Helping Students Learn More Expert Framing of Complex Causal Dynamics in Ecosystems Using EcoMUVE

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ABSTRACT

Research suggests that students make a different set of assumptions about the nature of the complex causal dynamics and systemic structure than ecosystems scientists do when reasoning about ecosystems dynamics (e.g. Grotzer & Basca, 2003; Hmelo-Silver, Pfeffer, & Malhotra, 2003). For instance, students are likely to assume that causes and effects behave in an event-like fashion, to act locally and within an abbreviated time span, and to assume obvious and observable causes. Seventh and eighth graders’ (n = 81) causal assumptions were tested early and late in the learning process as they worked with a Multi-user Virtual Environments (MUVE) called Eco-MUVE designed to simulate ecosystems patterns and structural causalities. The affordances designed into the Eco-MUVE enabled students to test their initial causal assumptions and to realize their limited explanatory power for solving an ecological problem posed within the virtual environment. Students’ later reasoning revealed shifts towards more expert framing of ecosystems causal dynamics for some of the ecosystems features such as action at a distance.

INTRODUCTION

Reasoning about complex causality is critical to learning about ecosystems, but research has demonstrated that students have difficulty conceptualizing ecosystems as systems and thinking about the inherent causal dynamics. Research shows that students often bring a limiting set of assumptions to their causal reasoning about ecosystems concepts (e.g. Grotzer & Basca, 2003; Hmelo-Silver, Pfeffer, & Malhotra, 2003)—ones that differ substantially from those of ecosystems scientists (e.g. Walker & Salt, 2006). A growing body of research in cognitive science underscores students’ tendency to focus on events not steady states or processes (e.g. Ferrari & Chi, 1998), to assume local causes and effects, immediate time frames, to focus on obvious causes in lieu of non-obvious causes when both are available (e.g. Grotzer, 2004).

A deep understanding of ecosystems concepts requires the understanding that ecosystems often are scaled such that one can have action at a distance, where impacts are felt far from their causes. There are often long time delays between causes and their effects, and often causes are non-obvious or act in concert with obvious causes. They may be distributed across many actors in space and time or due to natural causes without anthropogenic causes. The causal features inherent to ecosystem processes and relationships make it difficult to understand the dynamics involved in concepts such as energy transfer, matter recycling, decomposition, and the interaction between biotic and abiotic factors. Most middle school science curricula do not address these learning problems.

EcoMUVE is a multi-user virtual environment designed to support student learning of complex causality in ecosystems through a middle school ecosystems curriculum. It provides situated learning through immersion in a rich, interactive environment. Prior research with MUVEs for education (Clarke, Ketelhut, Nelson, & Dede, 2006) has found that MUVEs can be an effective platform for science inquiry. Addressing the ecological problems designed within EcoMUVE require students to realize the constraints of their limiting assumptions and to adopt new patterns of thinking about the ecosystem in order to solve them. EcoMUVE has affordances built in to scaffold students in this regard as discussed below. Situating causal concepts in the context of a MUVE-based “real-world” environmental problem and helping them to discover the limits of their
initial causal assumptions should help them to shift towards more scientifically valid ways of approaching ecosystem problems.

THEORETICAL UNDERPINNINGS

Tensions Between Everyday Patterns and Expert Patterns of Causal Reasoning

Our everyday causal reasoning looks different from that of ecosystems scientists in a number of ways that can impact how deeply and well students learn to perceive and reason about ecosystems dynamics (Grotzer, in press). Each of these tensions pulls against more expert reasoning.

Obvious vs. Non-Obvious Causes: Significant research has investigated how learners of different ages attend to obvious versus non-obvious variables. The causal learning research suggests that even very young children will search for a non-obvious cause when there is no obvious cause available (e.g. Shultz & Sommerville, 2006). Most children pursue a deterministic path and do not allow for causeless effects. However, these studies have focused on lab experiments where their attention is focused and the time frame for detection is constrained. Further, in the study of ecosystems, there may be many candidate obvious causes that are not necessarily the actual cause but that have salience for their ability to draw attention in ways that non-obvious causes are not able. A rich literature on multiple sufficient causes suggests that even adults are unlikely to pursue additional potential causes when a salient obvious possibility exists (See Grotzer, in press for a review.) So the question becomes not one of whether students can detect non-obvious causes when no obvious cause exists, but rather, are they able to look beyond obvious potential causes to continue their search for non-obvious possibilities. The science education research which focuses on more complex and confounded instances of causation reveals the many difficulties that students have when detecting causes that are non-obvious, abstract, or inferred in some respects (e.g. Frederiksen & White, 2000).

