A Taxonomy of Causal Models: The Conceptual Leaps Between Models and Students' Reflections on Them

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This paper is based on the results of research carried out during the first year of the Understandings of Consequence Project. We are continuing to research and develop the ideas presented here. If you have feedback for us or would like to keep in touch with developments on the project, please check our website at http://pzweb.harvard.edu/Research/UnderCon.htm or send us an email at Tina_Grotzer @PZ.Harvard.Edu.

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Introduction

Students reveal a variety of alternative conceptions that are substantially different from the scientifically accepted explanations for a multitude of science concepts. A rich literature extending over the last two decades documents students' alternative conceptions or misconceptions (for reviews, see Driver, Guesne, & Tiberghien, 1985; Driver, Squires, Rushworth, & Wood-Robinson, 1994). Considerable effort has been expended researching these conceptions–trying to determine sources of confusion and whether there are common patterns of reasoning that give rise to them.

While the scientifically accepted explanations may seem fairly straightforward at first glance, as soon as one scratches the surface and attempts to teach for deeper understanding, the concepts quickly become complex in a number of ways. For instance, they make reference to inferred entities that one cannot see such as protons and electrons. They involve causal patterns that extend beyond linear, unidirectional relationships, such as feedback loops and reciprocal causation. They involve causalities that are in various respects probabilistic–in that the level of correspondence between causes and effects varies. These are ways of thinking and abstractions that students typically are not familiar with.

This paper serves as an introduction to a collection of papers which discuss the role that complex forms of causality play in the difficulty students have with many science concepts. The collection of papers report on data collected during the first year of the Understandings of Consequence Project, funded by the National Science Foundation. The project attempts to address students' difficulty in learning advanced science concepts by addressing a paucity of causal models in students' understanding. This assumes that students' causal models are in some sense less than adequate for learning complex science concepts. The first part of the research project was designed to examine this assumption–to assess whether students hold assumptions about the nature of causality that can lead to alternative conceptions. The second part of the research project is to explore interventions that lead to scientifically accepted conceptions by increasing the sophistication of students' causal modeling. Researchers on the project have studied students' understanding of the following concepts: electricity, density, ecosystems, evolution, pressure and force and motion concepts. This introductory paper provides a conceptual framework and offers a way to organize the complexity of the forms of causality that students must grapple with in order to master a range of science concepts. The series of papers that follow look at some of the topics in depth--offering an opportunity to draw contrasts and parallels across topics.

The Inadequacy of Students' Notions of Causality

What about the assumption that students' causal models are in some sense less than adequate for learning complex science concepts? What evidence exists to support it? Examples can be found in just about any science classroom. As students are learning about simple circuits, they typically find it hard to focus at the level of the system and try to analyze effects locally (Shipstone, 1985). They commonly employ what might be called a "cyclic sequential" causal pattern for how the current flows. They envision the circuit as initially empty and that it fills with a "substance-like material" (Slotta & Chi, 1997) which eventually reaches the bulb and causes it to light. For instance, a typical student explanation sounds like this: "The electrons travel into the wire and they go to the bulb and then it lights. The electrons keep going until they are back in the battery and can travel around again. If the wire were longer, it would take longer for the bulb to light because it takes longer for the electrons to reach the bulb." Scientists, on the other hand, might envision the system as described by a "cyclic simultaneous" causality where electrons are already throughout the wire and hooking the wire up to a battery causes flow--the excess negative charge to repel electrons which repel other electrons. The current flows all at once, more like the movement of a bicycle chain. At a broader level of explanation, scientists might describe the system in terms of differentials between and electrical potential or by a system of constraints.

