Learning to Reason about Ecosystems Dynamics over Time: The Challenges of an Event-Based Causal Focus

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Expert reasoning about ecosystems requires a focus on the dynamics of the system, including the inherent processes, change over time, and responses to disturbances. However, students often bring assumptions to thinking about ecosystems that may limit their developing expertise. Cognitive science research has shown that novices often reduce ongoing patterns and processes to events across diverse science concepts. A robust, event-based focus may exacerbate student difficulties with reasoning about ecosystems in terms of resilience and change over time. In this study, we investigated middle-school students' initial reasoning about ecosystem dynamics and analyzed promising shifts in their reasoning after they interacted with a virtual environment with features designed to support thinking about change over time. Some students adopted a domino narrative pattern—a sequential story about the events and processes. The findings suggest that educators should consider the possibility that novices will bring event-based framing to their ecosystems learning.

Keywords: ecosystems dynamics, disturbances, learning to reason about ecosystems events, change over time

In recent decades, as ecosystem science has shifted from "a focus on the successional development of equilibrium communities" (Pickett and White 1987, p. xiii) to consideration of ecosystems dynamics in the form of resilience models (e.g., Walker and Salt 2006), a greater emphasis is placed on concepts related to processes, change over time, and responses to disturbances. Learning to reason about ecosystems involves learning about these concepts and dynamic interactions. Ecosystems scientists bring a sophisticated and nuanced disciplinary repertoire to their reasoning. This allows them to notice events within an ecosystem; to contextualize those events within longer-term processes, patterns, and change over time; and to consider both proximate and ultimate causes in their explanations. Novices lack this disciplinary knowledge, and according to the science education research, they tend to make default assumptions that interact with how they reason about ecosystems dynamics. For instance, they tend to constrain the spatial scale, miss nonobvious causes in the presence of more obvious possibilities (Grotzer et al. 2011), and focus on surface-level structure instead of deeper patterns (Hmelo-Silver et al. 2007). Among these patterns is a robust tendency of the students to focus on events and the proximate causes of those events more than on processes (Chi 1997, Ferrari and Chi 1998) and patterns over time. This tendency may interact with novices' ability to learn more expert conceptions—how they reason about events and processes in the context of longer-term patterns and changing dynamics over time.

Event-based reasoning as a default tendency

A considerable amount of research literature in cognitive science is focused on *events* as the basic units of how humans parse and characterize experience (e.g., Davidson 1969, Avrahami and Kareev 1994, Strickland and Keil 2011). This research suggests that event-based parsing allows the creation of units that enable easy recall (Minsky 1977, Schank and Abelson 1977, Nelson 1986). Cause-and-effect relationships are one of the structures that people use to delineate events (Davidson 1969, Avrahami and Kareev 1994), and some philosophers and causal theorists define *causality* (Sloman 2005) as event-like: A cause happens and is followed by an effect.

There is also evidence that people distort information to create event-like causal conceptual coherence (Bransford and Johnson 1972) even when it does not fit with the available cues. Memory is strongly inf uenced by what happens

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after an event (Strickland and Keil 2011), and people tend to revise what clues existed leading up to an event—a retroactive filling in of the causal information needed to fit a cause–effect structure. The tendency may affect our ability to attend to patterns over time without parsing them as events. This causal event-based characterization can be contrasted to a broader notion of causality as involving steady states, feedbacks, cyclic patterns, dynamic relationships, and occasional disturbances and thresholds, in which the primary characterization of *causality* is not event-like.

Events have attentional pull. Research on perception, attention, and cognition reveals that people perceive information implicitly on an ongoing basis and that certain stimuli have the capacity to grab our attention to garner our explicit perception (Mack and Rock 1998). Longer-term patterns, such as ongoing processes and change over time, are less perceptible and blend with the status quo, becoming the background information against which discrete (or more dramatic) changes are assessed. Changes measured against this backdrop represent one way in which cognitive scientists have conceptualized events: as transformation (Gibson and Spelke 1983) or as changes or disturbances to the status quo (Rosch 1978). Therefore, in contrast, these longer-term patterns can suffer from a lack of salience. The changes involved in events may evoke dramatic imagery that draws attention back toward them (Tversky and Kahneman 1982). Slow changes, such as erosion, species decline, or accumulating greenhouse gases, typically lack dramatic imagery unless there is significant accumulation.