Spatially Local versus Action at a Distance: Physical contiguity or proximity is one of the factors that we use to assess the existence of causal relationships. Infants are surprised by the notion of action at a distance—the idea that causes and effects can impact each other without touching. Early Piagetian research focused on billiard ball type causality where there was physical contiguity between causes and effects (Piaget, 1929). Spelke and colleagues demonstrated in research using shadows that infants reveal surprise when shadows move in concert with the object that they relate to without touching (Spelke, Phillips & Woodward, 1995). By preschool, children do come to accept the notion of action at a distance (Kushnir & Gopnik; Schultz, 1982; Schulz & Gopnik, 2004)

These shifts correlate with children’s learning about causal domains beyond the physical to include psychological and social events and with amassing more experience in a world with different causal mechanisms such as clickers and remote controls (Sobel & Buchanan, 2009). However, in all of this research, it appears that the default assumption is to expect contiguity and to overrule it when covariation data suggests the need to, preferring deterministic causes even if there was not contact over probabilistic ones that did (Kushnir & Gopnik, 2007).

When the concept of action at a distance is considered in ecosystems science, it is on a very different scale. Rather than focusing on whether there is physical causation or not, the reasoner needs to consider a problem space with a very different set of parameters. Water sheds can extend many, many miles. The boundaries of the problem space can be action at a vast distance.

Event-Based versus Process-Oriented Causality: Our everyday notions of causality tend to be event-like (Grotzer, in press). The characterization is fundamental to how many philosophers and causal theorists define causes and effects (Sloman, 2005). However, this characterization departs from the way that the sciences typically construe causal systems. Being able to reason about processes and what are referred to as “pulse” and “press” disturbances to balance and flux...
over time and are characterized by resilience. Pulse disturbances refer to short-term oscillations where the system undergoes sudden changes but that do not result in significant modifications to the system and press disturbances refer to continuous disturbances that result in more permanent change (Bender, Case, & Gilpin, 1984). Note that these are characterized more by shifts in dynamic than by events.

Chi and colleagues (1997; Ferrari & Chi, 1998) have argued that one of the difficulties that students have in learning science is that they often assign the wrong "ontological status" to concepts, for instance, treating processes as event-like. They distinguish between events and equilibration, arguing that events often have distinct actions with a beginning, middle, and an end. These actions are often contingent or causal, and that they unfold in a sequential order. Events are "goal-directed" and are completed when the goal is achieved. In contrast, equilibration often involves many actions occurring at once. The actions can be random and independent and they have a net effect at a systems level. A continuous dynamic is in play.

Multi-user Virtual Environments

Dede and colleagues (Dede, 2009) have built and investigated a number of Multi-User Virtual Environments or MUVEs. These are 3-d worlds that offer a simulated immersive experience to students. Each student in the world has an avatar that allows them to move through the world and see through the eyes of. The world can be set up so that it offers affordances that the real world cannot. In this way, the MUVE has the potential to scaffold students towards more expert performance. It also holds greater potential for transfer given the similarities at both the surface and deep structural level between the real world and the simulated world (Goldstone & Sakamoto, 2003).

MUVEs are often built upon a problem-based learning platform. Centered on an ill-structured, complex problem, students identify questions involved in solving the problem and gather the information necessary to solve the problem. Unlike other PBL curricular that begin with a problem, EcoMUVE is designed so that an ecological issue arises over time. This is to support students in having an opportunity to adopt a process rather than an event-based view of the ecosystem. However, given that issues unfold and are detected by students, similar to PBL interventions, we expect student gains having to do with self-reliance, better engagement and attitudes towards learning (e.g. David, 2008; Krajcik & Blumenfeld, 2006).

Dede has studied MUVEs as vehicles for authentic, situated learning and has found that they authentic inquiry-based tasks (problem finding and experimental design) that result in an increase in students’ engagement and self-efficacy (Ketelhut, 2007; Nelson, 2007; Clarke & Dede, 2009; Ketelhut et al, 2010). Dede (2009) argues that extended, interactive experiences such as those enabled by MUVEs are necessary for learning complex processes.