The students and the scientists' models have an essentially different type of causality at the core. Students characterize wind as an active causal agent, something that is human-like in its intent and its ability to self-propel rather than seeing it as an effect of a differential between high and low pressure that results in air rushing towards lower pressure. For instance, students explain the wind in terms such as these, "the wind is air blowing that wants to go to a certain place so it pushes to get there." The student explanation encompasses a simple linear model where-as the scientific explanation involves analyzing cause as embedded in an interaction or a relationship. Students typically characterize static electricity as a substance-like power that goes from one object to another–as an entity that causes effects in a simple linear pattern--rather than an imbalance of charge between two surfaces–more abstract than an entity and invoking an interactive or relational model of causality. For instance, students typically say things like, "The wool gives the balloon power that goes to the wall to make it stick."

The types of causality underlying students' models tend to be simple in form and to lead to simplified interpretations of the information in the more complex models. While simplified models may work for many aspects of explanation in our lives, they can also distort the scientific information to the point where parts of the causal story are lost or misconstrued. For instance, in the case of static electricity, students may miss the role that an induced positive charge plays and therefore may be less likely to notice related phenomenon that suggests a lightning strike is imminent. Or students may not understand why a lightning rod works.

Support for the assumption that students' causal models are in some sense less than adequate for learning complex science concepts can be found in the research literature. Driver, Guesne, and Tiberghien (1985) outlined characteristics of student thinking that impede students' ability to grasp scientific concepts. A number of these relate to how students reason about causality, for instance, focusing on changes as opposed to steady states and subsequently failing to see a need to explain systems in equilibrium or the tendency to engage in linear causal reasoning by looking only for sequential chains of causes and effects when systemic patterns are in play. di Sessa (1993) considered whether a core notion of causality underlay alternative conceptions, even if he did not consider it to be theory-like. He introduced the concept of phenomenological primitives (or p-prims), small knowledge structures that people use to describe a system's behavior. These schemata come into play as ready explanations or components of explanations. They are often considered to be self-explanatory and to need no justification. Similarly, Brown (1995) refers to core causal intuitions that can lead students astray as they bring them to bear in attempting to understand a variety of difficult science concepts. He focuses on core intuitions regarding how people attribute agency and how they assess responses to agency. He identifies a number of types (initiating; initiated; reactive and so on.) Andersson (1986) draws upon Lakoff and Johnson's (1980) notion of an experiential gestalt of causation as a possible underlying element in scientific misconceptions. He considers how students extend the primitive notion, learned in infancy of an agent that physically affects an object leads to a sense of "the nearer, the greater the effect." Andersson outlines how such primitive notions play a role in difficulties students have in learning various science concepts. This research suggests that how we reason about causality influences how we analyze specific instances of causation in science class and beyond.

Our own investigations across a number of topics support the idea that students bring impoverished causal models to their attempts to learn scientific concepts. We interviewed students on a number of science concepts on their causal explanations and models for why various phenomena occurred. We then analyzed the structure of those responses in terms of their complexity–whether they involved one or more entities, how abstract those entities were, whether cause was ever located in a relational pattern as opposed to an entity, and so on. Students' explanations tended to take very simple and efficient forms. For instance, in probing students' ideas about static electricity, it was typical to hear the following sorts of explanations:

> "I think it happened because the electricity went to the paper to make it stay."
> "I think it happened because of static electricity."
> "I think it happened because the electricity from the wool gave it to the balloon."
> "I think it happened because when you rub the cloth to the balloon something happens to the balloon to make it stick."

These explanations take a simple linear form and envision static electricity as substance- or entity-like. It was much less common (though it did happen occasionally) to hear students make comments that referred to a mutual causality or a relationship, such as:

> "There is an attraction between the wall and the balloon. Something about the wall and something about the balloon have been changed and it makes them attract."

The mutually causative forms that students offered were not necessarily scientifically accurate. For example, one student described air pressure as "pushing" the balloon to the wall while the wall "sucks" the balloon towards it using static cling. However, we were interested only in the causal form of the explanation.

