Students' Reasoning Tendencies about the Causal Dynamics of Ecosystems and the Impacts of MUVE vs. Non-MUVE Instructional Contexts

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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; Grotzer et al., 2013; Grotzer & Solis, 2015; Hmelo-Silver, Pfeffer, & Malhotra, 2003). This paper reports on a study carried out on student learning using a program called EcoMUVE (Metcalf et al, 2011) designed to simulate ecosystems patterns and structural causalities. EcoMUVE has affordances that students can use, such as the ability to move forwards and backwards in time and graphing functions to test their causal assumptions in order to realize their limited explanatory power for solving an ecological problem posed within the virtual environment. The study assessed whether seventh and eighth graders (n = 260) revealed the limiting assumptions suggested by prior research and contrasted the learning of complex causal dynamics by students working with EcoMUVE and its inquiry-oriented, problem-based immersive context to a problem-based, non-MUVE comparison curriculum. Students' reasoning revealed the predicted assumptions while their later reasoning revealed shifts towards more expert framing of causal dynamics related to spatial relationships and change over time. Between the two groups, there were no significant differences in the gains in the proportion of non-obvious and spatially distant responses, however, EcoMUVE students had fewer gains in the proportion of responses related to reasoning across large spatial gaps where causes and effects exist in different attentional frames. This raises the question of whether the ease of moving about in the virtual world impacted students' ability to learn about the importance of reasoning beyond their immediate attentional frame when considering spatial gaps in ecosystems dynamics.

1. Rationale

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. Students apply a limiting set of assumptions to their causal reasoning about ecosystems concepts (e.g. Grotzer & Basca, 2003; Hmelo-Silver, Pfeffer, & Malhotra, 2003). For instance, they focus on events at the expense of the broader context of processes and steady states over time (e.g. Ferrari & Chi, 1998, Grotzer et al., 2013) and focus on the structural components of ecosystems rather than the deeper level systemic and functional aspects (Hmelo-Silver, et al, 2007). Elementary students constrained their conceptions of cause and effect to spatially local causes (Grotzer & Solis, 2015).

These assumptions differ substantially from those of ecosystems scientists (e.g. Walker & Salt, 2006, Weathers, Strayer, & Likens, 2013). Ecosystems are complex and controlled by many factors (Weathers et al, 2013). A deep understanding of ecosystems concepts requires a long view both in space and time including the realization that causal action can occur 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. Change over time may be subtle as in weathering patterns or more dramatic as in weather events or fire. They may be due to anthropogenic causes that are distributed across many actors in space and time or due to natural causes without significant human impacts.

As large systems with many interacting components at many different levels of scale, teaching ecosystems concepts in ways that are non-reductionist and non-static can be challenging. Students are often taught isolated processes, such as decomposition, predator-prey interactions, and so forth. Increasingly, computer simulations have allowed for students to grapple with the dynamics of these processes in ways that enable them to manipulate variables and to observe the effects at different levels of scale. Some programs simulate emergent properties that result from massively parallel interacting agents, such as Star Logo (Resnick, 1996) and Net-Logo-based models (e.g. Wilensky, 1999). Reptools (2007) enables students to interact with aquarium ecosystems to see how particular variables behave in a dynamic system. Multi-user Virtual Environments or MUVES such as River City (Dede et al), OMOSA (Jacobsen , 2012) and EcoMUVE (Metcalf et al., 2011) are virtual worlds that enable students to engage with concepts in computer environments that attempt to simulate important features of reality.

EcoMUVE is a multi-user virtual environment designed to support student learning of complex causality in ecosystems through a middle school ecosystems curriculum (Metcalf et al, 2011; Grotzer et al 2013). It provides situated learning through immersion in a rich, interactive environment. 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.

2. Background

2.1 Tensions Between Novice and Expert Patterns of Causal Reasoning

Research on causal induction suggests that everyday causal reasoning differs 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 (e.g. Grotzer & Tutwiler, 2014). The assumptions that students make are often in tension with more expert reasoning about the inherent causal dynamics.

2.1.1 Obvious vs. Non-Obvious Causes:

Significant research has investigated how learners of different ages attend to obvious versus non-obvious variables. Even very young children will search for a non-obvious cause when there is no obvious cause available (e.g. Schulz & Sommerville, 2006). And while young children's causal assumptions are influenced by perceptual evidence (e.g. Cohen & Oakes, 1993; Leslie, 1988; Leslie & Keeble, 1987; Oakes & Cohen, 1990), they do invoke nonobvious mechanisms for some biological phenomena (Gelman & Gottfried, 1996; Gelman & Kremer, 1991) and will express notions that something can be contaminated due to non-obvious and non-visible causal mechanisms (Au, Sidle, & Rollins, 1993; Kalish, 1996; Springer & Belk, 1994; Siegal & Share, 1990).

However, if an obvious candidate cause is present, even adults have been shown not to pursue a nonobvious one (Kushnir, Gopnik, Schulz, & Danks, 2003). Further, studies finding that learners of all ages do not allow for causeless effects and thus seek a non-obvious cause when an obvious one is not present (e.g. Schulz et al, 2006) have been lab experiments in which the task and subjects' attention is constrained. In ecosystems dynamics, there may be many candidate obvious causes for an outcome that are not necessarily the actual cause but that are salient and draw attention in ways that non-obvious causes are not able.

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). In reasoning about ecosystems and biological concepts, students struggle to recognize non-obvious causes such as the microbes responsible for decay (Brinkman & Boschhuizen, 1989; Leach, Driver, Scott, & Wood-Robinson, 1992; Grotzer et al., 2003; Hogan et al., 1996).

