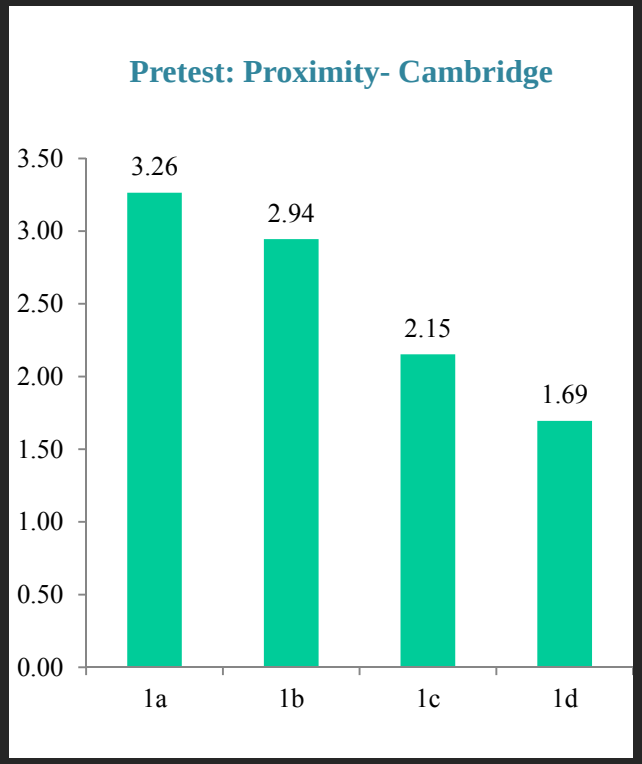
Students collect physical, chemical, and population data over time, graphing patterns to see relationships between behaviors and outcomes.