One might argue that simple linear models are an artifact of how we speak and in some cases, they probably are. However, upon probing, most students were unable to offer more than very basic explanations that involve one entity and one outcome in a linear form. This does not always lead to incorrect as much as shallow explanations. For instance, saying that "friction made it stop" is a scientifically accurate statement at a very basic level of explanation. In any case, simple linear entity explanations do not invite students into deeper understanding of the concept at hand.

Simple linear models such as these were found across the topics that we studied. It was common for students to consider the cause of sinking and floating as having to do with the weight of an object rather than considering the role of relational densities. When learning about pressure, students typically argued that the cause of fluid going up a straw was the act of sucking, rather than due to differentials in air pressure. Students had difficulty realizing the cyclic nature of decay. The relational aspects of Newton's laws were difficult to apply to real life instances. The papers that follow will offer concrete, in-depth examples of the difficulties students had.

From a developmental perspective, one might argue that it is no surprise that students had difficulty generating the more complex causal models on their own. For instance, according to Case (1985), the ability to coordinate dimensions of a problem emerges in middle childhood and during this time, students develop dimensional control structures (for instance, coordinating weight and number in terms of one variable as a function of the other). It is not until adolescence that children learn abstract control structures, second-order dimensional, or vectorial operations including the abilities of operational consolidation (ex. comparing the magnitude of one quantitative dimension with that of another); operational coordination (ex. coordinating weight and distance on the balance beam to predict whether two sides will balance.); bifocal coordination (can take into account ratio or "dividing things up" so that you are performing a division operation on a division operation); elaborated coordination (the operation that was performed at the last substage can now be performed on both dimensions). So one might expect that it is not until the adolescent years that students are ready to begin learning about more complex causal forms.

However, a difficulty with relying on the developmental literature to ascertain what children can do at various ages is that it suffers from the “null curriculum problem.” The majority of developmental studies do not attempt to teach children anything. Rather, they test what children can do in consequence of the kinds of instruction and other experiences normal in our society. This makes it problematic to borrow without critical examination from the developmental literature. Whether the patterns we’ve observed are due to developmental constraints or the lack of an effective pedagogy is an open question. In addition, it is worth noting that many students well past the adolescence display at least some of the misunderstandings documented in the literature. Accordingly, general developmental factors may be a necessary condition, but cannot be considered a sufficient condition, for the kinds of causal understanding explored here.

A Taxonomy of Causal Models

Helping students develop a greater repertoire of complex causal models necessitates a vision of what such a repertoire might look like. We introduce here a taxonomy that attempts to organize increasing complexity of causal explanation. Its purpose is to organize the increasing complexity and to help guide pedagogical efforts in thinking about sources of complexity that students must deal with as they are learning the forms of causality implicit in many science topics. See Table 1. The taxonomy has at its core four dimensions along which causal complexity is characterized:

[Insert Table 1 about here.]

1. *Underlying Causality*- This dimension refers to the causal mechanism one invokes in an explanation. In its most superficial form, it can be given as a simple (and not necessarily correct) generalization from experience like “animals learn their necks need to be longer” or a same level account such as in the token use of labels like “the balloon sticks to the wall because of static electricity.” In its most in-depth form, it can entail numerous levels of underlying mechanism involving properties, entities, and rules introduced that are not part of the surface situation but are called upon to account for it. Examples include electrons or DNA and the rule systems that govern them

2. *Relational Causality*- This dimension refers to the patterns of interaction between causes and effects. These patterns can, for instance, involve simple linear patterns that are unidirectional and hold one-to-one correspondences (such as when students view lightning as electricity that comes from the sky and affects the ground) or interactive causalities where mutual attraction, states of balance or imbalance, and so on, set in motion a two-way, mutual causality (such as the balancing out of electrons and protons that takes place in lightning and static electricity or the weather effects of imbalances in pressures). It also includes patterns of constraint-based causality, where the focus is on the system as a whole and the resulting patterns due to rules that are obeyed (as in explanations of the simple circuit based on Ohm’s law.)