2.1.2 *Spatially Local versus Action at a Distance*

Physical contiguity or proximity is one of the factors that people use to assess the existence of causal relationships. Early Piagetian research focused on billiard ball type causality where there was physical contiguity between causes and effects (Piaget, 1929). Infants are surprised by action at a distance—the idea that causes and effects can impact each other without touching. In a series of studied using shadows, Spelke, Phillips and Woodward (1995) demonstrated that infants reveal surprise when shadows move in concert with the object that they relate to without touching.). 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). Again, these studies took place in lab contexts in which the spatial gap was constrained.

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 action at a distance across vast spatial gaps. Water sheds can extend many, many miles. Grotzer and Solis (2015) introduced the concept of "action at an attentional distance" to account for phenomena in which the causes and effects are in separate attentional frames. When causes and effects are in different attentional frames, it removes the possibility of discerning the regularity of the covariation relationships that suggest a causal connection (Grotzer & Tutwiler, 2015). Grotzer and Solis (2015) found that elementary students were more likely to consider local than distal causes, but when they did consider distal causes they relied upon mechanism to make a connection. This supports the argument that removing the salience of the covariation relationship requires the reasoner to seek other means to determine that a causal relationship exists.

2.2 Multi-User Virtual Environments

Dede and colleagues (Dede, 2009) have developed 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 a complex problem, students identify questions involved in solving the problem and gather the information necessary to solve the problem. 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). Learning in EcoMUVE is related to content gains (Metcalf et al., 2013) and greater self-efficacy in scientific inquiry (Chen & Metcalf, 2013). Dede (2009) argues that extended, interactive experiences such as those enabled by MUVES are necessary for learning complex processes.

2.3 EcoMUVE Design

The EcoMUVE Pond curriculum module comprises a two-week experience. 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

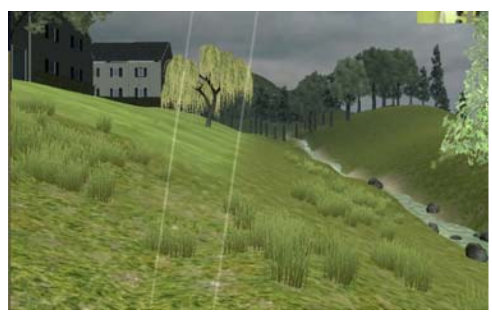

Figure 2: Runoff From a Housing Development

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.

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.

2.3.1 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.

2.3.2 Recognizing Action at an Attentional Distance

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 an attentional distance (Grotzer & Solis, 2015) 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.

3. **Research Questions**

Based upon the extant research, we expected that, at the outset, students might hold simplifying assumptions about the nature of the embedded causalities related to the obviousness of the variables and the spatial relationship between causes and effects. Teaching the causal dynamics and how they differ from simpler assumptions has been shown to be effective across a variety of contexts (e.g. Perkins & Grotzer, 2005; Gramling et al, 2014). However, this teaching relies heavily on teacher willingness to devote instructional time to the causal dynamics and the capacity to provide effective instruction. EcoMUVE is designed with affordances that invite students to discover aspects of the underlying causal dynamics as described above. These affordances, such as traveling with ease over space and back and forth in time and having visual representations of nonobvious variables, as specific to computer technology and are characteristic of MUVEs. If students held simplifying assumptions at the outset, how would learning in the EcoMUVE impact these assumptions, if at all? How might this learning compare to learning in a non-MUVE context in which students did not have the embedded affordances but had the benefit of "best practices" instruction? This study compared the learning of complex causal dynamics in students working with EcoMUVE Pond curriculum to those working with a closely aligned, best practices non-MUVE problem-based comparison curriculum, as described below. Each group was introduced to the concept of unintended consequences and that causality can be more complex than anticipated, however, neither intervention invited explicit instruction about or reflection upon the specific causal patterns within the ecological scenario in the curricula.

We sought to address the following research questions:

RQ1: What reasoning tendencies were revealed in students' initial explanations?
RQ2: Did students using the EcoMUVE and comparison curricula demonstrate gains in the proportion of complex causal responses?
RQ3: What was the effect of the use of the EcoMUVE on gains in complex causal responses, controlling for student and teacher-level fixed effects?

4. Methods

4.1 Design

Participants were 260 seventh and eighth graders nested within 5 teachers from urban and suburban schools (60% Caucasian, 15% Black/African American, 15% Latino, 5% Asian and FRL of 25%). Each teacher's classes were randomly assigned to the EcoMUVE or non-MUVE conditions to ensure that inclusion was unrelated to characteristics that may bias the estimation of the impact. The Non-MUVE group was taught with high fidelity by the teacher and one researcher. Pre- and post-tests included a causal survey that assessed students' reasoning about non-obvious variables and spatially and attentionally-distant causal dynamics. "Attentionally-distant" references causes and effects that reside in different attentional frames (Grotzer & Solis, 2015) so here it translated to causes originating beyond sight of the pond.

4.1.2 Intervention materials

Students in the EcoMUVE condition used the curriculum described above. 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.

Students in the Non-MUVE Instructional Condition participated in a stand-alone, problem-based, ecosystems curriculum entitled, Environmental Detectives in the GEMS series by the Lawrence Hall of Science. Both curriculum modules focus on what happened to lead up to a fishkill and the focuses students' attention to a watershed. Environmental Detectives explicitly focuses on a broader water shed than EcoMUVE; It includes a city, a town, forests, a river, a lake, and a pond in addition to a shoreline within the area that students consider. EcoMUVE enables students to travel to a housing development across a road and up a hill. It is not visually obvious from the pond. In Environmental Detectives, students are exposed to characters who play a role in the ecological mystery and develop a timeline of the events leading up to the fishkill. The teaching of both units followed best practices in the following ways. Students engaged with the problem-based scenario and teachers offered guiding structure through the program materials. Students were encouraged to look for evidence and offer the reasoning supporting their ideas. The teacher asked probing questions to help guide their investigation but did not engage in didactic instruction.