As we attempt to bridge uses of the terms *events* and *processes* in the cognitive sciences and in ecosystems science, some clarifications are necessary. By *events*, from a cognitive science and science education perspective, we mean discrete occurrences within a delineated time period that are characterized by a beginning and an ending. Chi (2005) argued that events often have distinct actions that are contingent or causal and that unfold in a sequential order. Although this definition fits with the findings from cognitive science and education in terms of characterizing students' default tendency, it contrasts with the richer, more contextualized notion of *events* held by ecosystems experts, as it is elaborated below. In the science education literature, *processes* can also be time delineated, but they are characterized as phenomena that take place over time, such as the process of erosion or dynamic weather changes due to pressure differentials. Discrete events may occur within processes. Below, we contrast this novice event-based focus with more expert notions that have a contextualized focus, in which events are placed in the context of patterns, process, and change over time and in which understanding of resilience, disturbances, and dynamic relationships and their interactions in the broader context of change over time is necessary (see table 1).

Table 1. Novice and expert conceptions of **ecosystems dynamics.**

Novices	Experts
Tend to focus on events	View events within a broader context, including pulse and press conceptions, disturbances, and recovery
See balance in snapshots (they see the system as balanced or not) and see balance as a goal	Frame balance in a context of dynamic equilibrium, resilience, and multiple basins of attraction; are aware of stabilizing or destabilizing feedbacks within the system, and see imbalance as the normal state
Suggest simple linear cause-and-effect patterns	Are aware of interactions and relationships among variables and of multiscalar drivers and responses
Are limited to a short, delineated time frame	Consider the ecosystem at multiple time scales, attend to longer-term patterns, address both fast and slowly changing variables, and attend to variability and rates of change

Expert reasoning about ecosystem dynamics

A focus on relationships and processes, along with attention to drivers of and responses to change, is an important aspect of reasoning about ecosystems. In recent decades, expert conceptions have shifted toward a resilience perspective (Folke 2006) that is focused on characterizing variability across scales and understanding patterns and processes of disturbance. In classical ecology, an ecosystem was characterized by balance and equilibrium (Sander et al. 2006); in current conceptions, imbalance represents the normal state, and nonlinearities and surprises are the norm (Folke 2006).

Ecosystem experts often think about events within the theoretical framework of ecological disturbance. Rather than thinking of a disturbance as a single event, experts characterize disturbances as *pulse* or *press* events, referring to relatively discrete (possibly recurring) events or to prolonged (sometimes directional) perturbations to an underlying system or process, respectively (Glasby and Underwood 1996, Smith et al. 2009). Disturbances occur in a context of change over time, and experts reason about processes, interactions between fast and slow variables, the legacy of past disturbances, delays, and extended time scales (e.g., Carpenter and Turner 2001) rather than a snapshot of the disturbed ecosystem at a single time. This expert framing calls on disciplinary assumptions that depart from how laypeople typically think of disturbances. Pickett and White (1987) wrote about what they called "processes of disturbance" and noted that disturbances "include not only coarse-scale infrequent events like hurricanes but the shifting mosaic of badger mounds in a prairie" (p. xiii). Expert conceptions indicate an underlying understanding of the multiscalar and dynamic nature of disturbance. We offer an example of how experts might bring their disciplinary knowledge to reasoning about an event in a pond ecosystem below.