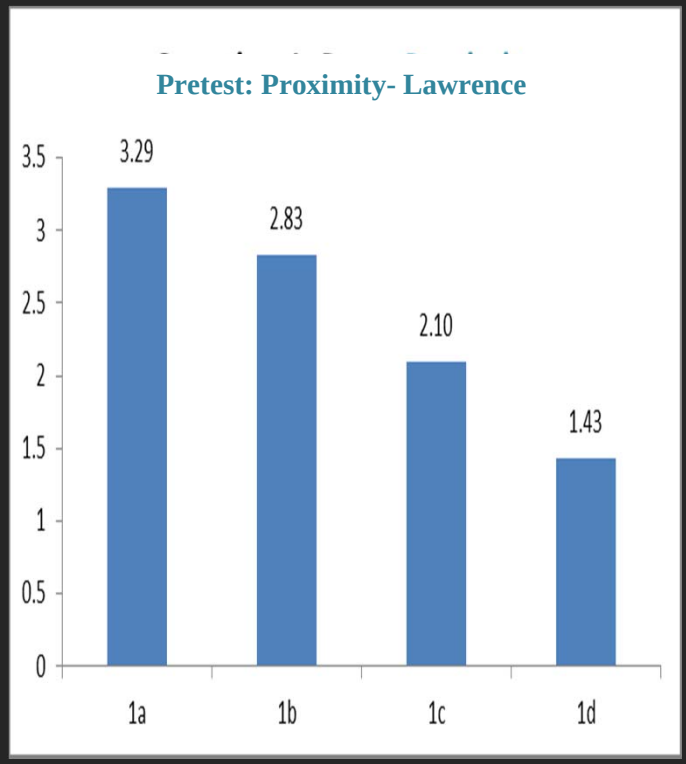
Graphical Representations



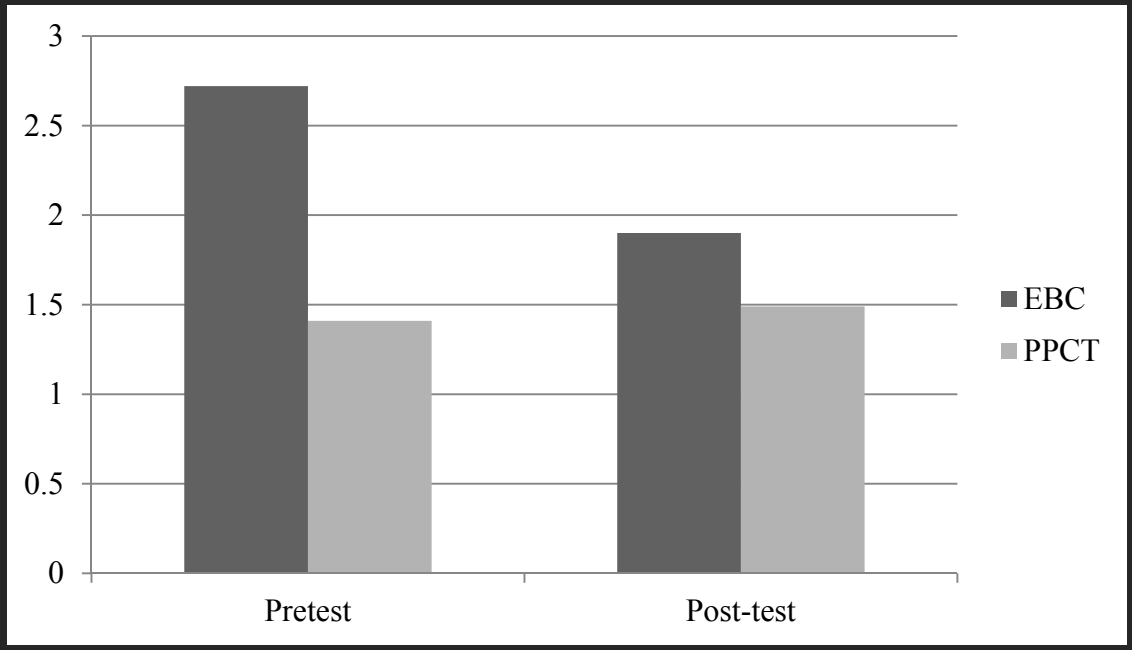
Action at a Distance: Runoff From Housing Development

Environmental Knowledge: Comparing Cambridge and Lawrence Students in Initial Assumptions





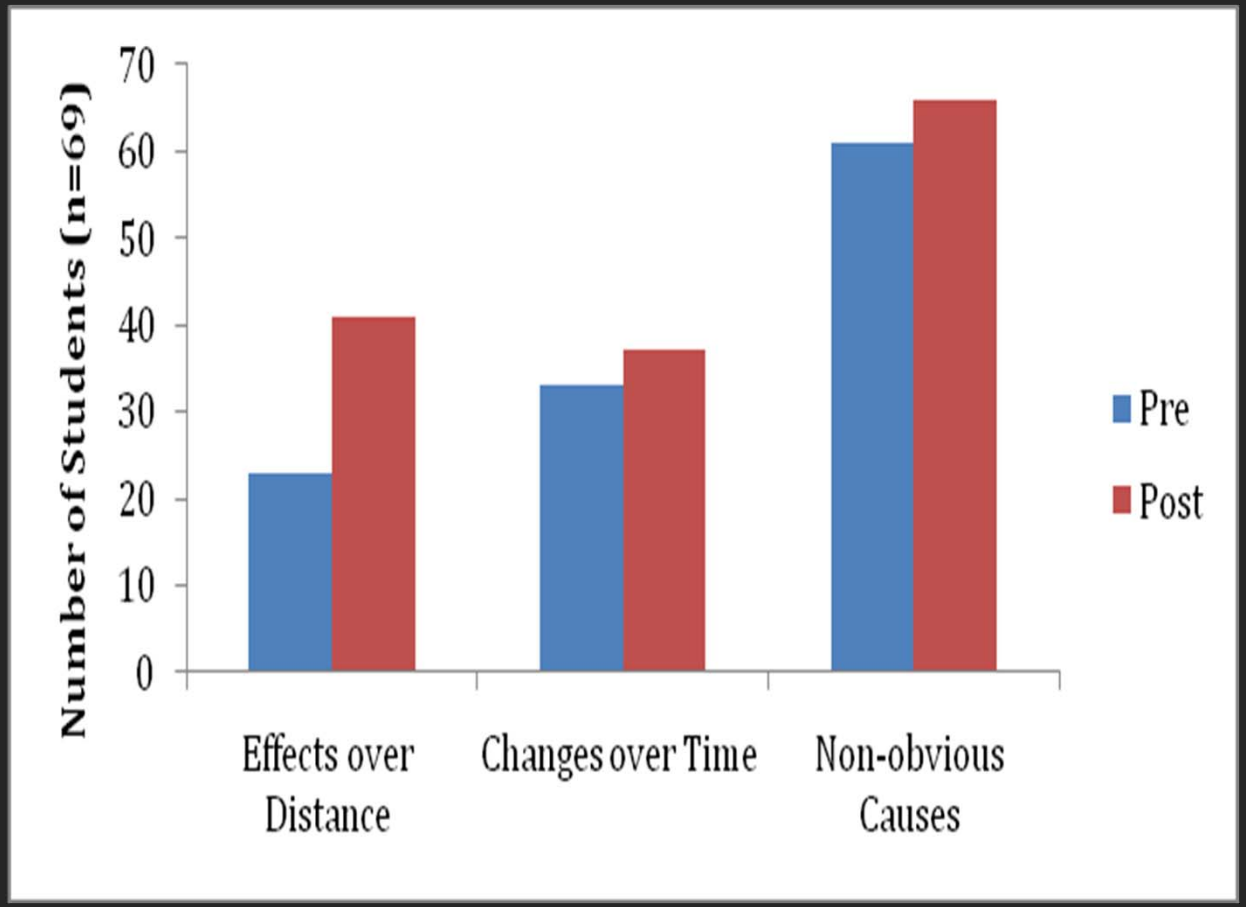
Reasoning about Events vs. Change Over Time