Students in each condition participated in 10 class sessions with some overlapping instructional components. For instance, both classes participated in computer-based, didactic instruction with multiple choice questions on dissolved oxygen and chlorophyll on the sixth day. On the seventh day, they read a story called “Parachuting Cats into Borneo” that introduces the concept that causality can be more complex than it initially appears and had a discussion about the complexity of ecosystems. In both conditions, students participated in class discussions about what they believed happened to the fish and developed concept maps to explain what they believed happened to the fish. (See Appendix A. for Curriculum Details.) An unaccounted for point of departure between the two conditions is that the students in the EcoMUVE worked in roles. On Day 4, they were assigned roles to work in to collect data. Each role corresponded to data that the student needed to collect. These included a microscopic specialist, whose role was to look for creatures who live in our environment but are difficult to see; a private investigator who interacted with characters in the world to learn more about the environment; a water chemist who used water measurement tools to measure changes in the water over time, and a naturalist who tracked animal species and their populations over time.

Students in the treatment and control conditions shared a common teacher introducing the potential for contamination between conditions. This was not likely to be a problem for three reasons. Firstly, researchers were present in the classroom during each day of instruction, primarily to provide technical assistance. They would have also been able to keep teachers “on task” in each curriculum, though none of them reported having seen teachers mention or try to replicate content across the conditions. Secondly, the aspects of the MUVE that were hypothesized to make it more immersive while learning ecosystems, such as the ability for students to instantly travel back and forth through time to observe critical events or to quickly shrink to microscopic or atomic scales to view various processes were not replicable by the teacher. Aside from these differences, the two curricula were very similar. It is therefore unlikely that curricular cross-contamination occurred.

4.1.3 Assessment Instrument

Students were given the *Ecosystem Causal Dynamics Assessment*, a researcher-developed assessment that considers whether students grasp the causal features of ecosystems dynamics. The scoring scheme results in high levels of inter-coder reliability (over .89 Cohen’s Kappa). The assessment proceeded 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. (See Appendix B.)

In addition a twenty-one question ecosystems content knowledge assessment (Cronbach’s alpha=0.75) was given prior to the intervention.

4.1.4 Scoring

This study focused on the gain in proportions of non-obvious, spatially distant, and attentionally distant causal explanations on the causal survey. (See Appendix C.) 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. 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 1 answers were coded for whether they reflected causes that were/had: a) obvious versus non-obvious causes; and b) local versus non-local causes as follows.

The protocols were scored for whether the types of causes that students focused on as likely explanations for the fish kill were obvious versus non-obvious. 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.

The protocols were also 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 an attentional 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.

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 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.

4.1.5 Measures and Data Analytic Plan

Using these instruments, we developed a series of measures to address our research questions. Below, we highlight these measures in terms of their use in our analytic models. Descriptive statistics are given in Table 1. Pearson product-moment correlations for the variables in the model are presented in Appendix D. The following outcome measures were developed:

NOPR.GAIN- A continuous variable, bounded at -1 and 1, constructed by subtracting the proportion of pre-intervention student explanations that included non-obvious causes (NOPR.PRE) from the post-intervention measure of that proportion (NOPR.POST).
SDPR.GAIN- A continuous variable, bounded at -1 and 1, constructed by subtracting the proportion of pre-intervention student explanations that included spatially distant causes (SDPR.PRE) from the post-intervention measure of that proportion (SDPR.POST).
ADPR.GAIN- A continuous variable, bounded at -1 and 1, constructed by subtracting the proportion of pre-intervention student explanations that included attentionally distant causes (ADPR.PRE) from the post-intervention measure of that proportion (ADPR.POST).

The following question predictor was used:
EcoMUVE- A dichotomous predictor variable, coded 1 if the student was in the EcoMUVE condition or 0 if they were in the comparison curriculum.

The following were student fixed-effects:
FEMALE- A dichotomous control variable, coded 1 if the student was female or 0 if the student was male. Included to control for possible gender effects of the use of virtual environment-based curricula (e.g., Ketelhut, 2007; Lin, Tutwiler, & Chang, 2012)
KNOW.PRE- A continuous control variable, ranging from 0 to 48, indicating student pre-intervention ecosystems science content knowledge.
NOPR.PRE- A continuous control variable, ranging from 0 to 1, indicating the proportion of pre-intervention student explanations that included non-obvious causes. We did not include this variable in models where NOPR.GAIN was the outcome.
SDPR.PRE- A continuous control variable, ranging from 0 to 1, indicating the proportion of pre-intervention student explanations that included spatially distant causes. We did not include this variable in models where SDPR.GAIN was the outcome.
ADPR.PRE- A continuous control variable, ranging from 0 to 1, indicating the proportion of pre-intervention student explanations that included attentionally distant causes. We did not include this variable in models where ADPR.GAIN was the outcome.

The following were teacher fixed-effects:
TEACH1 – TEACH5- A vector of dichotomous variables set to 1 if a student has a given teacher, and 0 if not. We excluded Teacher 5 from our models as the reference category.

A null multi-level model (MLM) was fit with students in each condition being clustered by teacher. For example, the hypothesized population-level model for gains in the proportion of non-obvious causal statements for students in the EcoMUVE condition would be:

$$Level\ 1: NOPR.GAIN_{ij} = \beta_0 + \varepsilon_{ij}$$
$$Level\ 2: \beta_0 = \pi_{00} + \zeta_{0j}$$

Where π_{00} represents the population-level average gain score in non-obvious causal statements across all students and teachers. We assessed the magnitude, direction, and statistical significance of this covariate. (If it is statistically significant and positive, we can conclude that student made gains. Conversely, if it is statistically significant and negative, we can conclude that the opposite is true: students mentioned fewer non-obvious causal statements after using the EcoMUVE.) These analyses were completed for each outcome with students in each condition.