The difficulties associated with an event-based focus in science learning

Cognitive science research suggests that a default tendency of focusing on events can create difficulties for learning science. Chi (1997, Ferrari and Chi 1998) found that students often assign the wrong ontological status to concepts—for instance, treating electrical current as matter instead of as a process. The *ontological status* of a concept refers to the fundamental nature of that concept (Chi et al. 1994). How a concept is categorized in the mind of a learner affects how easily conceptual change will take place. If students fundamentally categorize a concept differently from the way in which scientists do, learning is more difficult. Furthermore, the salience of the concept matters. Students tend to focus on properties that are visible in the everyday world and rarely attend to processes (Sander et al. 2006). Students tend to treat the processes involved in diffusion and electricity, for example, as event-like (Chi et al. 2012).

Adopting discrete, event-based framing in the form of simple cause-then-effect relationships can lead to linear notions of ecosystem dynamics and to missing more complex patterns, such as reciprocal and cyclic relationships (White 1989, Green 1997, Grotzer and Basca 2003). Assaraf and Orion (2005) found that 66% of the middle-school students that they tested described dynamic relationships as static, that they viewed balance or imbalance as discrete events (a system is balanced, or it is not), rather than in terms of dynamic equilibrium over time. Even student teachers initially gave nonlinked, sketchy explanations of cycles and processes (Magntorn and Helldén 2005). Learners also struggle with the many time scales at which one can analyze ecosystems (Dodick and Orion 2003).

EcoMUVE: Supporting the development of more expert reasoning?

Dede (2009) designed and investigated multiuser virtual environments (MUVEs). These three-dimensional virtual worlds invite students into an immersive simulated experience that offers learning support that the real world cannot and extended, interactive experiences for learning complex patterns. EcoMUVE is a MUVE designed to help students learn about ecosystem dynamics (Grotzer et al. 2011, Metcalf et al. 2011). The types of support within EcoMUVE, which are described below, might help students develop a more contextualized focus on events in ecological explanations.

The EcoMUVE module used in the present study represents a pond and its surroundings, including a golf course and a housing development. Students visit the pond (figure 1) over a number of virtual days in summer, using their avatars to explore the environment; to see realistic organisms in their natural habitats; to talk to embedded characters; and to collect water, weather, and population data. Moving within EcoMUVE helps the students to become aware of its features. The avatars walk uphill to a housing development and

Figure 1. Screenshot of the opening screen of the EcoMUVE pond module.

down along a drainage ditch, where the students may notice water flowing into the pond. Linked visual representations reinforce abstract concepts; the students can measure pond turbidity and can link the measurements to their experiences walking under the water and seeing how murky it looks on different days. Virtual agents, such as a park ranger, a dog walker, and a lawn care professional, offer information, including observations about how many herons are at the pond, how muddy the water looks, or that the lawns of the houses are being fertilized.

In most problem-based scenarios, students are given a problem to solve, whereas in EcoMUVE, in order to simulate how real ecological problems may arise, they must discern the problem themselves. Over time, changes occur within the pond. These changes are subtle but detectable, both visually and through measurements of water quality. Eventually, an attention-grabbing event occurs: The large fish in the pond die overnight. We hypothesized that, initially, the students might try to explain the die-off as a discrete occurrence, but the support and available evidence built into EcoMUVE might lead them to a more elaborate and contextualized explanation focused on longer-term patterns in the simulated environment.

An expert interpretation of the fish die-off would include attention to the relationships and interactions among the chemical, biological, and physical patterns in and around the pond. Experts might monitor the levels of phosphate, nitrate, and dissolved oxygen as part of their regular study of the pond, but if they did not, the fish die-off would draw their attention to these relationships. They might then look for patterns such as which fish died and where the remaining fish are swimming; they might consider regular patterns, such as diurnal ones, in addition to less regular ones, such as especially high temperature levels. They might consider the history of patterns in the pond and the surrounding landscape. This expert stance attends to the event as important information and contextualizes it within a broader context that includes proximal and distal causes. As is illustrated in figure 2, EcoMUVE simulates a scenario in which the proximal cause of the fish die-off is low dissolved oxygen concentrations in the pond during a particularly warm and windless night, but the ultimate cause is the process of eutrophication driven by excessive fertilizer runoff and the consequent algae growth and decomposition. Understanding the fish die-off involves recognizing the role of distant drivers of change, such as fertilizer that was applied in the watershed and ran off into the pond during a recent storm.