3. *Probabilistic Causality*- This dimension refers to the level of certainty in the causal relationship–the correspondence between causes and effects–whether there is absolute consistency or not. It ranges from deterministic systems in which one expects 100% covariation to systems that are fundamentally uncertain, such as those in quantum theory.

4. *Emergent Causality*- This dimension refers to agency and to the compounding of causes and effects in ways that lead to new and in some instances, not easily anticipated, outcomes. It ranges from centralized agents with immediate influence (such as how many students and at one time, scientists, believed birds flocked together guided by a lead bird and ant social behavior is governed by the queen) to emergent entities and processes that are organized out of earlier causal processes, perhaps at a lower level (such as how scientists are coming to believe bird flocking and ant social behavior are generated by simple rule

systems followed by each member of the population.)

The taxonomy categories lean toward greater complexity as one moves down each column, but this does not mean that complexity is "good" in itself. Surface explanations serve many everyday situations perfectly well and scientific explanation does not always require invented entities like electrons or DNA. For instance, Darwin's original theory of evolution had no specific mechanism of heredity like DNA. The level of complexity that one needs to use in a given explanation are just those sufficient to the explanatory task at hand.

Conceptual Leaps in the Taxonomy

How might one use the dimensions of complexity to analyze the conceptual difficulties that students have in understanding a given science concept? Here is an example from our work. Many students' initial explanations of static electricity take the form of explaining the phenomena that they observe as "caused by static electricity." This explanation takes the form of a "token agent" on the dimension of underlying causality in that static electricity is used as a kind of placeholder for a deeper explanation. It does not deepen our understanding of what is going on, but merely gives it a name. On the dimension of relational causality, it takes the form of simple linear causality, one entity or cause creating an effect. The student explanation does not address the dimensions of probabilistic causality or emergent causality.

The teacher's goals for the students might be to move them along the underlying causality dimension to view the process as analogy (opposites want to be together as in magnets) or underlying mechanism in which new entities, rules, and properties are introduced (electrons, protons, opposites attract while likes repel, and so forth). On the dimension of relational causality, the teacher might encourage students to view the process as interactive causality (a mutual attraction, the balancing out of imbalance). On the dimension of probabilistic causality, static electricity phenomena are not reliably observed. The teacher may want students to understand static phenomena as noisy systems dependent on a variety of intervening variables (weather conditions and so forth.) On the dimension of emergent causality, the teacher may encourage students to view the build up of charge imbalance as a "trigger effect" to help students understand why they sometimes feel shocks but at not other times and why lightning suddenly occurs.

For each of the dimensions along which the teacher is attempting to move students towards more sophisticated explanations, there are conceptual leaps between levels that can make it difficult for students to move from one to the next. For instance, linear causality is easier to grasp that interactive causality where the causal agent is often a relationship of balance or imbalance. In some causal patterns, there may be a more active agent (as in electrons that do the moving) and a more passive agent (as in the case of protons that don't move but are part of the mutual attraction.) This can obscure the interactive causal pattern. For instance, most students view lightning as a uni-directional, simple linear causal event. It comes down from the sky. This impression is so strong that it can make it difficult to recognize events on earth that indicate that a positive charge is being induced and is accumulating. Similarly, if students seek out a deterministic system and the system is essentially a noisy one, students may challenge the explanation of what is going on. If they don't reliably witness static electricity phenomena, then they may question the explanation rather that look for sources of noise in the system.

In the course of our research, students commented on aspects of causality that they found difficult to grasp. We offer a few examples here, drawing support from the research literature.