A series of nested ordinary least-square (OLS) regression models were fit to determine the effect of being assigned to the EcoMUVE treatment on the gains in the proportion of the complex causal statements under study. We chose to use this, versus the MLM strategy above, in order to prevent possible correlation between level-two residuals and predictors in the model, owing to the fact that students are not randomly assigned to teacher (Murnane & Willett, 2010). For example, the hypothesized population-level OLS model for gains in the proportion of non-obvious causal statements is:

$$NOPR.GAIN_{ij} = \alpha + \beta_1 EcoMUVE_i + \delta S_{ij} + \omega\tau_j + \varepsilon_{ij}$$

Where α is the intercept (population level average gain for a male student in the comparison condition of Teacher 5, controlling for all other factors in the model), β_1 is the effect of being assigned to the EcoMUVE condition, δ is the effect of the vector of student fixed effects defined above, ω is the effect of the vector of teacher fixed-effects, and ε_{ij} is the residual (unexplained variation in the outcome). We will evaluate the magnitude, direction, and statistical significance of β_1 to answer the second part of each research question. If it is statistically significant and positive, we can claim that student use of the EcoMUVE results in more gains than their peers in the comparison curricular condition; if it statistically significant and negative, we can claim the opposite; and if it is not statistically significant, we can claim no difference between the groups, on average in the population and controlling for all other covariates. Identical models were fit for all other outcomes, and evaluated in exactly the same manner.

For our second research question, we used the "nlme" package (Pinheiro et al., 2015) of the open-source statistical software R (R Core Team, 2015). To answer the third question, we used the "lm" function in R, fitting each OLS model by first including the question predictor (EcoMUVE) then adding student-level and teacher fixed-effects. No violations of OLS assumptions were detected, nor were there any detectable statistical interactions.

An unaccounted for source of potential variation and thus a threat to the internal validity of the findings is that in both the treatment and control conditions, the students were grouped in specific class-periods and/or working groups. This limitation prevents us from being able to account for shared similarities between students within each class or group, which might potentially upwardly-bias the magnitude of the regression coefficients (Murnane & Willett, 2010).

4.2 Analysis and Findings

Pretest answers were in the expected direction of novice-type assumptions with more obvious than non-obvious and local than distal explanations (See Table 1.) across both groups. For example a low proportion of non-obvious causal responses was given by the EcoMUVE (mean=0.289, sd=0.151) and comparison (mean=0.293, sd=0.165) students. The proportion of non-obvious responses then rose for students in each group (mean=0.165, sd=0.193; mean=0.129, sd=0.198).

Non-MUVE students gained in the proportion of non-obvious (β=0.129, p<.001), spatially distant (β=0.053, p<.001), and attentionally-distant (β=0.046, p<.001) responses (Table 2). EcoMUVE students gained in the proportion of non-obvious (β=0.165, p<.001) and spatially distant (β=0.048, p<.001) responses, but not attentionally-distant responses (Table 3). Between the two groups, there were no significant differences in the gains in the proportion of non-obvious and spatially distant responses, controlling for student and teacher fixed-effects: EcoMUVE students performed as well as Non-MUVE students on these measures. However, EcoMUVE students had fewer gains in the proportion of attentional-distance responses (β=-0.054, p<.001, d=2.84) with an effect size of 2.84 SD units (See Table 4).

On the pretest, students talked about the importance of, "looking at the water"; "looking in the pond for toxins whereas on the post-test, students framed more answers in terms of distance ("acid rain; chemical gets in pond from factory; chemicals from cars in water." They attended to more visible and salient possible causes such as "sewage from a pipe is flowing into the pond" whereas on the post-assessment, they attended to less obvious variables (disease, changing oxygen levels, drop in water temperature).

Table 1. Descriptive statistics

	EcoMUVE (n=127)	Compare (n=133)	Difference
FEMALE	0.546 (0.499)	0.520 (0.502)	0.026
KNOW.PRE	23.248 (5.976)	22.945 (5.996)	0.303
TEACH1	0.195 (0.398)	0.283 (0.452)	0.088
TEACH2	0.120 (0.327)	0.118 (0.324)	0.002
TEACH3	0.241 (0.429)	0.244 (0.431)	0.003
TEACH4	0.218 (0.414)	0.260 (0.440)	0.042
TEACH5	0.226 (0.420)	0.094 (0.294)	0.132**
NOPR.PRE	0.289 (0.151)	0.293 (0.165)	0.004
SDPR.PRE	0.007 (0.033)	0.006 (0.026)	0.001
ADPR.PRE	0.046 (0.067)	0.036 (0.066)	0.010
NOPR.GAIN	0.165 (0.193)	0.129 (0.198)	0.036
SDPR.GAIN	0.048 (0.072)	0.052 (0.076)	0.004
ADPR.GAIN	-0.006 (0.078)	0.046 (0.102)	0.040***

Note: $^{**}p<0.01$, $^{***}p<0.001$

Table 2. Null multilevel models predicting gain in proportion of complex causal explanations for students who did not use the EcoMUVE pond unit.

	Gain Scores		
	Non-Obvious	Spatial Distance	Attentional Distance
Intercept	0.129*** (0.017)	0.053*** (0.009)	0.046*** (0.009)
Variance Components			
Residual	0.196822	0.0739252	0.1018579
Intercept (Teacher)	0	0.01476279	0
Observations	127	127	127
-2LL	-52.45532	-297.789	-219.7706

Cells are estimates (s.d.)
Note: ***p<0.001

Table 3. Null multilevel models predicting gain in proportion of complex causal explanations for students who used the EcoMUVE pond unit.