The students have opportunities to make observations and to take measurements of ecosystem components and their interactions. *Learning quests* (additional computer-based minimodules) focused on respiration and photosynthesis are included to support learning about processes that lead to an increase (e.g., photosynthesis, mixing) or a decrease (e.g., [bacterial] respiration, warming temperatures) in dissolved oxygen concentrations in a pond and about the typical ranges for water quality measurements, learning that monitoring these levels is part of understanding the longer-term patterns in the ecosystem, and learning how processes and

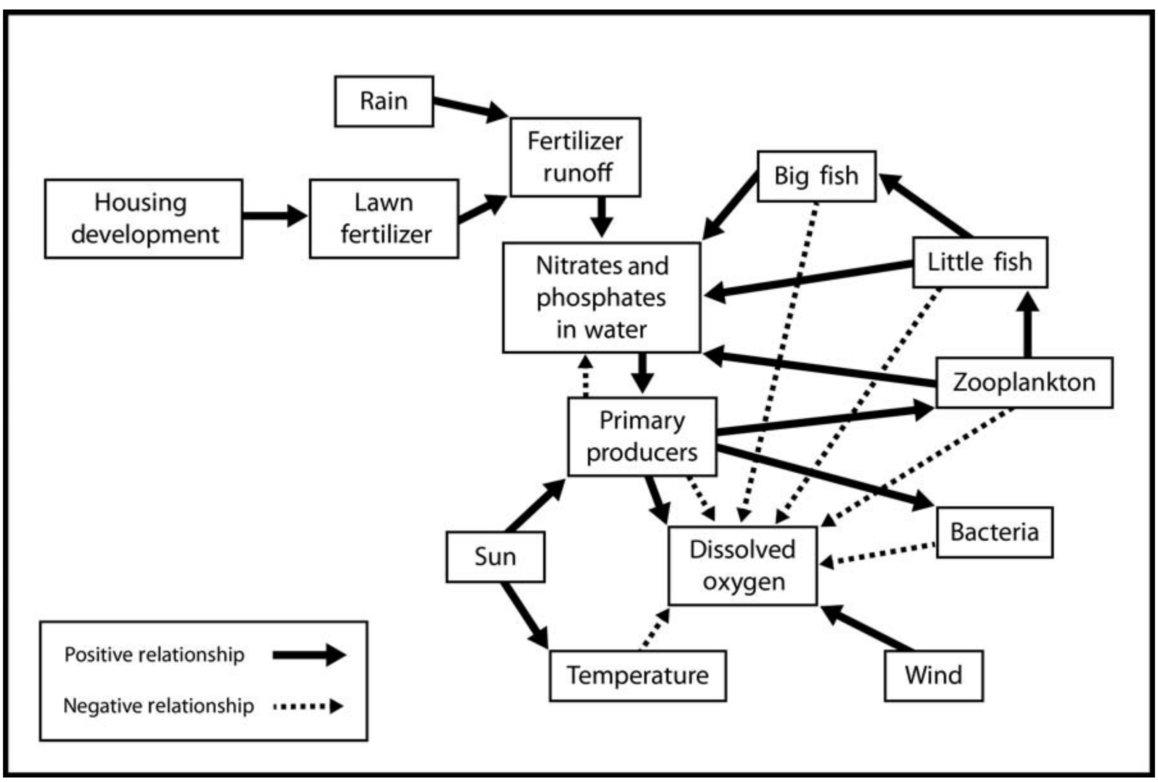

Figure 2. The causal relationships and interactions in EcoMUVE.

