# Chapter 9
# Teaching Students to Grasp Complexity in Biology Education Using a "Body of Evidence" Approach

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## 9.1 Introduction

Epistemology in the biological sciences includes approaches that respect the connectedness within systems, the value of accumulated evidence, long time scales and attention to steady states in addition to change. Helping students to understand the epistemic origins of biological knowledge—how we come to understand and agree upon knowledge based upon how evidence is gathered and claims are made in the discipline—is critical to their deep understanding and appreciation of it. Yet often, science education focuses on disciplinary knowledge to the exclusion of how knowledge is generated, how epistemology differs across scientific disciplines, and how such assumptions relate to the inherent complexity and connectedness of systems concepts. When there is a focus on scientific practices, these seldom reach down to the level of the epistemic assumptions underlying the generation of knowledge in the biological sciences. In this chapter, we focus specifically on ecosystems science as an exemplar within the biological sciences.

Efforts to introduce students to epistemology in science are often narrowly framed as an isolation and control of variables approach and a stereotyped version of the scientific method; centered on lab-based approaches and manipulatable phenomena, these efforts ignore approaches that draw upon accumulated evidence (Sinatra & Hofer, 2016) as in the biological sciences. A focus on isolating and controlling for variables misses the larger complex causal dynamics in ecosystems and does not begin to approach how ecosystems scientists engage in research. Helping students to learn the multitude of ways that ecosystems scientists develop

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evidence-based explanations for systems concepts in a complex world should be an essential part of biological education.

Yet even as science education reform documents push beyond a single, narrow version of the scientific method, resources for supporting teachers' efforts to broaden the epistemological approaches that students are exposed to are relatively few (Kamarainen & Grotzer, 2019). A study of how K-12 teachers understand epistemologically authentic approaches in ecosystems found that while they held relatively sophisticated perspectives on the diverse approaches used by ecosystem scientists, these were not reflected in the descriptions of their practices within their ecosystem science units. The results suggest the need to support teachers in adopting the epistemologically authentic practices within ecosystems science and in finding ways to translate those to the classroom (Kamarainen et al., 2021).

This chapter argues for the importance of introducing students to the epistemic assumptions that biological scientists make when framing their work particularly as they relate to understanding the connectedness of systems. It discusses an approach called a "Body of Evidence Approach" (BOE) for analyzing the causal complexity of ecosystems and introduces a study that was conducted to assess the impact of teaching this approach to middle school students.

### *9.1.1 What Is a Body of Evidence Approach?*

Through a series of open-ended interviews with ecosystems scientists, Kamarainen and Grotzer (2019) found that they characterize causal patterns and relationships in ecosystems as embedded in a complex matrix of interactions, subject to inherent and sometimes irreducible variability and not always subjectable to manipulative experimentation. In these situations, they use strategies to construct understanding of complex systems through constructing a Body of Evidence approach—integrating results of multiple approaches, measuring and describing variability, conducting experiments in context, taking advantage of natural experiments, thinking across levels and considering the limits to generalizability. Ecosystems scientists also demonstrated considerable "epistemic fluency"—referring to the ability to discern and engage in a variety of investigative approaches for gaining knowledge in a certain field (Goodyear & Zenios, 2007).

At the core of a BOE approach are ways to think about the nature of causality that fit with the information available to ecosystems scientists. Kamarainen and Grotzer (2019) argue that, "Moving from a correlational to a causal account involves epistemological assumptions in any discipline. It presents particular challenges when phenomena involve multiple causes, time-lags, feedbacks, or thresholds as is the case in ecosystem science. While reductionist approaches may contribute to explanatory efforts, investigation in ecosystems science requires a systems perspective" (p. 533). The ecosystems scientists in the study pushed against the notion that complex systems can be understood through reduction alone. They argued for the use of confirmatory approaches such as developing complementary possible models to consider, holding models in consideration until enough evidence exists to determine that they are clearly wrong, considering multiple lines of evidence and the soundness of the evidence for possible mechanisms (Pickett et al., 1994). They also argued for using 'natural experiments' and non-traditional forms of experimentation (Jensen et al., 2012) for instance, dividing a pond with a nylon curtain and treating one side and not the other as a comparison study (Bennett & Schipanski (2013) or placing a tent over a steam to exclude leaf litter and accessing the impact over time (Strayer, 2013).

### *9.1.2 A BOE Approach for Middle School Science: Understanding Goals*

How might this approach translate to what students in secondary school are taught? The following set of Understanding Goals represents the substance of how we approached teaching students about the ways that ecosystems scientists think about causality in complex contexts:

1. It is not always possible or desirable to conduct an experiment.
2. When it is not possible or desirable to do an experiment, ecosystem scientists use an approach where they systematically look for lots of different types of evidence. (They call this a "Body of Evidence" approach.)
3. The more evidence that can be gathered in support of a claim, the more likely it is that that the claim will be accepted. The evidence should be from different and varied sources.
4. In addition to trying to find out what makes something happen, scientists try to collect as much information as they can on how the cause and effect relationship varies—the range of possible outcomes. (For example, a variable might cause an outcome when it reaches a certain amount, but not at lesser amounts. It also might not cause more of an outcome as you keep adding more. Or it might be that the amount of outcome increases stepwise with the amount of the causal variable.)
5. Sometimes nature "conducts experiments" that scientists can interpret. They use these as natural opportunities to learn about what happens. Natural opportunities can be especially helpful in cases when an experiment is not possible or desirable.
6. Scientists talk about how much certainty they have in a set of findings. They may express uncertainty. They may express certainty at different levels of analysis of a problem and not at others. They may talk about certainty in some contexts but say that it is not generalizable to other contexts (limits to generalizability).

## 9.2 Research Questions

The case study described below incorporated these Understanding Goals (UGs) into a broader ecosystems science unit to investigate how students responded to the BOE UGs and how it influenced their learning. Their understanding was contrasted to students who experienced the unit without the BOE components. The study sought to address the following questions:

1. What characterizes the understanding of students in each class?
2. What can be learned from the contrast about helping middle school students to learn about BOE as an approach in ecosystems science that can inform future educational efforts?

We hypothesized that students experiencing the BOE components would demonstrate understandings that are more closely aligned with the UGs above and that they would be more likely to seek out multiple and corroborating forms of evidence.

## 9.3 Methods

### *9.3.1 Design*

The impact of teaching a BOE approach to middle school students learning about ecosystems complexity was explored by comparing the understanding of students in two classes from an urban school who participated in a Problem-Based Learning (PBL) Curriculum called EcoXPT (with the XPT used as shorthand to capture its specific focus on experimentation within ecosystems science) in a case study. Both classes participated in the curriculum; One class had additional instructional components related to a BOE approach infused (EcoXPT+ BOE) while the other did not (EcoXPT). Assessments included concept-maps (containing evidence for each claim) and post-interviews. Students also took an on-line pre- and post-inventory as in other studies of the impact of the EcoXPT curriculum, but given the small n, no clear patterns emerged so this data is not included here. The pre-inventory data suggested that the groups were equal upon expectation at the outset of the study.

### *9.3.2 Participants*

Two seventh grade classes of the same teacher participated. The students were from an inner-city charter school with 91% minority enrollment, low socio-economic status (SES) and low scores on a state-wide, standardized test (the Massachusetts Comprehensive Assessment System (MCAS)) (Math Proficiency—27%; Reading Proficiency—34%). A total of 22 students participated with 12 students in EcoXPT and 10 students in EcoXPT + BOE. Students worked on the curriculum in pairs and participated in both individualized and pair assessments. As a case study, the sample size was quite small and thus is a limitation to the generalizability of the findings.