	Gain Scores		
	Non-Obvious	Spatial Distance	Attentional Distance
Intercept	0.165***	0.048***	0.006
	(0.017)	(0.006)	(0.009)
Variance Components			
Residual	0.192097	0.07209624	0.07770718
Intercept (Teacher)	0	0	0.003656026
Observations	133	133	133
-2LL	-61.39714	-322.0768	-301.8554

Cells are estimates (s.d.)
Note: ***p<0.001

Table 4. OLS regression models predicting effect of the use of the EcoMUVE on the gain in proportion of complex causal explanations, controlling for student and teacher fixed-effects.

	Final Models (Gain Scores)		
	Non-Obvious	Spatial Distance	Attentional Distance
EcoMUVE	0.026	-0.004	-0.054***
	(0.025)	(0.009)	(0.012)
Student Fixed-Effects	✓	✓	✓
Teacher Fixed-Effects	✓	✓	✓
Constant	0.102*	0.067***	0.043
	(0.058)	(0.023)	(0.028)
Observations	260	260	260
R^2	0.031	0.052	0.108

Cells are estimates (s.d.)
Note: *p<0.05, ***p<0.001

5. Discussion

Students in both conditions revealed the initial assumptions that were consistent with the trends seen in the literature. It might be argued that starting with what is obvious and local to the effect are good initial choices when reasoning as a novice about a particular problem space. However, what is important is the ability to look beyond these assumptions when warranted by the evidence and to realize that there may be non-obvious and distant variables accounting for an outcome even when one's attention is more immediately drawn to variables with greater salience.

Students in both conditions made significant gains. These findings suggest that virtual environments can support students' learning of complex causal dynamics and that students' assumptions shifted towards more expert construals. However, students in the non-MUVE PBL curriculum performed as well on the measures assessed in this study and performed better on the concept of action at an attentional distance. This suggests that engaging in the problem space with the support of the problem structure in the EcoMUVE and the Environmental Detectives Program was enough to help students make progress towards recognizing less obvious variables and more distal causes. However, the finding about action at an attentional distance raises puzzles to be explored further. It is possible that virtual worlds are less effective in supporting the learning of action at an attentional distance given the ease with which students move in the virtual space. Students may not learn that causes can be very far away from their effects and even at an attentional distance because the students don't experience distance in the same way in the MUVE.

This study focused on two aspects of the causal dynamics related to ecosystems. It is possible that EcoMUVE students might outperform students receiving non-MUVE instruction in other ways not measured here, such as detecting systems dynamics in un-cued contexts or transferring them to new instances—forms of learning that may be well supported by the immersive contexts.

There are some threats to validity to consider. The potential impact of the roles that students adopted in EcoMUVE is a potentially complicating factor. Particularly in the case of the microscopic specialist, it may have interacted with the findings, for instance, how those students thought about nonobvious causes. Alternatively, the roles may have introduced cognitive load or served as a distraction from the affordances related to space and obviousness in the MUVE. The generalizability of the findings are constrained by the characteristics of the participating teachers and their students. The teachers were self-selecting—volunteers from schools with curricular (ecosystems-science unit strongly aligned with the National Science Education Standards) and technological infrastructures deemed sufficient for participation in the study (PCs or Macs capable of displaying polygonal 3D graphics, fast and stable internet connections). Students in this school were ethnically diverse, but with a low rate of free-and-reduced price lunches. Future research should attend to these issues.

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. 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.

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Appendix A. Curriculum Comparison

Lesson	Non-MUVE Comparison (Environmental Detectives with some modifications)	EcoMUVE (Immersive World and Instructional Components)
1	Learn about the Gray Area Watershed/ character Information/Timeline Activity and Discussion	Exploration and Navigation of Scheele Pond/Try out tools including submarine, camera, and field guide
2	Food web Tool and Activity Sheet, Decomposers, Consumers, and Producers	Food web Tool and Activity Sheet, Decomposers, Consumers, and Producers
3	Acid Rain (pH) Lesson/ Collect data on pH in watershed/Review Acid Rain File	Exploration using measurement tools and calendar tools Introduce Learning Quests for students to access as needed
4	Sediment (Turbidity) Lesson/ Testing turbidity in cartons, sediment and erosion demo, Review Turbidity File	Divide into roles, work to collect data according to roles (including atom tracker) Learning Quests Available
5	Atom Tracker	Atom Tracker
6	Do Learning Quests for Dissolved Oxygen and Chlorophyll A	Discuss photosynthesis, respiration, decomposition
7	Parachuting Cats into Borneo Story and Discussion/Discussion of Complexity in Ecosystems/ Draw a draft concept map of Gray Area	Parachuting Cats into Borneo Story and Discussion//Discussion of Complexity in Ecosystems/ Draw a draft concept map of Scheele Pond
8	James Pond Tests (Hands-on water quality tests in lab)/Discussion of graphing	Work as a team to look at evidence and build an argument/Discussion of graphing
9	Finish James Pond Tests/ Add on to or modify the concept map/ prepare presentation	Add on to or modify concept map/Put together final arguments of cause of fish kill/prepare presentation
10	Present ideas about what is causing the fish to die to the class/Wrap up discussion	Present to the class/Wrap up discussion

Appendix B: Ecosystems Causal Dynamics Assessment

Name Date

Imagine that you have just found a lot of dead fish at a local pond! What do you think may have caused the fish to die? Try to give at least three ideas. Explain each idea as fully as you can. (For each idea, tell where, when, what, who, why and how.)

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 <u>the dead fish at the pond</u>.