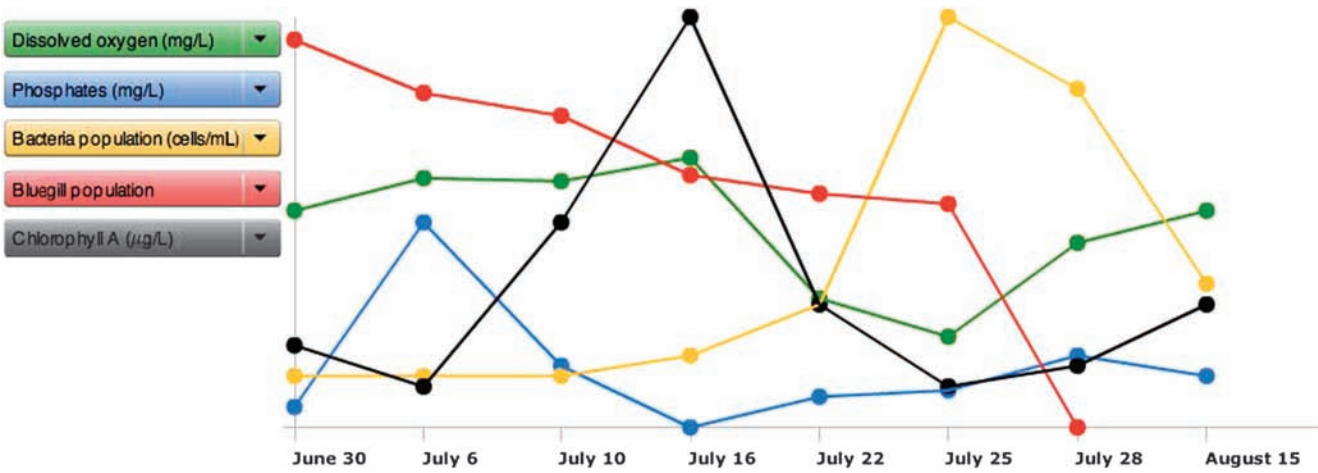

Figure 3. A screenshot of a graph of the five variables within the EcoMUVE data over time. Abbreviations: mg/L, milligrams per liter; mL, milliliter; µg/L, micrograms per liter.

interactions result in variation in the measurements that the students can observe. EcoMUVE includes targeted support to help the students realize the limits of focusing on events without broader context. For instance, a time-traveling tool allows the students to go back and forth in time to see the subtle changes that they missed. The data that they collect is stored in a table, so that they can analyze temporal trends using a built-in graphing function. Figure 3 illustrates one of the possible graphs that the students can generate in order to study the levels of dissolved oxygen, phosphates, bacteria, fish populations, and chlorophyll A in the pond over time. The students conclude the unit by constructing concept maps to represent their understanding of the ecosystem dynamics related to the fish die-off and are asked to support the relationships that they have identified with evidence that they have collected.

The present study: How using EcoMUVE interacted with students' reasoning patterns

In this study, we examined how students framed their initial ideas about what was going on in the EcoMUVE scenario and what shifts, if any, were seen in the students' reasoning. We asked the following questions: What initial assumptions do the students make about the nature of the fish die-off? Does the evidence suggest that they bring an event-based focus as is suggested by the extant research or that they attend to the longer-term patterns, including both events and processes, in their explanations of the fish die-off? Is there evidence of shifts in the students' reasoning after they have explored the information available in EcoMUVE about the inherent ecological patterns and processes over time?

Seventh and eighth graders (n = 81) in three classes in the Boston area were introduced by their teacher to the EcoMUVE pond module at the beginning of the week and given an opportunity to explore it. After noticing the fish die-off, the students took a written assessment in which they were asked to offer their initial insights into what might explain the fish die-off. The students worked within EcoMUVE for two weeks and were then given a parallel written assessment. Video of the class discussions, including the teachers' language, was recorded and analyzed.

The assessments were open ended to allow the students to structure their own responses. The students were asked to list as many ideas as they could about the possible causes of the fish die-off and what information might help them to explain it. They were given five blank lines and were told to "use the back of the paper if [they] would like more space." Paired dependent t-tests were used to explore pretest-to-posttest changes in the students' responses. Significant pretest-to-posttest differences (at α = .05) in a student's patterns of response were interpreted as evidence for shifts in reasoning.