### *9.3.3 Curriculum*

Both classes participated in the EcoXPT curriculum for 14 days (See overview in Appendix). The curriculum centers on an immersive virtual world that depicts a pond ecosystem. (See Fig. 9.1.) (A full description of the EcoXPT curriculum and the Teacher’s Guide are available here: https://ecolearn.gse.harvard.edu/projects/ecoxpt). Students worked in teams of two to a computer. During Curriculum Days 1–3, they explored the world and were instructed to “get to know it.” On about the third Curriculum Day, students discovered that a fish die-off had occurred on a certain day within the virtual world. They then began to investigate possible causes for the fish die-off by traveling in virtual time before and after the event to observe and collect data on population levels and water quality measurements. They used data tools in the world to view and graph this data which allowed them to see patterns between the different types of data. On Curriculum Day 7, students in both classes had access to experimental tools and to scientists in the world who shared the rationale for certain kinds of approaches and their epistemological assumptions. The experimental tools varied widely to include lab-based experimental tools such as tolerance tanks and comparison tanks and in-situ experimental tools such as mesocosms, tracers and a water buoy that collected data over a period of virtual months. (See in-depth descriptions of these tools in Appendix.) Other sources of information


**Fig. 9.1** Image of the EcoXPT immersive world

available to students included observation of organisms, changes over time, a microscope that allowed them to zoom in on microscopic organisms in the pond, the testimony of virtual scientists and other non-player characters in the world and a field guide that offered information about the organisms that they found in the ecosystem.

Throughout the curriculum, students in both classes were introduced to a set of science-related thinking moves, illustrated by classroom posters that they could refer back to (thus reducing the memory demands of learning the thinking moves) while working in EcoXPT and short explanatory videos supported by in-depth teacher support notes to help students to learn how ecosystems scientists engage in scientific practices. These included a set of five posters for both groups: *Deep Seeing* which asks students to engage in careful observation of the ecosystem; *Evidence Seeking* which stresses the importance of using evidence to support one's claims; *Pattern Seeking* which asks student to look for patterns in the on-going processes and steady states of the system; *Analyzing Causality* which encourages students to seek out the causal mechanisms relevant to the relationship; and *Constructing Explanations* which asks students to put together the available evidence to construct the best causal story or explanation that they can. (See Appendix.)

### *9.3.4 BOE Intervention Components*

It is possible to add elements into the virtual world and to turn their appearance on or off. Using this capability, additions were made to the virtual world in the BOE condition. So, while both classes worked in a rich, contextualized immersive simulation, certain elements were present only for those in the BOE class. These included: additional dialogue by some of the virtual scientists in the world. For instance, students in both groups find Dr. Jabir standing outside near a set of mesocosm experiments. In both groups, he says, *"Let me tell you about the mesocosm experiment I've been running here for the last two weeks." However, for the BOE group, first he says, "Lab experiments are great for isolating and controlling variables, such as whether phosphate level affects fish. But mesocosms let us consider how other variables in the real world, like sunlight and temperature, interact with variables we are testing. Even though it is not the same as experimenting on the actual pond, it gives us more certainty about what is going on without hurting the pond."* The BOE students also meet Dr. Aziza Al Dahan standing near Amelia Pond which has turned bright green. She says, *"Hello, are you noticing what I am noticing? This small pond has turned bright green. What do you think is going on? Think about it for a little while and then come back to talk to me."* Later, they run into her again and she says, *"I investigated and found out that a farm worker put a new manure pile in a place where the run-off comes to this pond. This has caused a spike in the algae levels in the pond." "As an ecosystems scientist, there are times when something happens that was not intended, but that we can learn from. We wouldn't have done an experiment directly on this little pond, but now that it has happened, I am studying it to learn from what happened." "In this case, a person made this* *happen, but sometimes nature creates opportunities to study changes in the ecosystem—such as when a hurricane comes through and changes a landscape or fire removes the smaller trees and understory from a forest." "Does anything that you are seeing here corroborate what you are finding out about Scheele Pond?"*

Students in the BOE class were introduced to the BOE Thinking Move and saw a poster and accompanying video (See Appendix for script) explaining the *Body of Evidence Approach,* encouraging them to collect evidence from multiple sources, look for corroborating evidence of different types (including perceptual evidence, patterns in data and graphs, numerical information and testimony from trusted others) and to assess the validity and reliability of the sources of evidence. They used a Body of Evidence Worksheet (See Appendix) to consider how more evidence leads to greater certainty/stronger claims and worked with a partner to evaluate evidence through a BOE lens. Both classes did talk about different types of evidence and what can be learned from different types as part of the Evidence-Seeking Move and filled out a worksheet focused on this topic (See Appendix), however only the Plus BOE group discussed it within a BOE framework. Supporting materials included ways to talk about BOE for both students and teachers (see Appendix).

## 9.4 Data Sources and Analysis

### *9.4.1 Concept Maps*

Each pair of students developed an online concept map of their understanding of the causal dynamics within the virtual ecosystem. On the sixth day of the curriculum, students in both classes were introduced to a concept-mapping tool in the immersive world. (See Figs. 9.2 and 9.3.) Students choose from a set of images of factors that become the nodes of the map. They then define claims by drawing an arrow from one node to another and by choosing how to label the arrow (affects, does not affect) (for example, "phosphates affect green algae"). A button on the claim window invites them to state the evidence for the connection. This button opens to an index from the on-line notebook within the program where they track things that they are finding out in the virtual world. It offers evidence that is linked to the source that students used to identify the evidence. A text box asks students to explain their reasoning for how the evidence bears on the claim. For the purposes of this study, the concept mapping tool was modified to include a number along each arrow to alert the students as to how many pieces of evidence they had used to explain each arrow in their concept map. (See Fig. 9.4.) A box appears on the lines of each connection in the concept map to show how many pieces of evidence students provide for that given connection.

An analysis of student concept maps was conducted to look for potential differences in the number of connections, amount of evidence provided for each connection, as well as the percentage of connections for which they provided both evidence


**Fig. 9.2** Concept-mapping tool


**Fig. 9.3** Links to evidence within the tools

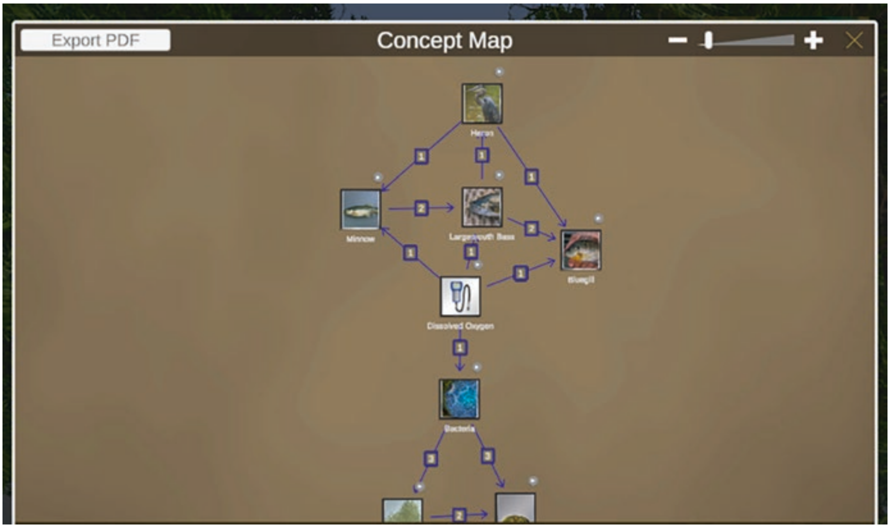


**Fig. 9.4** Boxes along lines in concept map show number of pieces of evidence

and reasoning. The maps were coded for the different types of evidence provided in each connection for each pair’s concept map and the frequency of use of different types of evidence was calculated to offer a quantitative view of how they considered evidence. These frequencies were calculated into class averages. A second round of coding analyzed the concept maps qualitatively. Major themes were identified from the connections that students made, the factors that they used, the evidence they provided in relation to the connections they made, as well as the type of causal connection they made (in that, “does not affect,” “affects each other,” “affects”).