Fourth grade students questioned whether a causal relationship could exist without perfect correspondence between causes and effects. Assuming the need for perfect correspondence makes it difficult to deal with the taxonomy category of probabilistic causality. When systems were noisy or chancy, fourth grade students used this information to deny the existence of a causal relationship. Issues of uncertainty or imperfect correspondence between causes and effects signaled to them that there was something wrong with the causal model. One class of students debated extensively whether the causal model (mutually causative and balancing) and the accompanying idea that electrons take the shortest path could indeed account for lightning and where it typically strikes if it doesn't always strike in the highest places. The conversation was precipitated by a student's observation that when she was at camp, lightning struck in a low spot so the scientific explanation couldn't possibly be true. According to Gelman, Bullock, & Baillargeon (1982), the expectation of determinism is an innate causal expectation revealed by the youngest of infants. Research (Schultz & Mendelson, 1975; Siegler, 1976; Siegler & Liebert, 1975) shows that imperfect covariation is difficult to grasp. Children prefer consistent covariation but the youngest (5 year olds) are untroubled by the lack of perfect correlation, presumably because they aren't accurate enough themselves in tracking it to be troubled by the lapses in correspondence. Older children (8 and 9) are troubled by lack of perfect covariation and use it to reason about whether a causal relationship exists. Kalish (1998) found that younger students do not understand the uncertain aspects of germ transmission and how people get sick. Because they are often told that certain actions will make them get sick and then they engage in the behaviors and do not consistently get sick, they assume that the behaviors and the outcome are not linked causally. This fits with the tendency to engage in risky behaviors again if one has gotten away with it in the past. These difficulties bear on students' ability to detect probabilistic causality.

Students also revealed a tendency to look for local effects rather than tracing out extended ones. This was clearly revealed in the ecosystems research where we were looking for whether or not students would construct extended domino-like patterns of causality. They tended to be short-sighted in how they searched for effects. This makes it difficult to understand compounde~~d~~ causal webs or to understand multiple~~,~~ linear causality. The following exchange was typical:

> Interviewer: "Do the green plants matter to any of the other animals here?"
> Student: "yes, to the insects, voles, toads, and foxes because they eat them."
> Interviewer: "What if the green plants completely disappeared? Are there any animals here that it would not matter to at all or would it matter to all of them?"
> Student: "It wouldn't matter to the spiders, toads, or snakes because they don't eat them."

This tendency may emerge at an early age. According to Leslie, Spelke and others (Leslie, 1982; 1984; Spelke, Phillips, & Woodward, 1995) infants are startled by action at a distance for physical effects. They expect spatial contact between causes and effects. Rubenstein, Van de Walle, and Spelke (as cited in Spelke et al, 1995) conducted a clever study with 5 and 8 month olds where they manipulated shadows by moving an object. Infants were startled by the natural event--that the shadow moved with the object presumably because it was not touching the object than they were by unnatural events where the object moved but not the shadow. They refer to this as the principle of contact or "no action at a distance."

With explicit teaching as outlined below, students were able to learn the simultaneous cyclic causality that characterizes the nature of the simple circuit. However, they found it difficult to talk about without resorting to a sequential explanation. Students said that they could picture it but that they found it hard to explain. A number of students said that the bicycle chain analogy made sense to them. As Ben said "It's kind of hard to think about. The way we have to learn it is like what's making what happen so you think of it in a line, so then it's really hard to think that it's happening all at once."

Intervention Efforts to Teach About The Nature of Causality

One approach to teaching the concepts that students typically have difficulty with is to teach what is going on in the specific instances of causation. Another approach might be to teach the rules of causality. A third approach would be to teach the rules of causality in the context of particular instances of causation. We followed this third approach and have sketched the nature of the interventions broadly below.
What is the difference between instances of causation and the rules of causality? Others have distinguished the two (e.g. Murayama, 1994; Pazzanni, 1991). Causation refers to explanations of cause and effect in specific instances–the particular mechanism in play and so forth, while causality refers to the rules of cause and effect relationships. The examples above do not differentiate between what students beliefs about the nature of causality are and what their beliefs are in the given instances under consideration. It could be argued that it is difficult to ascertain whether or not students' causal assumptions–their understanding of the rules of causality--affect their ability to grasp difficult science concepts. In order to address this question at the broadest level, we conducted intervention studies in which some students were introduced to and explicitly discussed the nature of causality–the specific causal rules in play--in the context of the scientifically accepted explanations. We compared their performances to those of students who did not engage in discussion of causal rules.