The responses were coded as follows: *Event-based causality* (EBC) explanations were those focused on discrete moments in time when something happened to cause the fish die-off. Examples included "the sun was too hot one day" and "a truck dumped dirt with poisons into the pond." *Pattern- or process-based change over time* (PPCT) explanations were responses that were not delineated by discrete events but instead referred to dynamic, ongoing processes over time: changes in levels of chemicals, microorganisms, or other populations or long, slow processes such as a disease that were introduced to the fishes and slowly killed some and not others, leading eventually to a fitter population. Attention was paid to the students' exact wording. Therefore, statements such as "a pipe broke and spilled sewage into the pond" and "sewage leaking into the pond from the nearby houses" would be scored as EBC and PPCT explanations, respectively. The scoring did not hinge on the scientific accuracy of the explanation but on how the students framed the causal features. For the initial analysis, each component of the narrative (i.e., each listed cause) was coded as EBC or PPCT. Responses that did not fit either characterization were coded as *other*.

Although an expert characterization would not dichotomize the EBC and PPCT explanations, this dichotomization allowed us to consider the hypothesis that the students might bring a tendency toward event-based framing, as was suggested by the extant literature. A PPCT coding does not rule out comments about events; it indicates that the students put them into a dynamic context or a longer time span or that they considered them as part of a larger pattern. For instance, "the levels of dissolved oxygen in the pond dipped to a low point because it was cloudy and warm and there wasn't much wind" is a response focused on a dynamic that occurs over time and how disruptions interact with that dynamic, so the response would be coded as a PPCT explanation.

The responses were scored by two independent coders who were blind to the condition (pre- versus posttest); one coded 100%, and the other coded a randomly selected 20% of the responses. Reliability was assessed on the categorization of each response as EBC or PPCT using Cohen's kappa coefficient, to account for instances of agreement by chance, yielding an agreement level of $\kappa = .837$. The total number of responses that the students gave varied between test groups and between students. The points of disagreement were discussed until an agreement was reached. The resulting data were in the form of the number of EBC and of PPCT responses for each student on the pre- and posttests.

Following this initial coding, a qualitative coding process was conducted to further characterize the patterns in the students' responses. Using a phenomenological approach, themes within the data were identified (e.g., Carini 1975), attending to how the students framed their explanations, the language that they used, and recurrent patterns across responses and between students. Two more coders (also blind to the test condition) first coded the data independently, identifying themes in the students' responses. Afterward, they shared their independently derived results and reported and refined any overlapping categories.

The video of the teachers' statements in the classroom summary discussions was analyzed by two independent observers. They selected statements representing EBC or PPCT emphasis at initial levels of 78%–84% agreement and then discussed those that only one coder had selected to reach 100% agreement on the numbers of representative statements.

What initial assumptions did the students have?

On the initial assessment, the students gave significantly more EBC than PPCT explanations (EBC, mean (M) = 2.72, standard deviation (SD) = 1.50; PPCT, M = 1.41, SD = 1.31; mean difference = 1.31, $t(77) = 4.47$, $p < .0001$), a difference of approximately one standard deviation. These results confirmed the hypothesis that students tend toward event-based framing for their reasoning about ecosystems dynamics. Their responses focused on what happened as opposed to longer-term processes of what was going on. Some example responses concerned whether there had been "an explosion" or "an oil spill." Other students responded, "The water got contaminated and the fish jumped out"; "Oil from a factory went into the water and killed the fish." Some of the students reasoned about a short time span: "What happened in the last few days?"

What reasoning shifts, if any, were evident after the students used EcoMUVE?