STUDY DESIGN

Seventh and eighth grade students (n = 81) in three middle school classes participated in the study. They were introduced to the EcoMUVE at the beginning of the week and given an opportunity to explore it. After an ecological issue was discovered, students were given a written assessment which asked them to offer their initial insights into what might have happened and what patterns of inquiry they might undertake in order to ascertain what happened as well as whether they agreed with a series of statements or not. Students worked within the EcoMUVE for the remainder of the week and the following week and afterwards were given another written assessment asking them how they might then approach such a problem.

EcoMUVE Design
The EcoMUVE module comprises a one-week experience within a broader ecosystems curriculum. It represents a pond ecosystem (Figure 1). Students explore the pond and the surrounding area, even under the water, see realistic organisms in their natural habitats, and collect water, weather, and population data. Students visit the pond over a number of virtual “days” and eventually make the surprising discovery that, on a day in late summer, many fish in the pond have suddenly died. Students are challenged to figure out what has been going on—they work in teams to collect and analyze data, and gather information to solve the mystery and understand the complex causality of the pond ecosystem.

![Figure 1: Screenshot of EcoMUVE Pond Ecosystem](image1)

![Figure 2: Action at a Distance: Runoff From Housing Development](image2)

The EcoMUVE pond module represents a complex ecological scenario that includes a number of ecosystem and causality concepts. During the time period simulated by the EcoMUVE, the large fish in the pond die overnight—an event known as a fishkill. Fishkills are the result of a complex series of events and changes as follows.

Runoff from nearby housing developments carries excess fertilizer to the pond. The phosphorus and nitrogen in the fertilizer support algae growth, leading to an algal bloom. When levels of phosphate become too low to support further growth of the algae population, dead algae accumulate on the bottom of the pond. Bacteria, the dominant decomposers in aquatic ecosystems, consume the dead algae and the bacteria population increases. During decomposition, the bacteria use up a lot of the oxygen in the pond. Eventually, there is not enough oxygen produced during photosynthesis during one virtual day to support the amount of oxygen used during respiration that night. Dissolved oxygen concentrations in the pond became very low overnight, leading to the death of the large fish in the pond from inadequate oxygen.

**Complex Causality Within the EcoMUVE**

In order to solve the mystery, students must acknowledge the following types of complex causal features. The EcoMUVE incorporates a number of affordances designed to help students extend their recognition of the complex causal features within the ecosystem problem space, as follows.

**Recognizing Non-Obvious Causes:** Like authentic ecosystems, there are many salient, obvious potential causes in the EcoMUVE that compete for students’ attention. For instance, predators are present in the form of hawks, herons, and bigger fish. People walk the edges of the pond, and a heavy rain leads to a muddy appearance in the water. These salient potential explanations compete with the non-obvious factors: microbes; phosphates; nitrates; levels of dissolved oxygen and so forth. However, essential to expert reasoning about ecosystems is the tendency to push beyond what is obvious, to look for hidden causes that might account for outcomes even in the face of salient obvious explanations.

The EcoMUVE has a number of affordances built in as an attempt to encourage students to recognize the importance of pursuing non-obvious causes. EcoMUVE’s submarine tool allows students to explore the microscopic organisms in the pond, such as algae and bacteria, helping
them to understand that organisms that they cannot see do play a critical role in the pond ecosystem. It also introduces tools to measure and graph levels of dissolved oxygen and other non-obvious factors making up the chemical composition of the pond.

**Recognizing Action at a Distance and Where to Draw the System Parameters:** Where one draws the parameters of an ecosystem has considerable impact on how one construes the variables of importance. While it is typical to imagine the pond ecosystem as the immediate area surrounding the pond, ecosystems scientists draw far larger parameters that include the surrounding watershed. Becoming more expert in reasoning about ecosystems involves realizing the need to look beyond the local confines and to consider the broader regional influences.