The causal rules were in some cases introduced through examples from social causality. Research (e.g. Spelke et al., 1995) suggests that children learn more complex models of causal interaction at earlier ages in social settings than they do in physical science settings. In other cases, the causal rules were introduced without social comparison.

We hypothesized that if indeed understandings about the nature of causality as opposed to specific instances of causation affect students' ability to grasp the science concepts, then we should see superior performance on behalf of the students exposed to discussions about the nature of causality. The papers that follow in this series offer support for that hypothesis. We see positive results looking across the topics. For instance, in our study of students' learning about electrical circuits, students who participated in discussions about the nature of causality within the context of specific instances of causation (Causal Models Group) showed significantly greater conceptual change than students who discussed specific instances of causation through activities designed (Activities Only Group) to help them do so and than students in a control group ($p < .05$). The students in the Causal Models Group also showed significantly superior understanding of the scientific concepts, gaining an average of 5.6 points, one standard deviation above the control group at 2.9 points and close to one standard deviation above the activities only group at 3.3 points, ($p < .05$). There were no significant differences between the control group and the activities only group. (These results are reported in detail in Grotzer & Sudbury, 2000.)

Similar results were found in our study of students' understanding of the connectedness within ecosystems. Intervention condition significantly affected students' gain scores in the total number of connections that they detected within the ecosystem (F (2, 26) = 3.63, $p = .04$) and the causal models group significantly outperformed the control group ($t = 2.41$, $p = .02$). Differences between the activities only and causal group were not significant though the causal models group fared better in trend. The mean gain score for each group was as follows: Causal Models = 21.2; Activities Only = 12.9; and Control = 6.1. Students in the causal models group detected more two-way connections on the post-test than students in other groups. Cyclic connections were only found on the post-test and then, only in the causal group. (These results are reported in detail in Bell, Grotzer, Donis, & Shaw, 2000.)

Discussion and Conclusions

These results suggest the importance of engaging students in consideration of the nature of causality in the scientific models and how it behaves differently from the causal assumptions that they bring to the subject matter. Based on the earlier research (e.g. di Sessa, 1993; Driver et al., 1985), it is not entirely surprising that addressing students' underlying assumptions about the nature of causality would positively impact students' performance. However, it is interesting to note how much better students who discussed the nature of causality in reference to particular instances of causation fared in comparison to students who studied the instances of causation through activities and situated discussions. When one considers the issues raised by students--things that didn't make sense to them, concepts that they found it possible to picture but hard to talk about, conceptual leaps between causal models that made it difficult for them to accept the scientific explanation being given--it makes sense that explicit conversation of such oddities might be helpful to them.

This first set of studies attempted to assess the feasibility of focusing on the nature of causality at the broadest level of grain. There are many lingering questions to be answered. Some of these have to do with the transferability and resistance of the changes we observed. For instance, do students who learn to think about density in terms of a relational causal model later reason about related concepts such as pressure using a relational causal model? How resistant are the changes we are seeing? Can they overcome students' tendencies to lapse back towards the appeal of a simple linear model? Others have to do with a finer look at the variety of conceptual leaps that we are asking students to make. The differences between the types of reasoning at various levels of the taxonomy suggest possible issues to consider.

This work assumes that students' causal reasoning is theory-like, even if it is limited. We expect that this will ultimately help teachers reason about the difficulties students may be having and to devise assessments to consider what types of underlying causal models students are attempting to build new scientific understandings upon. The alternative conceptions literature has offered teachers a wealth of advice–perhaps at the risk of overwhelming them. We hope that ultimately the contribution of this work will be to unite some of the disparate but important findings, to help teachers conceptualize and address students' difficulties, and to offer students a broader repertoire of causal models for understanding and analyzing their world.