On the posttest, there were no significant differences between the number of EBC and the number of PPCT explanations (EBC, M = 1.89, SD = 1.49; PPCT, M = 1.49, SD = 1.66; mean difference = 0.40, $t(78) = 1.25$, $p > .05$). The students gave significantly fewer event-based responses on the posttest than they did on the pretest (mean difference = 0.83, $t(75) = 3.75$, $p = .0003$). There was no significant difference between the pretest and the posttest in the number of PPCT responses (pretest, M = 1.41, SD = 1.31; posttest, M = 1.49, SD = 1.66; $p > .05$). The student responses on the posttest were less wide ranging than those on the pretest, more constrained by the available evidence (as is discussed below) than the more far-reaching brainstorming on the pretest (figure 4). This was confirmed by a paired t-test. The mean number of responses that the students supplied on their pre- and posttests differed significantly (pretest, M = 4.12, SD = 1.13; posttest, M = 3.39, SD = 1.32; mean difference = 0.82, $t(75) = 4.35$, $p < .0001$). An analysis was conducted to determine the proportion of the total number of responses that were EBC explanations. The difference between the pre- and posttest levels was not significant (pretest, M = 0.67, SD = 0.29; posttest, M = 0.59, SD = 0.40; mean difference = 0.07, $t(75) = 1.17$, $p > .05$), and the students still gave relatively more EBC than PPCT responses on the posttest at a level approaching significance (EBC, M = 0.59, SD = 0.40; PPCT, M = 0.41, SD = 0.40;

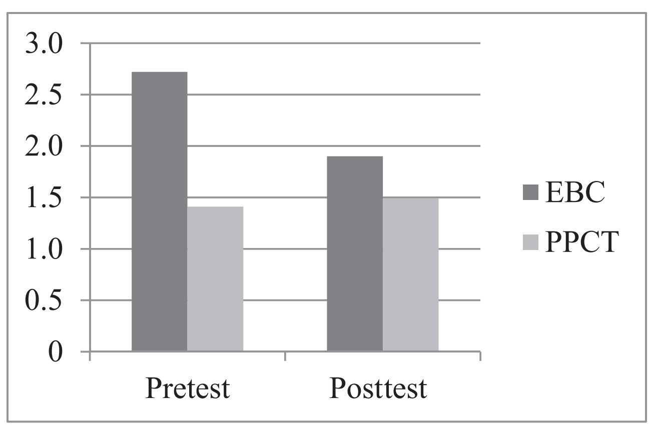

Figure 4. Pre- to posttest shifts in the balance of event-based causality and pattern- or process-based change-over-time responses. Abbreviations: EBC, responses categorized as event-based causality explanations; PPCT, responses categorized as pattern- or process-based change-over-time explanations.

mean difference = 0.17, $t(78) = 1.89$, $p = .06$) So, although it is notable that the absolute number of event-based explanations declined as the students focused on the broader evidence available in the EcoMUVE module, they still had a tendency to generate EBC explanations.

What reasoning patterns could be discerned in the students' responses?

The qualitative coding offers the following insights: The students' posttest responses were focused on variables present in EcoMUVE (e.g., phosphate, nitrate, and oxygen levels), and all of the students except two mentioned at least one of these variables. Table 2 shows the numbers of EcoMUVE variables that the students included on the pre- and posttests. Some of the students referred to changes in the levels of particular variables. One student wanted to determine population levels in order to investigate the fish die-off: "[I would find out if there are] too little phosphates; too little oxygen, population change in organisms in food chain, amount of algae in the food chain changes," and another talked about the need to monitor the amount of oxygen, phosphates, algae, fish, and fertilizer in the water every day. Other students' responses listed a mix of PPCT and EBC statements: "food chain broke, limiting resources, not enough oxygen."

Six students framed their entire posttest response as a "domino" narrative—in which one cause leads to an effect, which causes another effect, and so on—connecting EBC and PPCT statements in a coherent explanation that connected proximal and distal causes—for instance, "The fertilizer runoff went into the stream and then into the pond, and then… the algae grew a ton. Bacteria thrived. When fertilizer wore off, algae stopped growing. With all the [carbon dioxide] released from the decomposition of the algae, the fish went back to their maker." An additional 16 students included some narrative phrases—for instance, "fertilizer caused more algae, which causes more bacteria, which killed the fish"—within a broader list of possible causes on their posttests. One student gave a narrative phrase on the pretest. The remaining students listed their responses in a non-narrative format.

