« 4 » Second, there is the issue of how to define, assess, and design for this kind of thinking. Fortunately, "complex causal reasoning" about change in systems is gaining traction both in the sciences (NGSS Lead States 2013) and the social sciences (NCSS 2013). With this increased interest comes a responsibility to very clearly define what this thinking is, and how to evaluate whether students are getting better at it. The current trend, as far as I see, is for this kind of research to focus on mechanistic reasoning (e.g., Russ et al. 2008; Schwarz et al. 2009), in which a definition and assessment of learning is tied to students' identification and activation of these explanatory parts in their responses. However, and importantly, these approaches emphasize defining a start and end state of the system, implying that a move toward a linear explanation of a phenomenon is desirable and a sign that the student is getting better at reasoning about the phenomenon. I personally agree with this view: the ability to construct a linear macro-level explanation from the micro-level interactions has value and shows some ability in the student to project the possible consequences of letting the micro-level interactions "play out" over time. But at the same time, especially while reading this article, I am reminded of how this is also a simplistic view of the underlying micro-level interactions, and that it risks not capturing the students' thinking about the multitudes of ways in which the system can evolve, or for the kinds of unexpected, long-term changes in the system that we see in Füllsack's model. How can I, and the community of educators who push for helping students to learn this kind of thinking, do this? What are potential pathways to becoming "good" at it? Not just for the sake of grades and testing, but for being able to reason about important social phenomena that otherwise elude explanations and that will impact the future of our planet and humanity?

« 5 » I think Füllsack's article presents a convincing argument for a move toward using micro-level interactions to explain macro-level emergent phenomena that would otherwise have intractably circular explanations. I think it addresses some of the important philosophical and epistemological questions about emergent phenomena that we in education sometimes forget in our eagerness to design and assess. But given the issues of design and assessment above, I wonder: **Does the author have thoughts on addressing these issues in a way that would better enable us to help students learn this difficult but important kind of thinking? (Q1)**

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A Model of Causation Is Not Causation

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> Upshot • The target article is criticised because it conflates models of causation with causation itself. The arguments used in the target article to avoid a straightforward distinction between fine-grained measurements and the abstractions used to model them are discussed. The value of using the word "causation" to refer to atemporal models is questioned.

« 1 » One of the most fundamental results of "second-order cybernetics" is that a model is different from what it models (e.g., Foerster 1981). This is applicable regardless of whether one believes in an external reality or not, for perceptions and models exist at different levels. A set of measurements can be recorded and the same set reliably re-presented to consciousness, such as text like this. These measurements can be linked in relevance to the same target. In common parlance: the recordings are all of the same thing. One can compare any human abstraction to these recordings to check how good it is. One is not limited to one's original comprehensible perceptions of this finer grain, since one can revisit the recordings again and again. Further, one can develop formal models – other recordings manipulated according to known rules – and use these to represent the recordings of measurements. The formal models may be complex beyond our capability of understanding or perceiving, and they can be systematically developed to be compared to the fine-grained recordings of measurements.

« 2 » Causality has a number of different properties. The cause has to come before its effect, that is, the causality is embedded within time. The causal connection between cause and effect is amenable to an inspection of its detail. So for example, if one said "The bruise was caused by you hitting me," then one could (at least in principle) look at why a physical blow causes flesh to become coloured and tender – there is a finer grain of process that can be investigated to support the broad-brush causal statement. If event A makes event B happen without any intervening process (e.g., "Her incantations made my hair fall out"), we do not acknowledge event A as a cause but consider event B something that happened by "magic," or event A, simply "an apparent effect."

« 3 » In the target article, Manfred Füllsack aims to go beyond using circularity as a metaphor to a "firm epistemological base that fosters analysis" (abstract). However, he fails here because he confuses the models (which can be of any form) with finer-grain perceptions or measurements (or, if you are a realist, reality). Models can indeed be circular if they are atemporal. For example, category theory is a whole set of models of this form, which may include circular diagrams and differential equations, and may well include simultaneous interaction at an instant. However, just because one's model may be circular does not mean that the phenomena it models includes circular causation in any meaningful sense. In the case of these apparently circular models, they are resolved (analytically or computationally) into possible sequences within time, and it is to events within time that causation refers.