### *9.4.2 Post-interviews*

A set of interview questions focused on epistemology in ecosystems science and BOE were developed. It included questions such as: *“What are some things that ecosystems scientists do when they cannot conduct an experiment and want to make causal claims about what has happened in the ecosystem?” “Have you ever heard the term “Body of Evidence”? If yes, what do you think it means? If no, a Body of Evidence means “a collection of evidence.” What do you think that means?” Why is it important for ecosystems scientists to collect a “Body of Evidence” or a “Collection of Evidence”? What are some reasons that they do it?”* These questions were followed up with open-ended probes, such as, *Can you tell me more? What does that word mean to you?* etc., to get at students’ intended meanings. Following the intervention, eight students, four from each class, were interviewed in sessions that lasted approximately 30 min. This analysis included an emic process of surfacing emergent themes within each interview (Strauss & Corbin, 1967), capturing these as a memo about each subject's knowledge and then looking across memos for themes across interviews generally and as clustered by the two classes.

## 9.5 Results

### *9.5.1 Concept Maps*

As seen in Table 9.1, EcoXPT students made more connections but had fewer pieces of evidence within their connections than students in the EcoXPT plus BOE students. They also did not include both evidence and reasoning in their connections as much as EcoXPT plus BOE group. The EcoXPT plus BOE students made fewer connections but had more pieces of evidence within their connections. They also had higher rates of both evidence and reasoning in their connections. The EcoXPT Only students tried to use more factors to make more connections and to construct more of the causal story. This response pattern was frequently witnessed with students using less relevant reasoning to the connection they were constructing, but it would often help tell the "story" (in that reasoning often explained the connection or elaborated on it by "telling parts of the story."). Some students also didn't make broader or more complex connections, but instead they made minor connections (only two or three factors) across the causal scenario. They also used the same piece of evidence for multiple connections even if it wasn't the best evidence for a given connection. The EcoXPT with BOE students generally made fewer connections and there was a tighter range with less variability in the number of connections that they made. However, they included more of the "foundational" part of the story (usually related to fish, herons, abiotic factors you can test in a lab, etc.) and they tried supporting it well with evidence and reasoning. The tighter range with less variability may be due to the greater cognitive load of processing more evidence for each piece. It is not possible to know conclusively given the small n in each class and might also represent differences in the student samples.

The most frequently used types of evidence across both groups were the tolerance tank results and the field guide. (See Figs. 9.5 and 9.6.) This makes sense because of the progression of the Thinking Moves and curriculum. The curriculum

**Table 9.1** Concept map comparisons in EcoXPT vs. EcoXPT + BOE classes

| Intervention condition | Average number of connections | Average percentage of connections that contain both evidence and reasoning | Average number of pieces of evidence per connection |
|---|---|---|---|
| EcoXPT only (n = 12) | 10.3 (range 2–21) | 55.67% (range 17–100%) | 0.76 (range 0–2) |
| EcoXPT + BOE (n = 10) | 6.6 (range 4–12) | 75% (range from 0–100%) | 1.12 (range 0–3) |

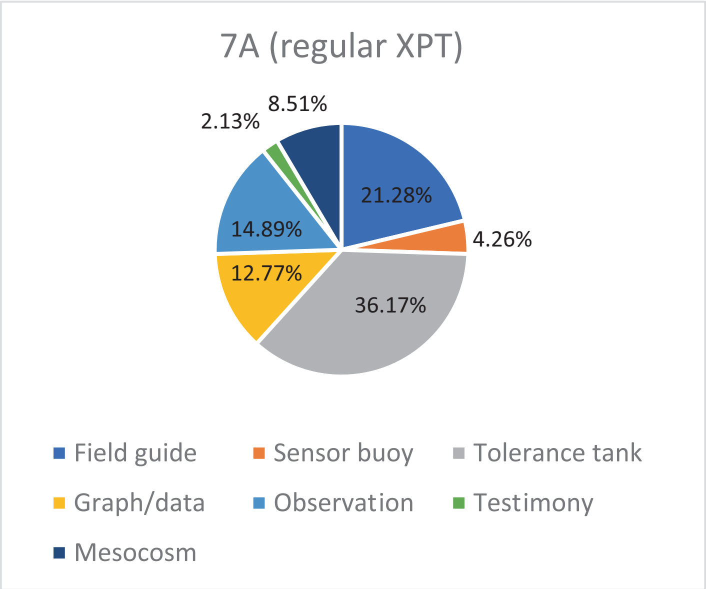


**Fig. 9.5** Evidence use by EcoXPT only students

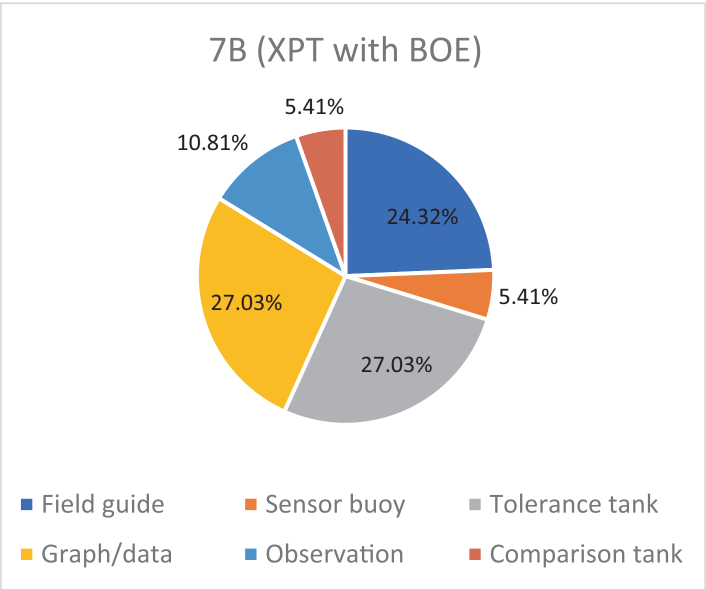


**Fig. 9.6** Evidence use by EcoXPT Plus BOE students

encourages observing and taking notes (or looking at notes, as in the field guide) and then analyzing causality (which is usually first explored through the use of the tolerance tanks in the lab because it's easy to isolate direct causal relationships). The BOE class tended to refer to pattern data (in the graphs) to a greater extent whereas the EcoXPT Only class used testimony to a greater extent.

## *9.5.2 Interviews*

The interviews suggest that some students in the BOE groups were able to grasp some aspects of a BOE perspective including the importance of varied sources, the belief that ecosystems scientists try to study the environment in ways that don't harm it—a "do-no-harm" perspective—and the value of holding multiple possible models in consideration, as elaborated below. Their ability to reflect explicitly on the framing for their evidence and the encompassing epistemology was somewhat more limited than anticipated and there were some clear challenges as well. The following themes were evident.

### 9.5.2.1 Confounding Causal Factors with Sources of Evidence

Students focused more on multiple causal factors involved in the eutrophication scenario than on the meta-level concept of multiple sources of evidence as necessary to support causal claims. When questioned about sources, they tended to confound them with factors. This response pattern occurred to some extent in both groups.

Most students gave sophisticated explanations of the complex causal factors involved in the eutrophication scenario. They seemed well able to think about complexity and multicausal scenarios and explained how causality might work. However, when asked about sources, students in both groups conflated multi-causal explanatory factors with the concept of multiple sources of evidence (as exemplified by subjects 3, 4 and 6 below).