This type of domino narrative may facilitate students' ability to connect proximal and distal events across time. It integrates PPCT and EBC statements in ways that more closely resemble the contextualized focus in the expert view; therefore, it may represent a level between the conceptions of the complete novice and more expert conceptions. Alternatively, Chi and colleagues (2012) argued that sequential narratives belong to an event-based ontology; therefore, students should not be able to build a deep understanding of processes from them. Even if event-based ontologies may make it more difficult to appreciate the nature of ongoing simultaneous processes, the students in our study were able to connect proximal and distal causes of the fish die-off through this type of narrative pattern. Further study could determine whether students who hold this model shift toward more expert reasoning if they are given more time to interact with EcoMUVE.

Table 2. The numbers of EcoMUVE variables that students included on the pretest and the posttest.

Number of EcoMUVE variables in response	Number of students	
	Pretest (n = 81)	Posttest (n = 79)
0	58	2
1	16	9
2	5	17
3	2	17
4	1	15
≥5	0	19

How might teacher statements have interacted with the students' reasoning patterns?

The teachers' statements during the summary discussion represented a balance between EBC and PPCT statements (teacher 1 EBC, $M = 8$; teacher 1 PPCT, $M = 10$; teacher 2 EBC, $M = 16$; teacher 2 PPCT, $M = 14$). There were also examples in which the teachers framed the ecosystem dynamics such that it may have introduced or reinforced the domino narrative pattern—for example, "So we had fertilizer as our first point… How many groups started with fertilizer as the beginning of that story? A lot of groups did." One teacher gave the students a language arts rubric to write EcoMUVE summaries, with a requirement that they organize the summary in a linear fashion. However, the teachers also made statements in which they emphasized the interactions and relationships among the variables over a longer time span and explicitly conveyed to the students that there were many simultaneous events:

> So our chlorophyll increased. So… an increase in the algae population made [the chlorophyll] increase…. Did the turbidity just increase or did it have something to do with the algae? Is the turbidity increasing a separate factor, or does it have something to do with the algae? So the chlorophyll increased because of the algae, but what about the turbidity? That's a good main line for the story, but we've got some other things going on. What are some other variables that we noticed? Let's see. Did anything happen with the water temperature?

Helping teachers differentiate between a novice tendency to focus on discrete events and a richer, expert conception of events in the context of the broader patterns of resilience, disturbance, ongoing processes, and change over time should help them to realize the value of these kinds of statements.

Conclusions

The students in the present study used nearly twice as many event-based explanations as they did explanations focused on patterns, processes, and change over time in their initial ideas and used more event-based explanations early in their exploration of EcoMUVE than they did at the conclusion. After exploring the MUVE, the students adjusted their explanations to ref ect the evidence and offered a greater balance between a focus on events and a focus on the broader processes and patterns in the pond ecosystem. This is a positive development in that as the students developed their explanations, they pruned event-based explanations and lessened their strong focus on discrete events. They maintained the number of pattern, process, and change-over-time comments and focused to a greater extent on ecological variables. Whether the students would transfer this tendency to a new ecosystem is an important question for future research. The students' shift toward narrative language included both event-based and pattern-, process-, or change-over-time–oriented explanations. Although this form of explanation does not fully contain the complexities of an expert, contextually situated conception, it more closely approximates it.

Some educators have called for using dramatic disturbances such as fire, hurricanes, and landslides to motivate college student interest in ecology (D'Avanzo 2004). Although these disturbances might compel more interest and active processing, educators should monitor how this lesson framing affects their students' novice perspective on events. Harp and Mayer (1998) found that dramatic events adversely affected college students' understanding of a causal phenomenon in text-based narratives, particularly when they were placed at the beginning of the narrative, because the salience of the event primed inappropriate schemas. *Disturbance*—event-like or not—is an important concept in ecology. However, when experts reason about disturbance, they contextualize it in a longer-term view of ecosystems processes and an understanding of how variables changing on different time scales may affect system dynamics. The present results suggest some promise to providing support for novices as they learn these important disciplinary assumptions while they are exploring ecosystem dynamics.

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