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

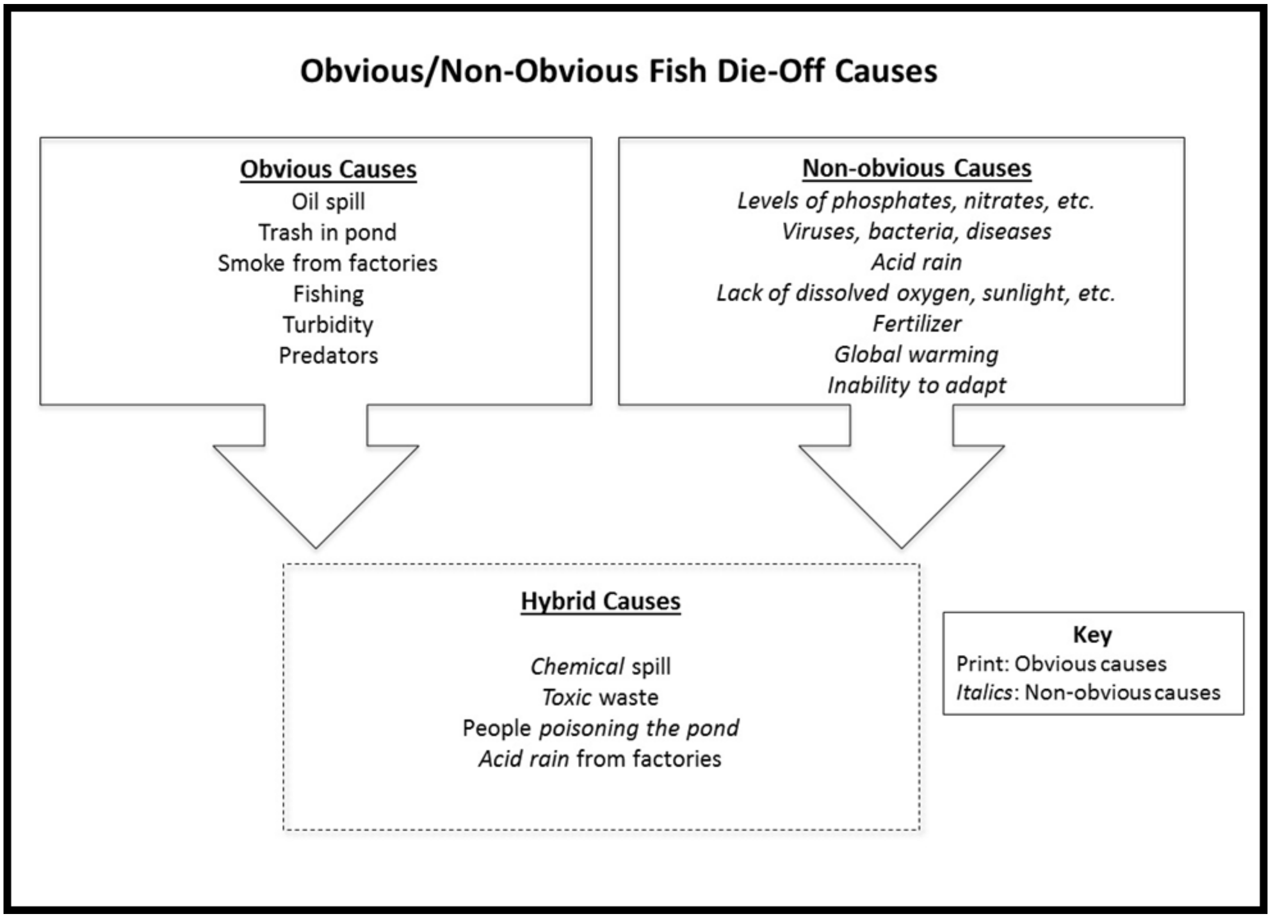
Why do you agree or disagree?

____

____

Appendix C: Scoring Scheme

Obvious/Non-obvious



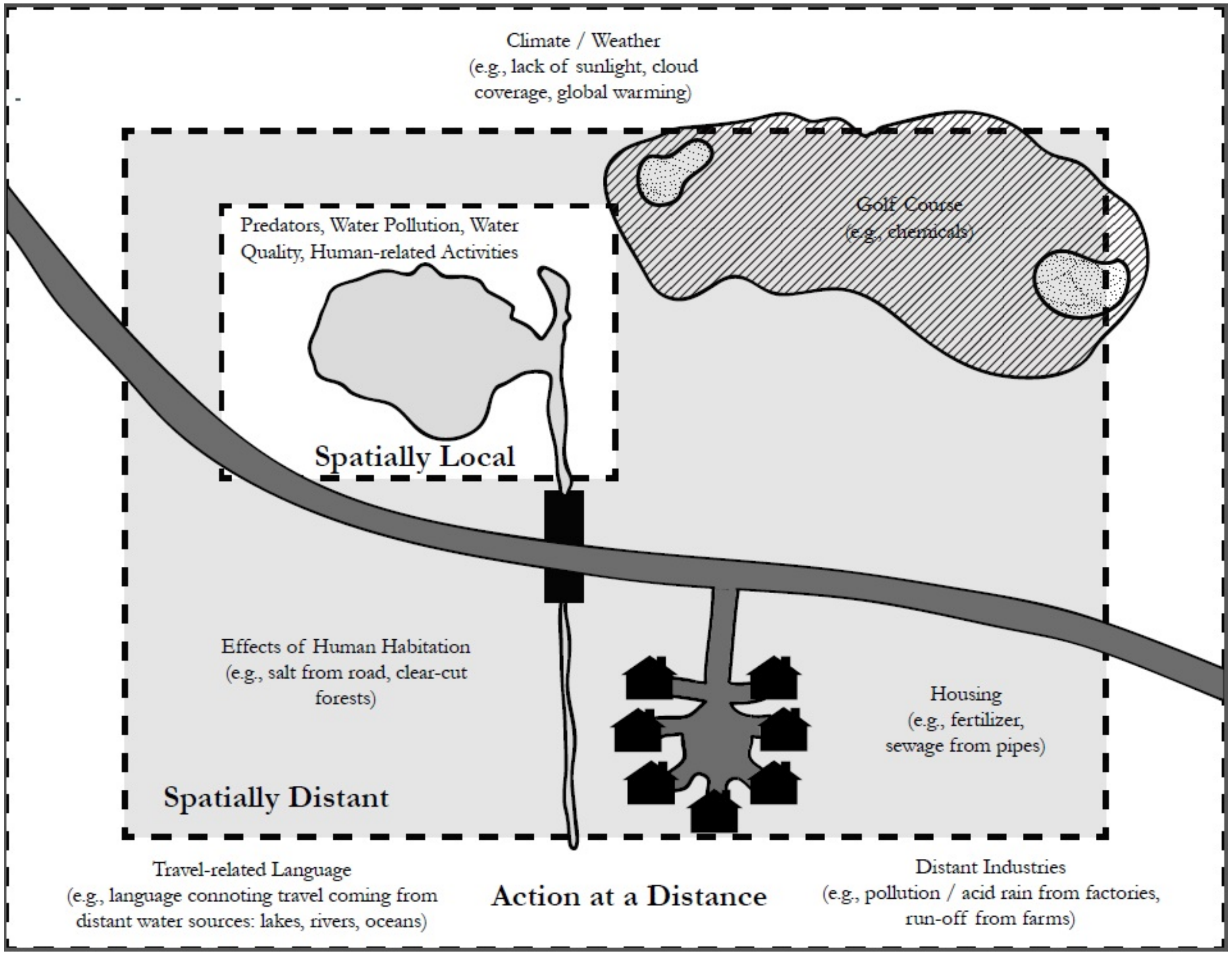
Obvious Causes vs. Non-Obvious Causes		
Concept	**Explanation**	**Examples**