Some students focused this part of the conversation on what they needed to do to find evidence—the behaviors that they would engage in, to a greater extent than the nature of the evidence itself and the meta-concept of the epistemology and a strong body of evidence. For instance:

Subject 3 (EcoXPT Only):

> *I-…can you give me examples, more examples, when you say they are collecting evidence?*
> *S3-They go to, they test the water, to see if the water is okay for animals to live. They check the soil and the plants to see if okay, that plant life can breathe. They try to find animals, see if there's a lot of animals or not that many animals.*

*I-…Yeah, you're kind of talking about this claim, there's evidence. Tell me more about how they connect.*
*S3-Oh they connect because we looked at the days- the day before they died, the day after they died and the day they died. And we looked for a pattern, something changed. And we thought the dissolved oxygen went down a little bit and [inaudible]*
*I-So in that case you're saying the claim-...*
*S3-Was like the dissolved oxygen killed the fish- was the cause of the fish died.*
*I-And what was the evidence?*
*S3-The evidence was that the day before the fish died, I think like the dissolved oxygen was perfect and then when the fish died the dissolved oxygen went I think either down or up.*
*I-OK. …why is it important for ecosystem scientists to collect a body of evidence, or a collection of evidence? And what are some of the reasons they might do it?*
*S3-It's important for them to collect because they want to say how the ecosystem changed in that time they collect evidence. And it's important because what if something bad happened to the ecosystem and they didn't collect evidence they don't know why, or what caused it.*

Subject 4 (EcoXPT Only):

*I-Tell me more about that, what do you mean by evidence to support their reasoning about the ecosystem?*
*S4-Well, evidence and their reasoning, they're going to want to find more evidence that actually is relevant for what they think is the reason why the ecosystem is damaged, or succeeding, or whatever state it's in.*
*I-Can you think of some examples about that type of evidence, or what they might be doing, ecosystem scientists?*
*S4-Well they would do, probably use tracers, so harmless chemicals that give off a glow, put them into an ecosystem to see what kinds of factors are going inside the water, or doing these certain things and affecting these. …Some other evidence is like, trying to find out populations. Trying to find out about the microorganisms, because microorganisms are a very big part of ecosystems, a very big part. …Because microorganisms, you may not see them, but they do a lot of things. Bacteria can travel real far. So you also gotta measure bacteria the most. There's a type of bacteria that's from Japan, that's native to Japan, that was found on a person, he lived in the USA. But the thing was, this person had never been to Japan. That is how far bacteria can travel. It can travel in and out of ecosystems, just like that.*
*I-So do you think that's something ecosystem scientists are doing?*
*S4-They're trying to see mostly all the factors. Mostly all, not really all because it's hard to find all factors. If you don't have all the stuff you try to find most of them, so that makes the most sense.*

Subject 6 (Plus BOE):

> *S6-Ok. Umm… Um, algae, bacteria levels. So algae multiplied because of the heat and the sunlight. They started growing too much. And then after it grew too much they died and then all the plants below start dying too because of lack of sunlight. Then bacteria started decomposing it and then the bacteria levels started increasing which made the dissolved oxygen levels decrease. So that's when it's being caused. Algae caused bacteria to increase which caused dissolved oxygen to decrease.*
> *…Well, they can get data and turn it into a graph to figure out how and what is causing the other one. Like the example that I used before- algae, bacteria and DO levels. That's the one that's causing it. And it could also be like something I thought before about the herons eating all the fish, so that was my answer at first because the heron population was increasing and the fish population was decreasing. So then that was my main, like source. But then I started thinking about it and then I figured out that wasn't correct because if the food source is going down then so should the predators.*

This focus on figuring out the factors involved in explaining what happened at the pond and on the actions that one would engage in to find out, by subjects in both conditions, is not, in retrospect, surprising. The response has more behavioral coherence with what they are being asked to do in EcoXPT—to investigate and develop an explanation for what has happened to the fish. Focusing on the sources of evidence introduces a meta-level to that process. It is possible that the increased cognitive load of the task was more than students in both groups were able to engage with. As considered in the discussion, this raises the question about whether there are instructionally more effective ways to get students to focus on sources of evidence—such as evaluating someone else's data and deciding whether information is trustworthy.

Two students, subject 5 from the BOE class and subject 2 from the EcoXPT Only class, clearly did differentiate between factors and sources—not confounding them—and talked about the importance of multiple sources, suggesting that students are able to do so. Subject 5 (BOE) talks about the importance of multiple sources of information in providing for a body of evidence. For example:

> *S5-Because you can't really rely on one source of something because you have to get a lot of sources to see if they match up. And some news can be fake from what you've heard, so you have to learn from other sources.*
> *I-…do you think it's better to have multiple different types of evidence or one type?*
> *S5-Um the same thing, multiple types of evidence because the thinking move body of evidence has something to do because you can maybe mark out like one claim we had about it and then something debunks it, we can't really see what debunks our claim of the situation if we only have one source of evidence.*
> *I:-Could you tell me what you think the term body of evidence means?*
> *S5-Um, it says body in it, so it means like, I think a lot of things like a lot of evidence to debunk your claim or support your claim, or maybe new questions along the way.*

*I-Is there anything else we should know about body of evidence?*
*S5-Um, don't have like, don't be disappointed or have high hopes. Just clear your mind and just not think about it too much. Or have an open mind about it.*
*I-Should they be different sources, same sources?*
*S5-I think they should be both so you can have a variety. …so you can have different types of sources to go back to. ….I guess it would be nice to have a variety in my opinion. I'd rather have a lot of things instead of like one source. I'd rather have a variety of sources.*
*I-Why is that important?*
*S5-Very reliable. It's very reliable to have a lot of sources or a lot of things.*

Subject 2, an EcoXPT Only class member, also differentiated between sources and factors. However, s/he insisted that evidence that is all from the same source is better, that if the evidence came from different sources that would not be as good. While s/he recognized that multiple pieces of evidence are helpful and gave a preference for experimental evidence, s/he explicitly rejects varied sources. It is possible that the student was expressing a distrust of testimony in particular and the need for additional evidence to back it up, but the interviewer did not probe this aspect of understanding further. For example:

*I-Well we're just talking about having multiple pieces and are all of the pieces of evidence from the same source, or different sources?*
*S2-All from the same source.*
*I-Let me think of an example. Pretend my claim is, dissolved oxygen affects fish and I have two pieces of evidence and they're both testimony, so I heard someone say something. I heard a scientist say "I know from my experimental experience that low dissolved oxygen causes fish to die," and someone at the pond said "I heard dissolved oxygen can cause the fish to die" Is it better to have two of the same type of evidence, does that make it strong?*
*S2-Yeah, because they both gave you really big pieces of evidence. And you could probably get something out of it, too, by yourself or something. And then probably make it stronger and stronger.*
*I-What if you had two different types of evidence? Let's say you had testimony and you had data. Is that also good or not as good?*
*S2-I think it's not as good because the testimony, you're testing it- I'd try the experiment thing though, because what people- what if they don't know what to do and they just said it to you? I would test it to see if it actually works. I would test it because it would be- you could get a lot of evidence out of it.*
*I-…Is it better to have two of the same- for example two people said something. Or is it better to have evidence from two different sources? So for example someone said something and data you collected.*
*S2-I think the same*
*I-because…?*
*S2-Because if they're thinking the same way, they can probably, we can all work together, try to find something else.*

#### 9.5.2.2 Expressing the Value of Multiple Possible Explanations/Models

At least one student expressed the value of multiple possible explanations and holding different possible models in mind (which is different from multiple factors, multi-causal explanation), connecting it to open-mindedness.

Subject 8, a student in the BOE Class expressed that s/he was holding more than one possible explanation in mind implying an open-mindedness that fits with the epistemic value of holding multiple possible models and the uncertainty and humility with which the ecosystems scientists considered possible explanations and supporting evidence (Kamarainen & Grotzer, 2019).

> *S8-And if the algae probably doesn't, this is my other theory- if the algae doesn't uh, like if the algae doesn't uh… Ok so, if the algae is like not working right, like if the algae is uh… Let's see… Oh yeah, so if the algae like uh… If the algae uh… Can you skip it? Skip it. Because I can't have an explanation for it.*
> *I-Yeah, do you want to think about it for a second? We have time.*
> *S8-Uh, yeah sure. Uh… Oh ok! So I got it now!*
> *I-Yeah.*
> *S8-So the nitrates probably activated the algae, so the algae can be produced more, the algae might cover up the, like the top of uh, the ceiling of water. And it probably can't make the photosynthesis go to the water, so the fish can't, so the plants down there can't do photosynthesis so they can't make oxygen for the fish. And when it does that, the fish is going to die because oxygen. And the bacteria is going to break it down and also there's more bacteria, bacteria also takes up the water, it takes up more water, the fish might not have a lot of water to breathe. So I think something caused the algae, like nitrates, or nitrogen probably taking up the oxygen I think.*

#### 9.5.2.3 Recognizing a Collection of Evidence Intended to Support a Claim

Interviewees in the BOE Class offered descriptions of BOE that included recognition that the evidence is a collection, not just randomly chosen and that the intent is to prove a claim.