EcoMUVE models the pond and surrounding watershed, including a nearby golf course and a housing development. Through exploration, students discover that fertilizer runoff from the development is the distant cause of an algae bloom at the local pond (Figure 2)—that human actions outside of the pond affect the pond ecosystem. The EcoMUVE environment has a number of characteristics that draw students’ attention to the broader ecological space. When first logging on, a map reveals the broader territory thus inviting learners to consider it. Research on action at a distance (Grotzer, Solis, & Tutwiler, 2011) reveals that when students can imagine a mechanism between cause and effect, they are more likely to consider action at a distance. Following a big rainstorm in the EcoMUVE, water fills a drainage pipe from the distant suburbs and can be followed to the pond—providing just such a mechanism. Other clues more local to the pond suggest that the golf course nearby is not the source of the problem because the caretaker has been attentive to the potential impact of the golf course on the pond and encourages students to keep on looking.

**Noticing Change over Time and Attending to Steady State Processes:** Attending to changes over time in any system involves sustained attention to that system. It was our expectation that subtly occurring changes in the EcoMUVE would not be detected until the fishkill event grabbed the students’ attention.

A number of affordances for recognizing change over time and event-based versus process-oriented causality are embedded in the EcoMUVE. Using a time-traveling calendar tool, students visit the pond on eight different dates over one-and-a-half months. On each date students may talk to residents or collect data and clues. Data they’ve collected is stored in a data table and students analyze temporal trends using a built-in graphing function. (Figure 3). Students also observe visual changes over time, like the color of the pond. (Figure 4). These clues provide evidence for the complex chain of events unfolding bit by bit over time. Within the EcoMUVE, subtle changes are occurring well before the fish kill that signal something is changing. Prior to the actual fish kill, fish are beginning to swim closer to the surface of the pond and begin taking gasps of oxygen from the pond’s surface.
**Assessment Design:** The assessment was designed to proceed from highly open-ended to structured questions to reveal how students would structure a response on their own and to assess particular ideas about the inherent causality in the problem. In Part 1, students were given five spaces to report their ideas about possible causes and were encouraged to add additional spaces if needed. Students were then asked to list as many ideas as they could about how they might figure out what killed the fish. In Part 2, students were asked to register agreement or disagreement about a series of statements pertaining to the possible causes and to explain their reasoning. It cannot be discounted that Part 2 resulted in some framing of the Part 1 answers. Students tended to work through the assessment from the first to the last question. However, some students might have read the questions on the back before completing the ones on the front. Further, it is possible, though not likely, that taking the complete test as a pretest may have impacted how students structured their post-test responses. Further research could investigate this possibility by including a control group that did not have access to the EcoMUVE and merely participated in a pre- and post-test with the same time frame in between.

**SCORING**

The data was scored blind as to whether it was a pre- or post-assessment by removing identifying information. Two independent coders scored the data until they reached between 85% and 95% agreement with one coder coding 100% of the data and the other coding 25%. Remaining cases were discussed until agreement was reached.

Part 1 answers were coded for whether they reflected causes that were/had: a) obvious versus non-obvious causes; b) local versus non-local causes; and c) event-based versus process–oriented as follows.

**Obvious vs. Non-Obvious Causes:** The protocols were scored for the types of causes that students focused on as likely explanations for the fish kill. Simulating a real pond, there were many obvious, perceptible potential causes to compete with non-obvious potential causes. For instance, herons slowly stalked the edges of the pond, bigger and smaller fish were clearly visible, and the very rainy weather gave the pond a brownish appearance following a particularly heavy rainstorm.

Obvious causes (OC) were coded as those that can be seen with the naked eye. A cause was scored non-obvious (NO) if it could not be seen with the naked eye; had to be inferred (at the level of a model like electrons and protons or at the level of a population effect such as an imbalance between the animals in the food web); or was not perceptible for some reason. Causes were not scored as non-obvious if they could be seen but the opportunity was missed (a person may have come to the pond at night when no one was around). Sample Obvious Causes included bigger fish; people polluting or throwing trash in the pond; overfishing; a death in the food chain; sharks; people putting toxins in the pond; visible invasive species, and the lack of food for fish. Sample Non-Obvious Causes included viruses, bacteria, salt, chemicals, global warming, toxins, pollution; limiting resources; lack of oxygen; fertilizer; invisible invasive species; and hunger.
Careful attention was paid to the ways that students framed their explanations. For instance, if students mentioned lack of plants for food, it was scored as an obvious cause unless they referred to microscopic plants. However, if they referred to hunger, then it was scored as non-obvious because presumably whether or not the fish were hungry would not be directly visible. “Toxins” were scored as non-obvious, yet “people putting toxins into the pond” was scored as obvious.