Obvious causes (OC)	Causes that can be seen with the naked eye. [In EcoMUVE, there are typically non-obvious causes that have been made obvious. For the purpose of the analysis, we will treat these the way that they would exist in the real world because we are assessing the impact of offering these affordances.]	• People polluting
		  o Throwing trash in the pond
		  o Dumping
		• Visible invasive species
		  o Bigger fish
		• Turbidity (including high/increased turbidity)
		• Types of pollution
		  o Pollution from cars/factories
		  o Factory smoke
		  o Oil spill
		  o Sewage/gas leak
		  o Run-off
		• Natural Causes with Observable Effects
		  o Wind
		  o Rain
		  o Sun
		  o Water dried up/evaporated
		  o Algal bloom
		• Miscellaneous
		  o Deforestation
		  o Throwing dead fish back in pond

Non-obvious (NO)	Causes that cannot be seen with the naked eye; has 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 is not perceptible for some reason. Do not score causes 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).	• Viruses, bacteria, diseases
		• Various Compounds
		  o Salt
		  o Chemicals
		  o Toxins
		  o Fertilizer
		  o Poison
		• Invisible invasive species
		• Natural Causes
		  o Global warming,
		  o Water was too warm/cold
		  o Wind dying down, no wind
		• Levels of something
		  o Too much pollution
		  o Too much turbidity
		  o Overfishing
		  o Overproduction/overpopulation
		• Limited resources
		  o lack of/not enough sunlight, food, oxygen
		• Some forms of pollution
		  o Lead in run-off pipes
		  o People flush medicine and it ends up in the watershed
		  o Pollutants and other contaminants that leak from factories
		  o That which results in acid rain
		  o Refers to levels of pollution
		• Acid rain
		• Mutations/Inability to Adapt
		  o Can't camouflage
		  o No immunity
		  o Unsuitable conditions
		• Things the fish ate
		  o Lack of food

		◦ Hunger • Miscellaneous ◦ Dying of old age ◦ Inability to breathe ◦ Electricity
Hybrid causes	Statements that are conceptually interrelated and contain obvious (OC) and non-obvious (NO) factors	• Acid rain (NO) from factories (OC) • Fertilizer (NO) got spilled from a landscaper (OC) • Chemicals (NO) from a factory (OC) • People (OC) put toxins/chemicals (NO) in water
Ambiguous Cause		• "Something" killed the fish • Weather/environmental changes • "Mother Nature"

Action-at-a-Distance



Spatially Local vs. Action at a Distance

Concept	Explanation	Examples

Spatially local (SL)	Within the same attentional set as the effect. Here, this refers to in the pond and along the banks of the pond. In other words, "*in the pond*."	• References "in the pond/water"
		• Bacteria/disease spread in the pond
		• People polluting
		  o Pollution in the water
		  o Throwing trash in the pond
		  o Dumping
		  o Oil spill in pond/ toxic water from an oil spill
		• Various Compounds *in the pond*
		  o Chemicals
		  o Toxins
		  o Poison
		• Water-related issues
		  o Dissolved oxygen in water (if student does not mention a more distant precipitating cause)
		  o Water was too warm/cold
		• Miscellaneous
		  o "Something in the water"
		  o Electricity killed the fish
		• Fisherman fishing
		• Any type of predator
		  o Bigger fish ate all the food in the pond

Spatially distant (SD)	Outside the attentional set of the effect. Here, this refers to beyond the banks of the pond. In other words, "*land around pond.*"	• Effects of human habitation
		  o Salt from the road leached in
		  o People cut down trees
		  o Chlorine from a pool/waterslide
		  o Human/animal waste
		• Housing development
		  o Runoff/sewage, pipe/drainage
		  o Fertilizer
		• Hazardous materials traveling from golf course
		• Some travel-related language
		  o Clearly connotes materials' traveling from outside the