Subject 7 made explicit comments to indicate that a Body of Evidence has meaning beyond just a bunch of random evidence, for example:

> *S7-They collect a bunch of evidence for um, so they will have more than one reason of why something would cause the other or something that happened. …A body of evidence, um… So a body of evidence is this like, collecting evidence and running tests to see if your right or wrong every day until you get it right eventually, or if you fail. And a bunch of evidence is like, just having evidence and basically not doing anything with it. I guess.*

S8 viewed BOE as needing to prove claims (though not necessarily in the context of broader epistemological considerations).

Subject 8 (BOE):

*I-Have you ever heard the term body of evidence?*
*S8-Yes.*
*I-Ok, what does it mean? Can you tell me?*
*S8-It means like, say for scientists there's like an experiment, you need evidence to show the experiment that he did or she did, so he or she would probably be doing an experiment about fish and they will see what happens in the ecosystem like five days after it rained. They need a body of evidence, so they need to take like notes, or like body work, or they need to like take pictures, to see how many, like a lot of body of evidence that they have to include and talk to other scientists to see what the can do to fix it.*
*I-Ah, ok. So tell me more. You mentioned they might have notes, they might have like temperature, things like that. Tell me what that means in terms of the body of evidence, like what is it?*
*S8-They'd probably have to take notes like, uh, like the turbidity went down below like 50 degrees, or uh, 50 Celsius I think. And they had to that and see what happens like everyday and see what happens during the day, see where body of evidence is- how much evidence that they have.*
*I-And so why, why is it important that ecosystems scientists collect a body of evidence? Like what are some reasons why they would do it?*
*S8-Because they need body of evidence, because if they just say it then like, oh yeah that happens, but then they need like a claim that can like prove their explanation.*
*I-So is this something that you did when you did EcoXPT? Did you think about this?*
*S8-Yeah I thought about that if I just say something I need to back up with evidence. If I just say that the algae killed the fish I have to go and research and have to go around and do temperature, water temperature, see what happens on the algae on this day, on the day that the fish died, the population of the algae, the green algae, blue algae and see what happens. Because if you say like it's algae- prove it! So I have to go out, search for stuff, research it, get like a body of evidence. So, yeah…*

#### 9.5.2.4 Making Connections to Other Learning about Evidence

Despite the lack of introduction to BOE as a concept, when asked what it might mean, students in the EcoXPT Only class made connections to what they had learned about providing evidence when writing in general and in science, in particular.

Students in the EcoXPT Only group made connections to an idea that they appear to have learned in class about writing and perhaps scientific writing in general where you have an introduction, then a body of evidence, then a conclusion. For example:

Subject 1 (EcoXPT Only):

> S1-*So, body of evidence could be- like in an essay you have the introduction which has a claim. Then you have the body of the claim, which has three, two, or some, or a certain amount of body evidence in your essay. …It's like an essay, when you have the body evidence, which is the evidence from the claim that you're making.*

Subject 3 (EcoXPT Only):

> *S3-Well I think like a hamburger, is like the meat is the middle, what you're doing, like an essay- no, not like an essay. Body, a paragraph- the middle of the, experiment? If you have evidence… …like if I explain something, I'm going to have to have evidence. So I'm going to have like the middle.*
> *I-So what does the term "body of evidence" or a collection of evidence in the context of ecosystems, what do you think that might mean? OR what we might use it for?*
> *S3-To see if the evidence goes with the claim you are trying to make.*
> *I-Okay, tell me more, why is that important?*
> *S3-Because if the evidence has nothing to do with the claim you're trying to make, it's going to be hard to back up your claim.*

#### 9.5.2.5 Acknowledging Ecosystems Science Experimentation as Sensitive to Not Harming the Environment

Students in the BOE Class talked about how ecosystems scientists attempt to "do no harm" and how this impacts experiments that they would not do.

Students in the BOE Group did seem to come away with a clear sense that ecosystems scientists try to do "do no harm" investigation—that they don't burn down the forest to see what happens and that they might investigate things that naturally occur (what is called "natural experiments" or "opportunistic investigation" in the curriculum) even if the students did not explicitly use those words. For example:

Subject 8 (BOE)

> *I-What are some things that ecosystem scientists do when they can't conduct an experiment but they want to make a causal claim?*
> *S8-Uhh, they probably might, uh let's see… Maybe they might do a tolerance tank, they might get a lot of fish and put a lot of stuff inside to see what kills them because they can't go outside and do that to all the fish to the ecosystem because they, it won't be good.. So yeah, the fish would probably die really fast, so they had to do it in a tank and see what happens. Or they probably, um,*

*they probably just do something that makes like, I'm not really sure, but I have an example. So say like, they want to go and see how many forest fires happened that one year, not forest fire that happened every once a year, a forest fire happens like, how high the temperature of the forest fire can get. …They're not going to go burn a forest fire and burn it. So they might probably get like a couple of branches and trees and they might like put it in their office and burn on fire and see what happens.*

Subject 5 (BOE):

*S5-So, if something like in the past, a lot of things happen in the US here or worldwide, so um, like a forest fire. They can't just put a forest fire on an actual forest because it could hurt the ecosystems in there that it's producing. And they could use some research of it from recent years, or how long it is and see the effect of it how it was before.*
*I-Anything else?*
*S5-Um, an internet one? Like an online one, like how you did it with EcoXPT without actually harming any fish in real life. ….Oh wait, what if they get already passed on fish and conduct an experiment on that?*

The interviews suggest evidence that some students are able to understand and use aspects of Body of Evidence reasoning, but also that the ability of the broader group of students to reflect explicitly on the framing for their evidence and the encompassing epistemology was somewhat more limited than anticipated.

## 9.6 Discussion

The findings suggest that there were subtle shifts in how students viewed the importance of evidence in support of their claims and that the BOE students focused on constructing a compelling body of evidence in support of each claim. Some of the interviews indicated an appreciation for holding different possible models in mind and considering multiple lines of evidence as the scientists did. It may have come at the expense of a fuller explanation of the complex causal scenario as they constructed less of the explanation in their concept maps. At the same time, their explanations focused on causal dynamics that were central to the eutrophication scenario. Given the period of time over which the curriculum plays out and the primary tasks of investigating the reasons behind the fish die-off, it makes sense that a focus on BOE in addition to constructing the causal connections would divide students' time and attention to some extent.

Both groups of students revealed understanding of the importance of evidence. The BOE group used more evidence in support of their concept map connections. Some of the BOE interviewees were able to talk explicitly about constructing a set of evidence and the importance of having corroborating evidence. The EcoXPT Only students also thought carefully about the types of evidence and the importance of providing support for testimony. The EcoXPT curriculum materials support these understandings (even without BOE framing) through the Evidence-Seeking Thinking Move and the supporting materials (See Appendix).

The findings also suggest that students in both groups focused more on talking about developing explanations with multiple causal connections and including multiple possible facts than multiple sources of information/evidence for each factor. This response pattern makes sense given that developing the causal story is more directly aligned with the primary goal of figuring out what happened to the fish and the other is at the meta-level of how they establish the causal connections and generate the scientific knowledge behind their explanations. The finding that the BOE focus translated into a stronger focus on collecting corroborating evidence even if it did not result in as much of an explicit awareness of the epistemology as anticipated is a step towards acknowledging the epistemological underpinnings.

There was clear evidence that BOE students understood that ecosystems scientists needed to find ways to construct causal explanations that did not harm the environment, that they entertain different possible explanations, and that they focus on constructing strong explanations and that this relates to the evidence that they can provide to support their explanations. Students in both classes expressed understanding of the value of experimentation in providing evidence.