The affordances of the EcoMUVE make some typically non-obvious causes obvious. For the purpose of the analysis, these were treated the way that they would exist in the real world because we were assessing the impact of offering these affordances. However, variables that students would be unlikely to experience in either world were also scored as non-obvious. For instance, “rapid change in water temperature” was scored as non-obvious because you can’t directly perceive it in the EcoMUVE (where students are relying on visual perception) and it is unlikely that they would perceive changes in temperature in the pond in the real world.

**Spatially Local versus Action at a Distance:** The protocols were scored for where the students drew the parameters of the problem space leading to the eventual fish kill. Spatially local (SL) causes were those that occurred in the parameters of the pond and along the banks of the pond. Examples of local causes include “bigger fish took all the food in the pond;” “a disease spread in the pond;” or “there are toxins in the pond” (without accounting for where they came from). A cause was scored as spatially distant (SD) if it occurred beyond the banks of the pond. For instance, this included explanations such as, “salt from the road (running by the pond) leached in.” These are other causes that result from action at a distance. (AD) Here this is defined as beyond what can be seen when standing at the pond. In the EcoMUVE scenario, examples are references to the leaching of chemicals from golf course beyond the pond or to the housing development some distance away. Some causes have ambiguous origins (AO) as stated by the students. The answers might imply distributed action at a distance, such as “acid rain.” However, if the student didn’t explicitly talk about the cause as distributed and distant, (for instance, “people all over the world contribute to acid rain that falls into the pond”), then it was scored it as having ambiguous origins. This was also the case for causes that could have definable locations but the location was not specified. For instance, if students said, “salt got into the pond” but did not specify where unlike in the cases where students referred to the road nearby.

**Event-Based versus Process-Oriented Causality:** The EcoMUVE offered many subtle clues that processes were playing out over time, such as changes in the dissolved oxygen levels in the pond, differences in the temperature at particular depths, and changes in where certain sized fish spent their time. It also presented a fairly dramatic event in the fish kill that revealed many dead fish lying on the banks of the pond. The protocols were analyzed for how students envisioned the pond dynamics—in terms of events or processes that played out over time.

Some causes were scored as event-like, encompassing a kind of “event-based causality” (EBC) that focused on specific moments in time when something happens. Examples of event-based causes include “a sewage leaked into the pond” or “a truck dumped dirt with poisons into the pond.” Other causes were scored as processes or steady state (PSS) phenomenon. These are dynamics that are on-going over time. For instance, they refer to balance of populations, or a disease that is introduced to the fishes and slowly kills some and not others leading eventually to a fitter population. Examples of PSS phenomenon include a focus on the levels of dissolved oxygen in the pond. Comments that address balance and imbalance, and changes to those levels are considered process or steady state explanations. A PSS focus does not rule out comments about events, it just puts it in a different context. For instance, “the balance of predators to prey was disrupted” focuses on the dynamic over time and how disruptions interact with that dynamic.

Again, very careful attention was paid to the exact wording that students used. Thus statements such as “poison leaked into the pond” were scored as event-based causality while statements like
“poison slowly leaked into the pond over time and it accumulated and hurt the fish” were scored as process comments.

Adequacy of the Explanations: The scoring of the causal features above did not hinge upon the adequacy of the explanation in accounting for what happened to the fish. For instance, “overfishing” does not adequately explain in a direct way why there are many dead fish on the banks of the pond in the EcoMUVE. While the adequacy of the explanation is critical to the eventual scientific explanation within the EcoMUVE, the focus here was on how the students framed the causal features and whether there were shifts in how expertly they did so.

Part 2 answers contained binary and open-ended questions designed to elucidate student understanding of the causal mechanisms at play in the EcoMUVE. Each statement indicates the mayor’s tendency to believe that causal agents must be 1) in close proximity to the effects, 2) temporally immediate, and 3) clearly visible. Students are first asked if they agree or disagree with his assertions, and are then asked to explain why. The binary (agree/disagree) questions are coded as such, while the open-ended questions were coded first for consistency with the binary responses and those in agreement with the binary coding were included (n = 69).