		- pond to inside the pond *without being directly dumped or thrown*, such as "draining in, rolling in, blowing in" - Phosphates leached into the water from the development
Action at a considerable distance (AD)	Causes that result from action at a considerable distance. Here this is defined as beyond what can be seen when standing at the pond. In other words, "*far away from land/pond*."	- Climate/Weather related - Global warming - Tsunami - Sunlight/lack of sunlight - Wind - Thunderstorms, lightening, - Impacts of distant factories/causes - Acid rain from a factory, cars, pollution, etc. - Nearby factories, farms - Runoff from farms - Pollution from companies - Some travel-related language - Travel coming from distant water sources: rivers, lakes, oceans - Something flowed into the river, which flowed into the pond
Ambiguous origins (AO)	Some causes have ambiguous origins (AO). The answers might imply distributed action at a distance, such as "acid rain." However, if the student doesn't talk about their cause as distributed and distant (e.g., "people all over the world contribute to acid rain that falls into the pond") then score it as having ambiguous origins. Take care not to project your interpretation of the cause but rather to try to see it as the student perceived of it.	- One-word answers without reference to origin/point of impact "Acid rain" "Toxins" "Oil spill" "Sediments" "Pollution" "Salt" "Natural disaster" (unless focus is on the pond) - Anything that "killed" the fish but doesn't mention that it was in the pond - Mother Nature - Food chain/web - Old Age

		• Weather is too hot or too cold

Main Rules for Spatially Local and Action-at-a-Distance Scoring

Print: Spatially Local; ***Italics:* Spatially Distant**; **Action-at-a-Distance**

Main Rules:

1. Give credit for the most distant precipitating cause
2. Give credit for the student's focus

Consider the following example in relation to the above rules,

- Pollution
  - Coded as ambiguous because it's a one-word answer and has no reference to a distal cause or point of contact
- Pollution killed the fish
  - Coded as ambiguous because "killed the fish" repeats the question prompt and doesn't give insight into the students' thinking about the location
- Pollution from **factories**
  - **"Factories"** gets coded as AD; students gives a precipitating cause for the pollution
- Pollution in the pond
  - Pollution here is considered spatially local because student mentions "in the pond"—compare this with the single-word answer "pollution" (which is ambiguous)
- Pollution from **factories** ~~in the pond~~
  - **"Factories"** gets coded as AD; students gives a precipitating cause for the pollution
  - Notice that the precipitating cause is a more important rule than student focus rule
- ~~Turbidity~~ blocked the **sunlight** from getting ~~into the pond~~
  - In this example **sunlight** gets credit for the most distant cause mentioned. It trumps turbidity as the precipitating cause as well as the focus on the pond.

Notes:

Most Distant Precipitating Cause

- Score the most distant precipitating cause in a set of linked causes and effects, not each intervening cause. For instance, if student gives a distal precipitating cause and then describes the mechanism for how it is linked to the fish in the pond (could be in a series of steps) just code the precipitating cause for its spatial location. View these as nested systems within systems and consider the furthest precipitating cause that is identified.

Student Focus

- If students do not mention a more distant cause, then things that are part of the pond environment such as “dissolved oxygen” should be spatially local. It depends on where the student placed their focus.

Ambiguous

- Wording matters. If students offer a short-hand answer such as “toxins,” then there is not enough information to score the origins. Code as ambiguous.
  - E.g., “The water was toxic from an oil spill from people who weren’t careful.” The precipitating cause is people, and it doesn’t tell how they were not careful: it could have been while filling their boat at the edge of the pond or miles away. Therefore, score as AO.

General

- Code tightly to the reasoning given. For example, in cases where one might be able to argue that something is AD, but the most that can be reliably argued is that it is SD, code as SD.
  - E.g., “Someone could have put down extra fertilizer and it was washed into the lake.” If it had to be washed in, then it is at least SD. It could be AD but if it isn’t signaled that way, mark it as SD.
  - E.g., If students focus on where something came from locally (a pipe into the pond) as opposed to distally, then score it as spatially local even though the pipe in the pond is considered spatially distal.
- People as agents can fall into any of the 3 categories depending upon the reasoning. If the student says that people are fishing or poured something into the pond then that is spatially local. If it isn’t clear where the people are, place them as distant as can reliably be argued for.
- Students are often not linear in their explanations. If this is the case, be sure to code the precipitating cause or causes. For instance in the example, “There would be too many phosphates in the water. The cause could be human waste, fertilizer, or animal waste.” This has three possible precipitating causes which should all be coded as spatially distal. “Phosphates,” the contingent cause, does not get coded.

Appendix D: Correlations

	female	raw.pre	raw.post	t1	t2	t3	t4	t5	eco	nopr.pre	sdpr.pre	adpr.pre	nopr.gain	sdpr.gain	adpr.gain
Female	1														
raw.pre	-0.016	1													
raw.post	0.093	0.786	1												
t1	-0.079	0.101	0.006	1											
t2	0.055	0.308	0.249	-0.206	1										
t3	0.055	0.231	0.360	-0.316	-0.208	1									
t4	0.029	-0.317	-0.334	-0.313	-0.206	-0.316	1								
t5	-0.055	-0.291	-0.258	-0.246	-0.161	-0.248	-0.246	1							
Eco	0.037	0.025	0.049	-0.103	0.003	-0.004	-0.049	0.178	1						
nopr.pre	0.034	0.183	0.276	-0.032	0.080	0.076	-0.070	-0.041	-0.012	1					
sdpr.pre	-0.040	0.067	-0.002	-0.043	-0.0004	-0.016	0.016	0.050	0.021	-0.097	1				
adpr.pre	-0.048	0.051	0.010	-0.089	0.023	0.080	0.054	-0.071	0.077	-0.109	0.046	1			
nopr.gain	0.052	0.059	0.043	-0.006	0.059	-0.033	-0.068	0.072	0.092	-0.635	0.015	0.077	1		
sdpr.gain	0.042	-0.112	-0.003	-0.140	0.059	-0.058	0.156	-0.002	-0.030	0.051	-0.471	0.001	-0.034	1	
adpr.gain	-0.026	-0.034	-0.047	0.104	-0.090	-0.080	0.020	0.029	-0.279	0.074	0.011	-0.610	-0.186	-0.152	1