This initial, exploratory study is promising, but limited in what can be learned from it. One could imagine that a longitudinal study would reveal more about how these understandings can be developed over time. With greater time to build such understandings, it seems that it would be possible to build the meta-level understandings about varied and multiple evidence and constructing a powerful explanation as an integrated part of figuring out what one believes to be the causal connections. A longer and somewhat larger study might also reveal particular points of difficulty in learning these ideas—both where they are challenging to learn and where they may interact with other concepts in ways that could lead to misunderstandings. It is also possible that students would learn more about the particulars of how ecosystems scientists construct complex causal explanations of systems if they had opportunities to contrast these epistemologies to approaches in other areas of the sciences as such juxtaposition would help to highlight the features of each. Despite its limitations, this study does suggest possibility and promise for developing important understandings in how biological systems are understood.

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# Appendix

## *Overview of the Plus BOE Curriculum*

| **Overview:** | | |
|---|---|---|
| **Day One:** *Essential question of the day: How can I get to know an ecosystem through exploration?*<br>Students begin exploring EcoXPT and focus on getting to know the layout of the world, what organisms live there (both micro- and macroscopic) and how the field guide tool works. They are introduced to a thinking move called Deep Seeing | **Unlocked:**<br>Camera<br>Field Guide<br>Submarine<br>Notebook | **Locked:**<br>Data View<br>Calendar<br>Water Tools<br>Weather Tool<br>Population Tool<br>Atom Tracker<br>Concept Map<br>Lab (includes scientists) |
| **Day Two:** *Essential question of the day: How might things change in an ecosystem over time?*<br>Students continue exploring EcoXPT and focus on traveling over time and seeing what can be learned on different days. They may also start collecting water quality measurements and gathering data for those measurements across time. The weather tool, population tool and Data View are also unlocked on the second day and some students will find them and use them. They will be more formally introduced on Day Three | **Unlocked (in addition to what was unlocked on previous days)**<br>Calendar<br>Water Tools<br>(Weather Tool)<br>(Population Tool)<br>(Data View) | |
| **Day Three:** *Essential question of the day: How can I collect evidence to help me figure out what's going on?*<br>Sometime during Day Two and Three, students will have found the fish die-off. If they have not yet found it by the beginning of Day Three, they are guided to exploring the date of July 28. They focus on their initial hypotheses about what may have happened and begin collecting evidence in support of their hypotheses. They are introduced to the move of Evidence Seeking. As they collect pieces of information, or evidence for what might be happening in the world, they are able to collect evidence in relation to each claim. The opening PPT draws their attention to the Population Tool, Data View and Weather Tool | | |
| **Day Four:** *Essential question of the day: How can I look for patterns that suggest what might be going on?*<br>Students continue seeking evidence in support of their ideas about what happened to the fish. They are introduced to the move of Pattern Seeking as they explore patterns in the data that suggest what might be going on | | |

(continued)

| Overview: | |
|---|---|
| **Day Five:** *Essential question of the day: How can I start to connect the information that I'm gathering?*<br>Students continue seeking evidence in support of their ideas about what happened to the fish. They are introduced to a Concept Mapping Tool that will help them to make possible connections and seek evidence for each claim represented in their concept map | **Unlocked:**<br>Concept Map |
| **Day Six:** *Essential question of the day: How can I use experiments to answer the questions that I have about what's going on?*<br>Students continue seeking evidence in support of their ideas about what happened to the fish and exploring patterns in the data that suggest what might be going on. Once they have discovered patterns between algae, bacteria and the fish die off, typically on Days Five or Six, they are introduced to the differences between correlation and causation and the Analyzing Causality Thinking Move. The "Lab Building" and related tools are unlocked so that they can begin to conduct experiments to confront some problems in reasoning only from patterns and will begin to see how it is important to explore the mechanisms behind the patterns. The Atom Tracker Tool appears on the Tool Bar but is not discussed until Day Seven | **Unlocked:**<br>Lab (includes:<br>Lab building<br>Tracers<br>Mescosm<br>And related Scientist NPCs)<br>(Atom Tracker) |
| **Day Seven:** *Essential question of the day: How can I continue to use experiments to test my claims, collect evidence and build causal connections?*<br>Students focus on asking questions about what might be going on in the ecosystem and on studying through experimentation and other forms of investigation about what might be happening. They continue working with the Evidence Seeking and Analyzing Causality moves to hypothesize about what might have happened in the world. The Atom Tracker is introduced | (Atom Tracker) |
| **Day Eight:** *Essential question of the day: How can I think about what parts of my explanation seem incomplete and what else I need to fill those gaps?*<br>Students step back and reflect upon what they do and do not know and to focus on getting the information that they need to really understand what is going on. As part of a class discussion, they consider the difference between seeing patterns and determining causality. They continue to refine their questions and to make sure that they have evidence to back up their claims | |
| **Day Nine:** *Essential question of the day: How can I use multiple pieces of evidence and multiple types of evidence to further develop my explanations about what's going on?*<br>Session Nine introduces the Body of Evidence Approach. Students learn from the PPT and the BOE Thinking Move how the BOE approach requires using multiple pieces of evidence and multiple types of evidence and how this can help them to evaluate the overall strength of each claim and to consider the level of certainty or uncertainty that is possible for each claim. Students evaluate two Bodies of Evidence and then evaluate their own explanations to see how they can further collect evidence to support their growing claims | *Remind students to talk to new NPC- Dr. Aziza Al Dahan |

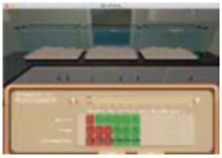
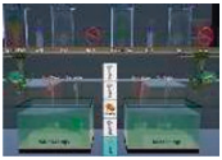
(continued)

| **Overview:** | |
|---|---|
| **Day Ten:** *Essential question of the day: How can I construct a scientific explanation about what's going on?*<br>This session picks up where Day Nine left off as students continue piecing through their explanations. They continue conducting experiments and using the evidence from their experiments to understand, as fully as possible, what is going on in the ecosystem. They are introduced to the "Constructing Explanations" Thinking Move. It is used along with the Concept Mapping Tool to support them in making sense of the "big picture" as they put all of their clues together | |
| **Day Eleven:** *Essential question of the day: How can I think about the values and limits of different types of evidence?*<br>Students transition from building their concept maps to finishing compiling their evidence and preparing to present their work to others. Students focus on building the fullest explanation that they can with their concept maps. As they are working, the teacher circulates and helps them to find gaps in their explanation. They use confirming and disconfirming evidence to support their explanation. With help from the visual cues/codes in the concept maps, they reflect on the kinds of evidence that they are using (patterns, textual information from the field guide, testimony from characters and outcomes from experimental studies) and figure out if there may be information that is missing from their explanation | |
| **Day Twelve:** *Essential question of the day: How can I communicate my findings about what's going on?*<br>For the first third of class, students continue preparing their concept maps to present to the class. They make sure that all of their evidence is listed and that there are no gaps in their explanations. They include confirming and disconfirming evidence in their concept maps. The teacher then stops them and asks them to carefully review their evidence and concept maps. Then the computers are put away and for the rest of class, students write up an individual essay explaining what they think happened to the fish | |
| **Day Thirteen:** *Essential question of the day: How can I communicate my findings about what's going on?*<br>Students share their findings for what happened at the pond. They are charged with listening carefully to each other's presentations and to help their classmates discover what is well-supported in their arguments and where evidence for claims may be missing. If conducted as a whole class discussion, it is facilitated so that all of the students are able to contribute aspects of the complex causal scenario underlying what happened in the ecosystem. The session underscores that a good explanation is a well-supported, well-reasoned one in which the mechanisms for the causal connections are explained | |

