Causal Patterns in Science
a professional development resource

Questions to Ask About Complex Causality: With Applicable Notes to Ecosystems Concepts Where Relevant

Questions:	Notes:
Obviousness/Concreteness of the Variables:	
1. Are there important variables that are non-obvious or hard to detect? (ex: air pressure, gases)	Microbes are responsible for the majority of decomposition but are invisible to the naked eye. This makes it easy to be unaware of them.
2. Are there important variables that students are likely to take for granted? (ex: the liquid in sinking and floating)	
3. Are there variables that are inferred or constructed as part of the currently accepted explanation, but not necessarily accessible? (ex: electrons and protons)	The process of photosynthesis is not directly observable and students typically learn it as a formula. It is a critical part of the causal equation, but not accessible to students.
4. Are there important variables that play a passive role? (ex: protons)	Energy transfer is a passive process. However, students focus more on the active process of "what eats what." This makes it less likely that they will attend to the transfer of energy at a systematic level.
5. Are there causes that are spatially far away from their effects or vice versa? (ex: the forces that cause satellites to orbit, how Hurricane Katrina affected gas prices nationally)	The sun is critical to life on earth and to the energy transfer in the food web. However, students often leave it out of the food webs that they draw due to its spatial distance.
6. Are there time delays or gaps between causes and effects? (ex: eating of infected beef and onset of Mad Cow Disease)	Ecosystems often involve time delays between causes and effects. There is often a period of time before the impact of particular causes can be assessed. It can be difficult to determine what the most appropriate scale of time is to consider causes and effects. Often what is not a pattern in the short term may appear as a pattern in the long term (global warming, for instance.)
7. Are there preconditions that are not necessarily part of the	

causal story, but are related to it in some way? (ex: Lightning typically occurs during temperature changes or when there are temperature differentials)	
Location of the Causes or Agents:	
8. Are there contributing causes in many different places (as compared to a cause in a central place)? (ex: the actions of the many individual voters or bloggers as compared to a president's decision)	A key area of study in biology has to do with population dynamics. Many of the outcomes in ecosystems have to do with the individual rules of interaction between organisms and the emergent effects at the population level. Even phenomena that seemingly were all top-down (such as the organizational structure of beehive) now appear to have bottom-up, distributed features.
9. If yes to Question 8, are those actions/intents uncoordinated as compared to coordinated? (ex: a lot of people driving cars contributing to global warming or individual actions that result in wide scale civil unrest vs. voting for a president)	The actions in ecosystems are typically uncoordinated— with individual organisms acting to ensure their own survival as best they can.
Interaction between Causes and Effects:	
10. Is the effect different in size/magnitude than the cause? (ex: repeated cause and no obvious effect until there is a very large effect (as in the point where the environment can no longer accommodate pollution, as in tipping point phenomena), smallish causes that precipitate complex interactions until there is a big outcome (such as the accident at the Chernobyl Nuclear Power Plant)	Effects within ecosystems can be difficult to detect because they may not become noticeable until they reach a certain "tipping point." Examples include toxins, acid rain, invasive species, and populations out of balance, etc.
11. Do the causes or effects add up or interact with each other? (ex: accumulation or where one set of effects amplifies another set of effects, etc., accumulation of pollution, greenhouse gases.)	There are often complex interacting effects in an ecosystem. Slight changes in temperature impact what organisms live there. Organisms can impact the temperature and rate of evaporation of their habitats by the shade that they provide, and so on.
12. Are there multiple possible causes where any of the causes is enough to get the effect? (ex: application of heat or pressure are each sufficient to make something boil.)	In a food web, organisms opportunistically eat what is available to them. Flexibility in their diet provides stability in the population despite fluctuations in the available diet sources.

13. Are there multiple causes where causes work together to make something happen (and you need all of them)? (ex: certain chemicals for a chemical reaction to occur.)	
Causal Pattern:	
14. Are there indirect effects? (ex: the loss of green plants on carnivores)	The food web involves many direct and indirect connections. The loss of producers indirectly impacts the entire web.
15. Are there non-linear cause and effect relationships? (ex: as in home heating systems, etc.)	Matter recycling is non-linear. Matter is conserved and is constantly being recycled to make matter available for new life.
16. Are there bi-directional effects or causes? (ex: as in symbiotic relationships)	Symbiosis is one example of mutual or bi-directional causality. Bees pollinating flowers and gaining pollen from the flowers is another example.
17. Are there causes that impact the effect of another cause (act as a mediator—a catalyst or a barrier)? (ex: Insulation mediates the process of thermal equilibrium)	Ecosystem concepts involve many instances of mediating causes. For instance, if an animal excretes on a branch, it may facilitate the growth of plants that can take advantage of the extra nutrients (bromeliads). Ultimately, the bromeliads would grow faster and push out other plants living there such as orchids and ferns.
18. Are there multiple causes or multiple effects? (ex: an oil spill affects birds, sea life, cleanliness of beaches, and the fishing industry)	This is the rule more than the exception in ecosystems. There are seldom isolated impacts and one of the most difficult challenges that ecosystems scientists face is deciding where to draw the parameters of the system under study.
19. Can you make predictions about the causal system by reasoning about its constraints? (ex: reasoning from Ohm's Law)	It is common to reason from the "Law of Limiting Factors" when reasoning about ecosystems. Information about available resources makes it possible to calculate the carrying capacity of a certain habitat.
Contiguity:	
20. How much consistency is there between the cause and the effect? Does it always happen, some of the time, etc.? (ex: Deterministic causality where every cause is followed by an effect vs. probabilistic causality where the outcomes happen some of the time in response to the cause, but not consistently)	There are many examples of probabilistic causality in ecosystems concepts. One example stems from genetic variation. Because there is naturally occurring genetic variation amongst organisms, a toxin can impact certain members of a species and not others (leaving those that are un-impacted available to breed thus increasing the likelihood that the toxin will not have as much impact in the future.)
21. Is there "noise" that makes it hard to see the relationship between causes and effects? (ex: seasonal effects in detecting	Due to the large number of interacting variables in environmental systems, "noise" is the norm and the detection of patterns is

global warming)	complicated by such noise. Often multiple data sources are needed to detect patterns and one must look over the long term. For example, if you look at weather patterns in the short term, patterns of global warming may be undetectable due to noise.
Levels:	
22. Is there order at one level and not at another? (ex: the gas laws where disorder at one level is orderly at another)	
23. Do you need to understand the concepts at more than one level to understand what is going on? (ex: Understanding a circuit at the level of the individual electrons and protons vs. at the level of the system) If so, what is the relationship between the levels? Are there different sets of variables or causal patterns at different levels?	It is not enough to think about food web relationships as between individual animals as many students do. This leaves them feeling sorry for the animals that become prey. When one shifts to a population perspective, they come to realize that without predation of individuals within the population, the lack of balance would eventually cause the population to crash.