ANALYSIS AND FINDINGS

Part 1:

Table 1 illustrates students’ tendencies towards certain kinds of explanations on the pre-test in comparison to the post-test. On the initial assessment, as expected, students gave significantly more local explanations than distant ones (Spatially Local: M = 3.45 (SD = 1.35); Spatially Distant: M = .59 (SD = .79) (Mean difference = 2.89, t(73) =13.20, p < .0001). They tended to focus on the pond itself rather than the pond in its surroundings. They also gave more event-based explanations than process and steady state explanations (Event-based: M = 2.72 (SD = 1.50); Processes and Steady States: M = 1.41 (SD = 1.31) (Mean difference = 1.31, t(77) = 4.47, p < .0001). They tended to focus on “what happened” as opposed to “what was happening.” Students talked “finding out what was happening on the days before” (s164); “what happened in the last few days?” (s117).

Interestingly, they did focus on non-obvious causes to a greater extent than obvious ones. (Obvious Causes: M = 1.66 (SD = 1.02); Non-Obvious Causes: M = 2.46 (SD = 1.23) (Mean difference = -.79, t(77) = -3.56, p < .0006). This was surprising and bears further investigation. It is possible that the many affordances in the EcoMUVE influenced this reasoning but it is not possible to know prior to running data that has a control group.

The pre to post-test analysis showed significant shifts in student reasoning in the following categories: significantly fewer spatially local explanations (mean difference = .69 (t(77) = 3.22, p < .0018). On the pretest, students talked about the importance of, “looking at the water” (s118); “finding out what was happening on the days before” (s164); “what happened in the last few days?” (s117). On the post-test, students mentioned wanting to find out the population levels (“the fish population; algae population; bacteria population; dissolved oxygen; phosphates” (s153)). There were also answers framed more in terms of action at a distance (“acid rain; chemical gets in pond from factory; chemicals from cars in water” (s 124)). It also showed significantly fewer obvious causes (mean difference = .91 (t(77) = 7.50, p < .0001);

Students gave significantly less event-based causal explanations (mean difference = .83 (t(75) = 3.75, p < .0003) on the post-test (with no significant difference between the response types. (Event-based: M = 1.89, (SD = 1.49); Processes and Steady States: M = 1.49, (SD = 1.66), Mean difference = .40 t(78) = 1.25, p > .05). Students gave significantly fewer event-based responses on the post-test as compared to the pretest (mean difference = .83 (t(75) = 3.75, p < .0003). In analyzing the types of explanations that students gave, they tended to focus on long causal chains of events when they understood the connection between the fertilizer and the fish kill.
Table 1. Comparisons of Reasoning Tendencies on Pre and Post-test

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<tr>
<th></th>
<th>Pretest</th>
<th>Post-test</th>
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<tr>
<td></td>
<td>Mean difference = 2.89</td>
<td>Mean difference = 2.25</td>
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<tr>
<td></td>
<td>t(73) = 13.20, p &lt; .0001</td>
<td>t(76) = 11.68, p &lt; .0001</td>
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<td>Spatially Local vs.</td>
<td>M = 3.45 (SD = 1.35)</td>
<td>M = 2.77 (SD = 1.29)</td>
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<td>Spatially Distant</td>
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<tr>
<td>Causes</td>
<td>M = .59 (SD = .79)</td>
<td>M = .55 (SD = .78)</td>
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<tr>
<td></td>
<td>Mean difference = -.79</td>
<td>Mean difference = -1.91</td>
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<tr>
<td></td>
<td>t(77) = -3.56, p &lt; .0006</td>
<td>t(80) = -10.37, p &lt; .0001</td>
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<tr>
<td>Obvious vs.</td>
<td>M = 1.66 (SD = 1.02)</td>
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<tr>
<td>Non-Obvious Causes</td>
<td>M = 2.46 (SD = 1.23)</td>
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<td>M = .74 (SD = .77)</td>
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<td></td>
<td>Mean difference = 1.31</td>
<td>Mean difference = .40</td>
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<tr>
<td></td>
<td>t(77) = 4.47, p &lt; .0001</td>
<td>t(78) = 1.25, p &gt; .05</td>
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<tr>
<td>Event-Based Explanation</td>
<td>M = 2.72 (SD = 1.50)</td>
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<td>vs. Processes and</td>
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<td>Steady States</td>
<td>M = 1.41 (SD = 1.31)</td>
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<td>M = 1.49 (SD = 1.66)</td>
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Interestingly, students who had learned a lot about the scientific explanation by the post-test often retained "event-based wording" for the problem—viewing it as something "that happened." Many of these were in the form of linear, domino-like narratives. For instance:

"The fertilizer got into the water (which contains extra nutrients such as phosphates). The algae population increased because they got extra nutrients. This somehow affected the fish." (s117)

"The fertilizer run-off went into the stream and then into the pond and then pond, the algae grew a ton. Bacteria thrived. When fertilizer wore off, algae stopped growing. With all the CO2 released from the decomposition of the algae, the fish went back to their maker. (s167)

However, other students adopted slightly more process language:

"dissolved oxygen levels; nitrates; phosphates; temperature; algae levels" (s111)

"too little phosphates; too little oxygen, population change in organisms in food chain, amount of algae in the food chain changes." (s135) This student also referred to the importance of monitoring the amount of oxygen, phosphates, etc. in the water everyday.

There were also mixed answers "food chain broke; limiting resources; not enough oxygen." (s128)

However, it appears that they moved from an event-based notion to a series of events in terms of thinking about what happened. This is a step in the right direction and may serve as an intermediate level model to reasoning about steady states over time.

Part 2.

Part two looked at the data on whether students agreed or not with certain ideas about what was important to investigate in the ecosystem. (Figure 6). Students demonstrated significant increases in understanding the importance of effects over distance in analyzing ecosystem problems (McNemar test, $\chi^2(1,69) = 14.73$, $p < .0001$). Scores on questions related to changes over time also increased, though these results were not significant (McNemar test, $\chi^2(1,69) = 1.14$, $p >$
Scores also increased slightly on the question about non-obvious causes, but the gains were not significant, likely because students’ high pre-survey scores indicate that they already had an appreciation for non-obvious causes at the time of the pre-assessment (McNemar test, \(\chi^2(1,69) = 2.77, p > 0.05\)).

The initial analysis indicates that students often mention non-obvious causes (disease, changing oxygen levels, drop in water temperature), but situate their explanations proximally and temporally near the pond on the day of the fish kill (e.g., water temperature dropped the day before). Intentional responses were also common, such as “Some sort of toxin was dumped in the water” or “Someone threw something in the lake.” On the post-assessment, students were more likely to realize that causes could originate at a great distance, or at a previous time. For instance, as one student wrote, “the effect could have started months ago…”

DISCUSSION

The underlying causal dynamics of ecosystems are complex and yet students must know how to reason about them in order to live sustainably in the world. Our initial findings on causal understanding showed some increases in understanding of effects over distance, and in the kinds of information that they would need to monitor to be able to manage ecosystem dynamics and population behaviors. The shifts reported here are a small part of the bigger challenge but are important pieces to the puzzle of how we help students to better understand ecosystems dynamics. They are also important aspects of designing effective instruction.

This research suggests that it is possible to construct learning contexts that help students to shift their thinking about these broad level ecosystems concepts. This is particularly important given how challenging it can be to teach ecosystems dynamics in the classroom. Teachers with whom we have worked over the years have struggles to convey concepts across time and distance with simulation games and stories but found hands-on experiences more difficult because the concepts play out over time and space. The results here will help to offer ideas for instructional support and discussion guides to help teachers use the EcoMUVE effectively.

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REFERENCES


There are a lot of dead fish at Scheele Pond! What do you think may have caused the fish to die? List as many ideas as you can think of.

1. 

2. 

3. 

4. 

5. 

(Use the back of the paper if you would like more space.)

What information would you like to find out to help figure out what killed the fish? List as many ideas as you can think of.

1. 

2. 

3. 

4. 

5. 

(Use the back of the paper if you would like more space.)
Answer the following questions about the dead fish at Scheele Pond.

The mayor told the local news what he considered to be the most important things to do to find out the cause of the fish kill. For each one, circle whether you agree or disagree that it is one of the most important things to do and tell why you agree or disagree.

1. “We need to focus on the area right around the pond. One of the most important things to do is to find out about the things that have happened within a few feet of the pond’s edges.”

Circle one:  I agree  I disagree

Why do you agree or disagree?

2. “We need to focus on the last couple of days. One of the most important things to do is to see what has been going on in the two to three days before the fish died.”

Circle one:  I agree  I disagree

Why do you agree or disagree?

3. “We need to focus on the things that we can see. If we just look, the problem will be obvious.”

Circle one:  I agree  I disagree

Why do you agree or disagree?