(continued)

| **Overview:** | |
|---|---|
| **Day Fourteen:** *Essential question of the day: How can I reflect on my experience in EcoXPT?*<br>This is a day of reflection on the big lessons from EcoXPT. It is not about the explanation that they came up with but about the messages that they learned about science, ecosystems science and coming up with an explanation. Students have an opportunity to reflect upon their own ideas and then the class has a discussion about it | |

## *Experimentation Tools in EcoXPT*

| Experimentation Tools in EcoXPT | |
|---|---|
|  | The Tolerance Tanks display three virtual fish tanks, each with a different type of fish and allow students to test any of seven factors to see if different levels of those factors would directly kill each type |
|  | The Comparison Tanks display two virtual fish tanks within a 3D lab environment. Each tank has an associated shelf of objects: a fan, a fish, a plant, or acid. Students choose to fill each tank with either pond or tap water and select up to one (or “none”) objects to place in each tank. Once the tanks are set up, students can “run” the experiment and use the water measurement tools to see the results |
|  | The Mesocosm Tool allows students to investigate how real-world contextualization interacts with the behavior of the variables that they combine in the pool. They consider how changing temperature, levels of nitrates, etc. interact over time. They configure up to four pools with up to two factors each. Once the pools are set up, student can “run” the experiment and use the water measurement tools to see the results |
|  | The Tracer Tool allows students to understand the movement of matter in the environment. They can test how the spatial lay-out and topography play a role in the process. They can choose to place tracers of different colors in different places. The tool allows then to understand how the spatial terrain interacts with the movement of materials |
|  | Buoy Sensor Data is collected over time in the pond. Students can access this data to understand changes in the pond over time that ultimately, they will realize, are relevant to understanding what happened to the fish. They access the buoy data by talking to a scientist at the edge of the pond (Dr. Hsieh) who has a tablet that enables them to access the information. |

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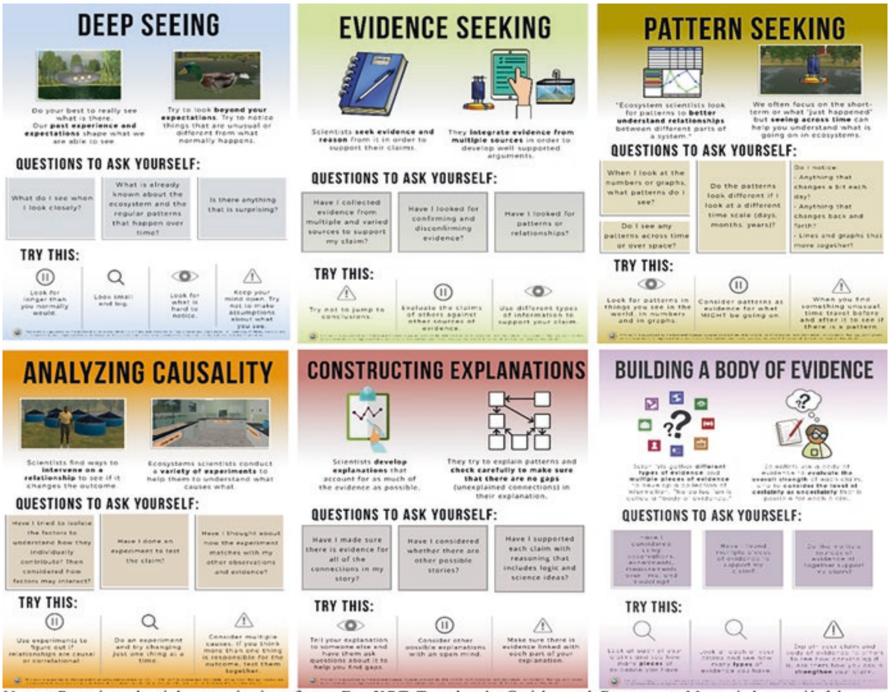
## *EcoXPT Thinking Move Posters Including a Body of Evidence Approach*

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## *Script for Body of Evidence Approach Thinking Move Video*

*Building a Body of Evidence Thinking Move:*

Wow, how cool is it that we get to use the experiments in the lab now?! Experiments can help test whether a pattern is actually a causal relationship. This evidence is useful because it helps us construct causal claims about what's going on in the world.

But we can’t always conduct an experiment. Here are some examples:

*Imagine you wanted to study the impacts of fires on forest ecosystems. You wouldn’t burn the forest down just to see the impacts. That would harm the ecosystem and the organisms that inhabit it!* OR *imagine you wanted to increase the* $CO_2$ *in the forest to find out what the long-term impacts are. This experiment might hurt the organisms and could also take many years to conduct.*

When they can’t conduct an experiment, scientists use something called the Body of Evidence Approach. A Body of Evidence Approach is when scientists look for multiple pieces of evidence and many different types of evidence in order to support their claim. Gathering multiple pieces and types of evidence from different sources reduces the uncertainty of the results.

But remember, a Body of Evidence Approach can be used even when we **can** conduct an experiment! Experimental results are just one of the ***many*** types of evidence that we can use to support our claims.

Remember that there are many types of evidence that we can collect in EcoXPT. Consider talking to people and other scientists, as well as using your observations, data and information you’ve collected from opportunistic experiments. Doing this will also help fill in some of the gaps you may have in your explanation!

In EcoXPT, use a Body of Evidence Approach, just like ecosystems scientists do. Be sure to use multiple types of evidence to support your claims. You can make sure that you are doing this by checking the evidence for the links in your Concept Map. Check to see that you’re using multiple pieces of evidence and evidence from different sources, by clicking on the arrow between factors you’ve used to build connections.

When you’re using the Building a Body of Evidence Thinking Move, remember to:

Use multiple pieces of evidence to support each claim.
Use multiple types of evidence.
Evaluate the overall strength of the evidence for each claim.
Consider the level of certainty or uncertainty that is possible for each claim.

## *Body of Evidence Worksheet*

"I then decided to conduct an experiment. In one cage, I kept a tomato plant on its own. In the second cage, I kept a tomato plant and some beetles. After a week, I noticed that the tomato plant without beetles was compeletely normal and healthy, while the other tomato plant with the beetles in the cage had holes in its leaves from being eatern."

**What about Jasmine's claim and its supporting evidence feels convincing and strong to you? Where does it feel like it could be improved, or where do you have questions about it?**

______________________________________________

______________________________________________

______________________________________________

______________________________________________

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______________________________________________

______________________________________________

______________________________________________

**Which of the two statements above do you feel has a stronger Body of Evidence? Why?**

______________________________________________

______________________________________________

**Which of the two statements above do you feel more certain about the findings? Why?**

______________________________________________

______________________________________________

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## *Thinking About Different Types of Evidence Worksheet (Both Classes)*

Name_______________________________________ Date_________________

**Thinking about Different Tpes of Evidence**

Think about each type of evidence. Draw the symbol from the Notebook connected with each type of evidence from the world. Then answer the two questions about each type of evidence. How can it help you to understand what is going on in EcoXPT? How might it be wrong or misleading?

| Symbol in Notebook | Type of Evidence | How can it help me to understand what might be going on? | How might it be wrong or misleading? |
|---|---|---|---|
| Observation | Observations or Things that I see | | |
| Field Guide | Information that I read in the Field Guide and in the written information in the world | | |
| People and Things | Things that characters in the world and videos tell me (scientists and other people) | | |
| Data Graph | Patterns that I see in the graphs and numbers | | |
| All Experiments | Experiments that I conduct in the lab | | |
| | Experiments that I conduct in the world | | |

Name __*Sample Responses*__________________________________ Date__________________

**Thinking about Different Tpes of Evidence**

Think about each type of evidence. Draw the symbol from the Notebook connected with each type of evidence from the world. Then answer the two questions about each type of evidence. How can it help you to understand what is going on in EcoXPT? How might it be wrong or misleading?