Pre-test: More EBC than PPCT explanations (EBC: M = 2.72 (SD = 1.50); PPCT: M = 1.41 (SD = 1.31) (M Difference = 1.31, t(77) = 4.47, p < .0001).
Post-test: No significant differences between EBC and PPCT explanations (EBC: M = 1.89, (SD = 1.49); PPCT: M = 1.49, (SD = 1.66), M Difference = 0.40 t(78) = 1.25, p > 0.05).

Grotzer, T.A., Kamarainen, A., Tutwiler, M.S, Metcalf, S, & Dede, C. (2013). Learning to reason about ecosystems dynamics over time: The challenges of an event-based causal focus. *BioScience, 63(4),* 288-296.

Pre- to Post-test Shifts



Distance, $\chi 2(1,69) = 14.73$, $p < .0001$), Changes over time $\chi 2(1,69) = 1.14$, $p > 0.05$); and non-obvious causes $\chi 2(1,69) = 2.77$, $p > 0.05$) ns

Metcalf, S.J., Kamarainen, A., Tutwiler, M.S., Grotzer, T.A. & Dede, C. J. (2011). Ecosystem science learning via multi-user virtual environments. *International Journal of Gaming and Computer-Mediated Simulations. 3*(1)86-90.

Measures that consider perceptual and attentional tendencies?

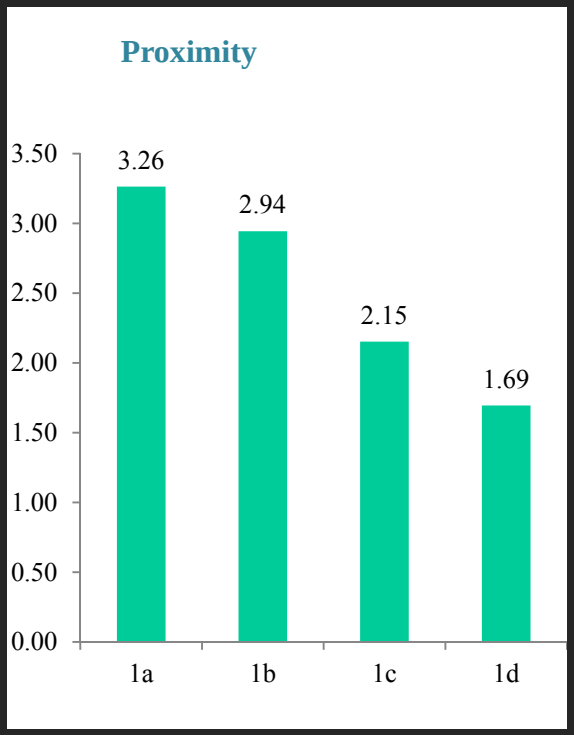
- Mapping of student movement
- Logfile data indicating how they spent their time
- The importance that they attach to particular variables in the EcoMUVE