« 4 » The author attempts to avoid the above straightforward account in three ways: (1) by moving from events to non-events, (2) by limiting the world to what can be "brought into being" by human perception and cognition, and (3) by conflating circularity and recursion. I think these examples all fail to escape the mundanity of causal linearity in any helpful way. I will deal with each in turn.

The shift from events to non-events

« 5 » Non-events, or a state where an event does not occur, only make sense where there is some expectation that an event of a particular kind might occur. Otherwise we always live in an transinfinite sea of non-events with no way of distinguishing which are relevant. In this sense a non-event can be a condition of another event (e.g., an open door) but not, in of itself, its cause. Non-events only become causes through their sampling at particular points in time.

« 6 » Take the example of potential protestors under an authoritarian regime in the example raised in the target article. In this situation a potential protestor might check every now and then whether another is protesting – it is not the continual non-protesting that is the detailed cause but the results of checking that is an event (albeit one indicating the continuation of the non-event). Each actor has a *model* of each other in a continual state of non-protesting or protesting, but that is an abstraction: the causation happens at a finer grain, and there it is events. The author's own model illustrates this difference beautifully. In the simulation there is certainly no circular causation, because the execution of the code has to be sequential in time. It is possible to use our models of how people think to abstract a circular diagram in terms of mutually supporting non-protesting, but this does not change the causation, merely the way we are conceiving it. There is no continual non-causation in this simulation, only events in complicated sequences. So one could wonder: **What would be the detailed mechanism by which a non-event or a lack of an event caused something else? Would not this mechanism supply the causal chain that the model summarised? (Q1)**

Limiting the world to what can be "brought into being" by human perception and cognition

« 7 » It is beyond doubt that what can be consciously thought about or perceived is limited for us. Finer detail cannot be apprehended but is dealt with in two ways: (a) by attending to a very small bit of detail at a time or (b) via abstractions. However, this does not necessitate a collapsing of models or recordings of them to the same level because of the ability to systematically re-present recordings to our consciousness and compare complex formal models to them. All we need is the ability to comprehend this process: the comparison and the ability to systematically transform the formal models for progress beyond what we can apprehend. If the formal models do not correspond with our apprehensions or fit with the recordings of measurements, we can change either our apprehensions or formal models. The fact that we can only "bring into being" a few aspects of the recordings or formal models (via other recordings) does not matter, since we can revisit them many times to check different aspects each time.

« 8 » In the case of the simulation described in the target article, we can copy the simulation, rerun it to get new (but comparable) results, and inspect bits of the detail of the code. We may not be able to comprehend the simulation as a whole, but that does not make it circular since we can use the above procedure to check causation in it, even if it is directly beyond our apprehension. As Mark Bedau (1997) pointed out, in simulations that exhibit "weak emergence," there is no "shortcut" to predicting the results from the setup other than via the complex simulations running themselves. Since the complicated details of the setup and simulation inference are beyond us, we describe these results in different terms from the simulation details, so that this is radically new from our point of view. We cannot directly see how this new description comes about from the detail. However, the description is just another model of the detail, it is not necessarily a causal model. The causation itself occurs at the level of the simulation detail.

« 9 » In the case of biological evolution, what causes a particular gene line to survive is a complicated sequence of events (just having enough energy and speed to catch some particular prey, which allows the animal to feed its young, etc.). Concepts such as "fitness" and "positive adaption" are our abstractions, abstractions we can apprehend and consciously deal with in explanations. That, like in the simulation, there is a different level from that of the detail to what can be abstracted or perceived about the outcomes is essential to understanding what is happening. Moves that seek to gloss over the micro-macro gap in understanding (Schelling 1978) impoverish this. This suggests the question: **Why do the limitations of our cognition mean there can be circular causes in any sense other than analogical? (Q2)**

Circularity and recursion

« 10 » There are many cases that are defined recursively. Computer programs can be defined recursively, as can processes of other kinds. Fixed-point definitions may simultaneously relate a whole to an aspect of itself. However, although the definition appears to be circular, if it actually defines anything, it is not circular when used. Thus, for example, Google's page-rank algorithm is defined as a fixed point of a matrix-defined process, and this point is estimated using an iterative algorithm that outputs the point with increasing accuracy. The fixed-point definition is not circular but recursive, the algorithm does iterate over the same process but each time over increasingly accurate (hence different) values.