| Symbol in Notebook | Type of Evidence | How can it help me to understand what might be going on? | How might it be wrong or misleading? |
|---|---|---|---|
| Observation | Observations or Things that I see | *It can help me to notice fine grain details; I might record something that seems irrelevant now but later as more information is known, it might be part of the causal story.* | *I might not know what something is or I might not get to look really well at it; I might mistakenly write down my interpretation of what I see instead of just what I observe and the interpretation could be wrong.* |
| Field Guide | Information that I read in the Field Guide and in the written information in the world | *Information from secondary sources can be really useful in gaining more information from experts and others who know more about a topic that I do; I can get details about things such as listings of ingredients on the fertilizer bag.* | *I have to think about where the information in a written source comes from. The information in the field guide probably comes from scientists and is probably well researched. I can probably trust the information. It might not tell everything about a species.* |
| People and Things | Things that characters in the world and videos tell me (scientists and other people) | *The characters in the world have noticed different things and give information. THere are a lot of scientists who tell about how they do their work and talk about how to think like a scientist.* | *I don't know if all of the characters give the right information or how much they know. Some of the characters I don't know much about, for instance, the dog walker or Tommy.* |
| Data Graph | Patterns that I see in the graphs and numbers | *The patterns can help me see how the variables change in relation to each other. I can see lots of different variables at the same time.* | *Even if two things move together, I still don't know if one thing causes another to change. There could be a causal relationship or it could just be a correlation caused by something else or it could be a coincidence.* |
| All Experiments | Experiments that I conduct in the lab | *I can focus on just the factors that I want and really see how certain things impact each other.* | *It is possible that in the real world other factors may influence the factors that I focused on and make them work differently. The lab is different from the real world because it leaves a lot of stuff out.* |
| | Experiments that I conduct in the world | *It is possible to see how things might work in the real world and how parts of the real world impact the outcome of the experiments. For example, tracers move according to how the texture of the land goes.* | *With a lot going on at once in the real world, it is hard to figure out the exact relationships between things.* |

## *Supporting Materials for Body of Evidence Thinking Move*

| Thinking Moves Scientists Use | Try this: | Ask: |
|---|---|---|
| **Building a Body of Evidence**<br>*Instead of focusing mainly on discrete pieces of evidence, scientists consider what the collection of evidence suggests in order to support a causal claim.*<br>They gather multiple pieces and forms of evidence.<br>They evaluate the strength and weaknesses of the collection of evidence.<br>They consider their level of certainty and uncertainty about the claim based upon what the collection of evidence can support. | It is not always possible to conduct an experiment to test for causality. However, if the collection of evidence is varied (especially if it includes natural contrasts or opportunistic experiments), extensive and highly suggestive of causality, a causal claim may be warranted.<br>Make sure that you consider the body of evidence through the same questions as you would for "Evidence-Seeking" above.<br>Include information about the strengths and weaknesses of your body of evidence in your explanation.<br>Include information about your level of certainty and uncertainty, as scientists do, when offering a causal explanation. | Have I included multiple and diverse pieces of evidence (including data from observations, patterns), experiments (including natural contrasts and opportunistic experiments) and trustworthy sources?<br>Have I evaluated the body of evidence carefully (as per the "Evidence-Seeking" guidelines above)?<br>Have I included information about the strengths and weaknesses of my body of evidence in my explanation?<br>Have I included information about my level of certainty and uncertainty for specific claims, as well as what claims the body of evidence supports, in my explanation? |

| Accompanying Teacher Pedagogical Moves to Support Student Thinking Moves: |
|---|
| **Building a Body of Evidence Approach:** |
| Help students to realize ways that there are different kinds of information and that some are more useful in determining causality than others.<br>Help students to evaluate the trustworthiness of claims by considering whether claims appear to predict outcomes. For instance, if a claim states that adding phosphates and nitrates should increase algae levels, is that what happens when they do?<br>Help students think about other cases that are hard to test but the overwhelming evidence points in a certain direction. For instance, it is difficult to link behaviors like smoking to cancer but over the years, a body of evidence supported the finding of a causal relationship.<br>Help students to think about instances that are hard to test, such as processes that take a long time to reveal outcomes or where there are many possible interacting causes. These are often cases when a Body of Evidence Approach is helpful. |

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## *Learning from Opportunistic Experiments*

### Discussion Sheet

Experimentation is easier to conduct in some disciplines than others. Ecosystems scientists do conduct small scale experiments in a lab, but when they want to understand changes in the broader environment, they need to rely on a variety of approaches. One of these approaches is using "Opportunistic Experiments" or "Natural Experiments." They involve studying changes that happened either through natural processes or unintentionally by humans or other animals.

"Opportunistic Experimentation" or "Natural Experiments" are often used in cases where an intentional experiment would cause harm or would be unethical, for instance to an ecosystem or a population of people. For example, if you wanted to know if chemicals are harmful to a pond, scientists wouldn't fill one pond with the chemical and compare it to another pond without it. But if a chemical spill releases the chemical into a pond, they could study it and compare it to other ponds. Similarly, if scientists what to know the impact of environment on children, they can study identical twins but they can't send one twin to live in a different environment. However, if they find twins who were somehow separated at birth, they can study their differences.

In EcoXPT on Lesson Day 9, there is a scientist by a small woodland pond and she is studying what happened to the pond such that it turns bright green. She discovers that a farm worker moved a manure pile such that the runoff began entering the pond and explains this to the students.

Consider the following questions:

1. Did any of you meet a scientist on Day 9 at a small woodland pond that had turned green? If so, what did you learn from her?
2. What do you think opportunistic experiments are? Why are they so important in ecosystems science?
3. Ecosystems scientists adopt a "do no harm" approach. Do you think this means that they never conduct an experiment in which an organism dies? Are there any instances in which this might be justified?
4. What other examples of opportunistic experiments or natural experiments can you think of? Make a list together as a class.

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## *Uncertainty and Constructing a Best Explanation*

### Discussion Sheet

Scientists aim to construct the very best explanation that they can with the available evidence. Often it is not possible to definitively know the "right answer." Therefore, it is important that scientists talk about uncertainty and the sources of scientific uncertainty in their work.

The focus is a little different than talking about your personal certainty or uncertainty. There are always things that we as people don't know. Scientific uncertainty is more about what we do or do not have the data to support and even if it is possible to know something.

Scientific uncertainty is especially important when we are constructing explanations about the past. Think about fossil evidence, for example. We can use what is left behind to create the best story about what happened but since we can't travel backwards to the time of the dinosaurs we will never know for sure. Even for more recent events that we did witness, there are often different perspectives and different sources of data on what happened. Recall the last time you had a disagreement with a friend. You probably both give a different explanation.

Even when you are present to observe something happening, there can be uncertainty about what happened in between the times you are there. For instance, in EcoXPT, you only visit the pond during the day and so it is hard to know what happens when you are not there. So when you take measurements, you have the day to day data but you don't have the data points in between. When you collect data, you are guessing that there is a straight line between the data points, but you cannot be certain.

Sometimes new information causes scientists to revise their explanations. Revising explanations is part of how science works. An explanation can be the best one for a certain period of time and then new evidence might suggest an even better explanation. Even so, the old explanation may have been very helpful in the meanwhile.

It is common to hear scientists:

1. …express uncertainty. *(The data suggests that it might be due to this cause but we still have further questions about other possible causes.)*
2. …talk about how much certainty they have in a set of findings. *(We have a lot of certainty in these findings because we have seen this outcome so often.)*
3. …express certainty at some levels of analysis of a problem and not at others. *(We know how this chemical behaves in a lab but we don't know what happens over time in the broader ecosystem.)*
4. …talk about certainty in some contexts but say that it is not generalizable to other contexts. *(We know that these findings are reproducible in these contexts but in other contexts with changes in variables such as temperature, moisture levels, etc. they may not be reproducible.)*

Consider the following questions:

1. In what ways is scientific uncertainty similar to and different from personal uncertainty? *(Think of examples when you didn't know something because you didn't have the information yet but it was knowable. Think of examples of when you didn't know something because it was unknowable.)*
2. What are some instances when scientists might talk about uncertainty?
3. What does it mean to give the best possible explanation?
4. What are some places in EcoXPT where there are sources of uncertainty?

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