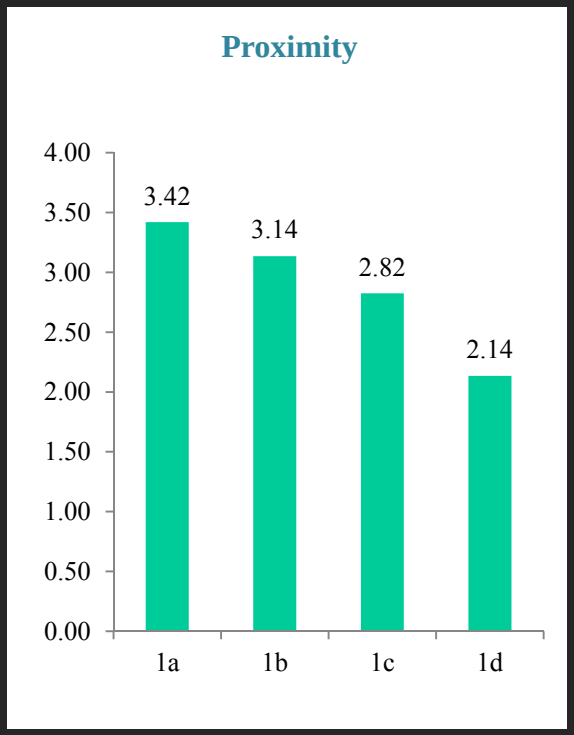
Studying Student Movement Within EcoMUVE

Shifts in What They Think Happened and What Variables They Attend to

- Day 3: Discover fish die-off, Make immediate assumption that sewage killed the fish. Sam says, “Yes, we know what caused it. The sewage.”
- Day 4: “I don’t think it was the sewage. I think it was the fertilizer.” – Zoe
- Day 5: “We figured it out.” – Zoe. “The day before it rained they were putting fertilizer on the golf course over here and on the instructions said not to put it on before it rains.” – Sam. “So it washed away, into the pond and killed the fish.” – Zoe

Subtle Shifts in Thinking About the Importance of Certain Kinds of Data?





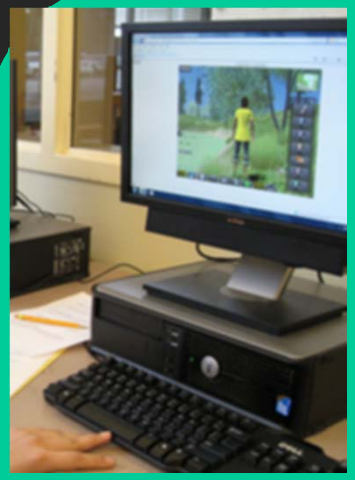
1= least important
4 = most important
a = most local
d= most distal

Forest Module

Settings

EcoMOBILE – Blended Learning Across Virtual and Natural Ecosystems


Fresh
AiR™
BLACK'S NOOK
GOLF COURSE
Starch
Water
Carbon Dioxide
Oxygen
Glucose
Location-Based
Augmented Reality
Playfreshair.com