Equipping students with a broader repertoire of causal understandings, in the context of learning various science concepts, should increase their sensitivity to possible causal patterns in play. This in turn should enable deeper understanding and a more systemic view of the concepts. Others have called for adequate, accessible causal models to help learners achieve complex scientific understandings (e.g. White & Frederiksen, 1990, 1995) and especially those that "build on intuitive notions of causality and mechanism" (White, 1993, p. 182). Helping students and teachers address their assumptions and learn to recognize new, more complex forms of causality may be a promising avenue towards inducing conceptual change and learning a host of science topics with genuine understanding.

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Table 1: Dimensions of Complexity in Models

Underlying Causality From a same-level account of a phenomenon to an inferred underlying mechanism	*Relational Causality* From A causes B to complex reciprocal relations and constraint systems	*Probabilistic Causality* From deterministic causality to chaotic and quantum systems	*Emergent Causality* From a central and direct agent to highly emergent causality
Surface generalization: Simply describes the regularity under consideration in a generalized way (often incorrect). Often variants of "More's law"—more of this means more of that. ***Token agent:*** Some agent, intentional or not, made things come out that way. Agent's behavior parallels phenomenon, no real differentiation. ***Composite explanation:*** Describes or explains in terms of objects and processes that are part of the system in question rather than underlying it. (Such theories can sometimes be illuminating. Natural selection is a composite explanation.) ***Analogical model:*** System explains target phenomenon by analogy and analogical mapping (e.g. electricity as fluid flow). ***Underlying mechanism:*** Properties, entities and rules introduced that are not part of the surface situation but account for it (e.g. Ohm's law; and underneath that electrons and their rules of conduct. *Note: There are often two or three levels of underlying mechanism, each underlying the previous*).	***Simple linear causality:*** A impinges on, pushes, influences B. A typically seen as not affected. (e.g. A pushes, pulls, initiates, resists, supports, stops B. A may be active as in pushing or passive as in resisting). ***Multiple linear causality:*** Multiple immediate causes, multiple immediate effects, necessary and sufficient causes etc. This often adds previously neglected agents of lower saliency to the causal story. ***Mediating cause:*** At least three agents in play, M mediates the effect of A on B (e.g. A affects M affects B, M is a barrier to A affecting B, M is a catalyst to A affecting B). ***Interactive causality:*** Mutual interaction of two or more agents (e.g. mutual attraction, net effects as in lift) ***Re-entrant causality:*** Simple causal loops as in escalation and homeostasis. ***Constraint-based causality:*** Behavior of system reflects a set of constraints that the system "obeys"—constancy, conservation, and covariation rules (e.g. conservation of energy, Ohm's law, law of gravitation)	***Deterministic systems:*** As in Ohm's law, law of gravitation. ***Noisy systems:*** Basically deterministic systems perturbed by random or unanalyzed factors (air friction, turbulence on thrown objects) ***Chancy systems:*** At certain junctures, things might go one way or another with a certain probability. ***Chaotic systems:*** Fundamental unpredictability in long term due to "butterfly effects" (e.g. the weather) ***Order from chaos:*** Averaging effects smooth out chaotic systems into highly orderly large-scale patterns (e.g. gas laws). ***Fundamentally uncertain systems:*** As in quantum theory, uncertainty build into the nature of objects and events, even for very small systems in the very short term.	***Central agents with immediate influence:*** One or a very small number of key factors fairly directly yield the result. ***Long causal chains, branching structures, cycles:*** E.g. as in ripple effects of an ecological disaster. ***Aggregate effects:*** Cumulative effects over time (e.g. erosion). ***Causal webs:*** Complex web of interactions as in ecologies. ***Trigger effects.*** A modest influence "topples" a complex system into a new state or pattern of activity. ("Tipping points.") ***Self-organizing systems.*** Seemingly messy systems evolve into clear patterns over time without an external agent or an internal blueprint. ***Emergent entities and processes:*** As with the emergence of new species, chemical compounds, etc.