« 11 » In these three cases, it must be asked what has been gained by calling causation itself circular when it is the model of the events that is circular, not the events themselves. Is it not simply clearer to say causation is not circular, but our models of causation can be expressed in self-referential forms? That we can only apprehend relatively simple aspects of complicated forms (e.g., processes, events, measurements) or that we seek to model a series of events in terms of vaguely defined "non-events," makes no difference to this question. Only in abstractions does circularity arise, otherwise we are stuck firmly within the flow of time. Put differently: **Is not recursion in a model different from causation between events or processes that the model might define? (Q3)**

Conclusion

« 12 » The target article essentially seeks to change the meaning of the word *causation* to apply to abstract entities within models. In doing so it creates confusion that does not seem helpful to the understanding of situations where there is emergence of different kinds. One suspects that this kind of rhetoric is aimed at escaping the confines of reductionist accounts, however, this account remains firmly on the analogical level – the level of models we use to understand the incomprehensibly complicated nature of our world.

« 13 » This suggests a final question: **What is gained from changing the meaning of the word causation to apply to abstract entities within models? (Q4)**

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Circularities, Organizations, and Constraints in Biology and Systems Theory

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> Upshot • The target article defends the fundamental role of circularity for systems sciences and the necessity to develop a conceptual and methodological approach to it. The concept of circularity, however, is multifarious, and two of the main challenges in this respect are to provide distinctions between different forms of circularities and explore in detail the roles they play in organizations. This commentary provides some suggestions in this direction with the aim to supplement the perspective presented in the target article with some insights from theoretical biology.

Introduction

« 1 » Manfred Füllsack's target article defends the role of circularity in science. It begins by emphasizing how this concept has often raised uneasiness in mathematics and logic due to the unusual approach to causation it entails, incompatible with a mainstream view based on well-specified first causes from which to build chains of causal relationships. Similarly, circularity was excluded from the natural sciences by the theoretical and formal framework of classical physics, i.e., the "Newtonian paradigm," whose limits in this regard were pointed out and analyzed by Robert Rosen (1991) among others.

Such exclusion is the direct consequence of very specific restrictions imposed on scientific descriptions by some fundamental theoretical assumptions (Bich & Bocchi 2012), i.e., that:

a all entities can be exhaustively characterized by their intrinsic properties without reference to anything else;
b that the environment (the boundary conditions) is fixed and cannot be influenced by the entities that interact in it; and
c that the rules that describe these interactions are extrinsic – that is, interactions do not change the properties of the interacting entities and vice versa.

« 2 » These three dimensions of the scientific description – objects, boundary conditions, and rules of interaction – have been assumed to be independent and segregated in distinct descriptive categories. As soon as the result of this operation of theoretical construction was no longer considered the product of just one of several possible strategies of description and was assumed as the ontological foundation of the natural world, the resulting picture was that of a passive nature incapable of transformation, studied through the tools of reductionist science. Thus, circular causal relationships did not find a place in the natural world constructed with the tools of modern science (see also Kant 1987).

« 3 » Yet the experience of phenomena such as the self-producing and self-maintaining dimension of life, which resists and cannot be accounted for by physical causality and contradicts the three assumptions listed above, called for a reintroduction of circularity into science. The paradigmatic example is the cell. By building and maintaining its membrane, a cell defines the spatial scale of the system and the concentration of the components in the cytoplasm, thereby establishing a new internal environment with specific boundary conditions distinct from those of the external environment. Through this selective compartment produced from within, the cell is capable of exerting a control over the dynamics of its internal components, which are no longer completely determined by the external environment. The internal metabolism, enabled by such new local boundary conditions, is capable of producing new components that can behave in different ways, therefore changing the previous rules of interaction and, in turn, cospecifying and modifying the boundary conditions of the internal environment. Moreover, the system as a whole, operating as an agent, can change its external environment. Originating with Immanuel Kant (1987) and Claude Bernard (1865), this line of reasoning in biochemistry and biology produced between the 1960s and the 1980s some fundamental theoretical and epistemological tools to understand circularity (often in close relation to mathematical modeling), not only