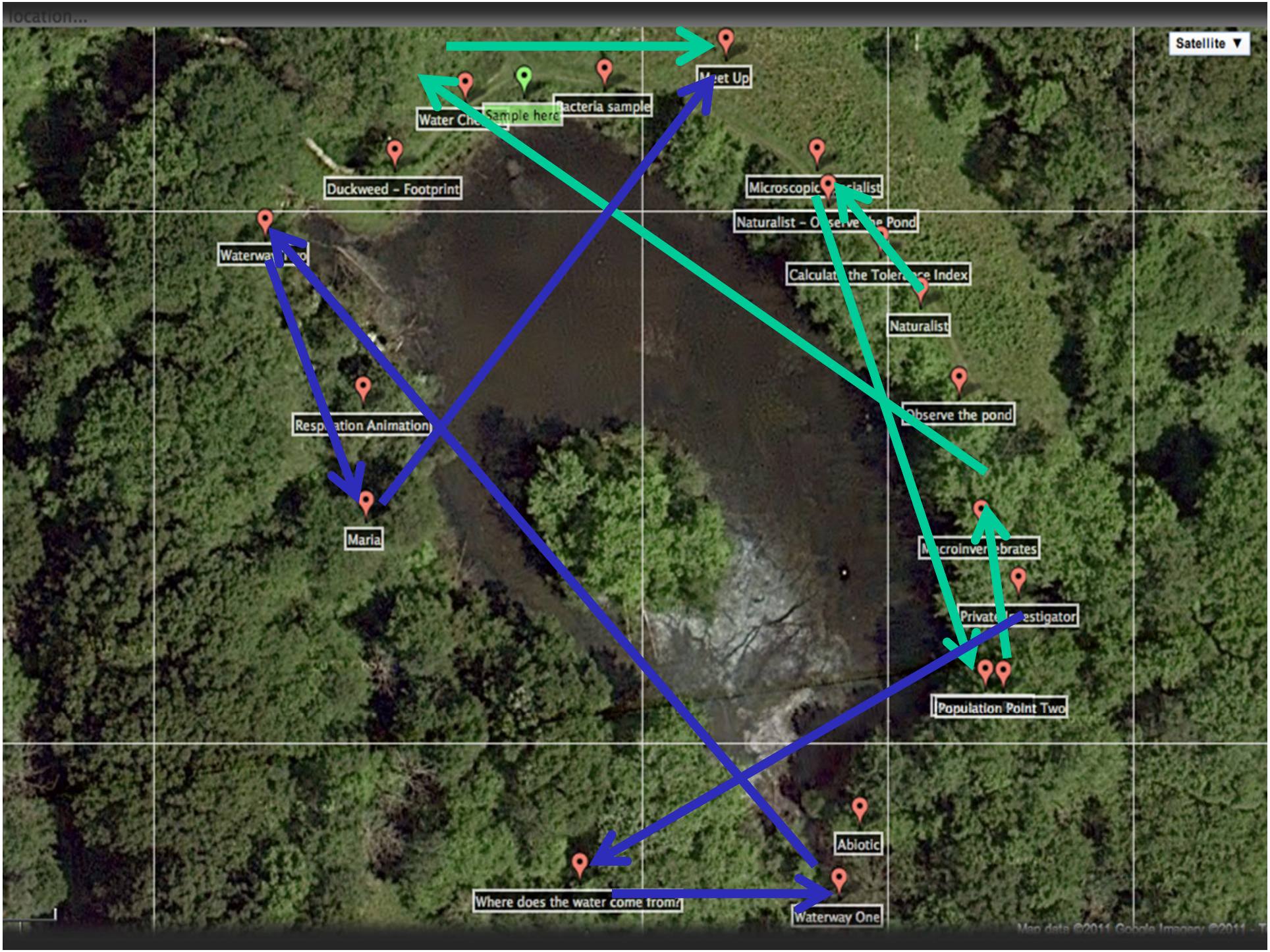


EcoMUVE

- Simulate experiences otherwise impossible in school settings.
- Explore time and scale
- Opportunities to take on roles, work in teams
- Shared immersive experience that contextualizes learning and supports inquiry

EcoMOBILE

- Greater fidelity and sensory richness, physical interactions with organisms and environments.
- Self-directed collection of real-world data and artifacts.
- Facilitated use of cameras, recording devices, probes, GPS, mapping, graphing, augmented reality.


Satellite
Meet Up
Water Ch
Sample here
acteria sample
Duckweed – Footprint
Microscopic
ialist
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serve
Pond
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Naturalist
Observe the pond
Resp
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Private
estigator
Population Point Two
Abiotic
Where does the water come from?
Waterway One

Virtual Binoculars

Time Transporter