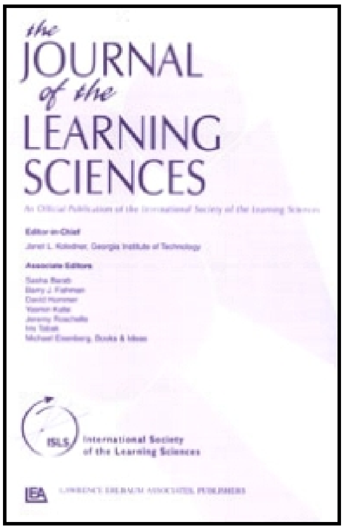

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On Static and Dynamic Intuitive Ontologies

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COMMENTARY

On Static and Dynamic Intuitive Ontologies

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We appreciate Professor Slotta's responding to our critique (Slotta, this issue) and the editors' providing him and us space in the *Journal of the Learning Sciences* for this exchange. It is often difficult to understand subtle new ideas without seeing them defended against misinterpretations. If we have misunderstood Chi's ideas, then we believe others have as well, and we would be glad to contribute to their further explication.

For our part, we believe that Professor Slotta has misinterpreted aspects of our position. There is not space, and it would not be appropriate, for us to reiterate our arguments from the article in question (Gupta, Hammer, & Redish, 2010), but there are two particular points we feel we should clarify. First, we explain here our use of "static ontologies," which we maintain applies. Second, we respond to the question of how our dynamic view could account for evidence of stabilities. In addition, we take the opportunity to note differences in methodology that, we believe, underlie much of this debate.

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STATIC AND DYNAMIC ONTOLOGIES

Slotta (this issue) attributes to us a misinterpretation, claiming that we thought Chi's framework disallows parallel ontologies by physics experts in their everyday reasoning (Slotta & Chi, 2006, p. 266). That was not our interpretation, and it was not the meaning we intended by "static ontologies." We do recognize and should have made clear that Chi's framework expects that experts hold parallel ontologies.

We chose the name "static ontologies," rather, to capture the meaning Slotta (this issue) asserts is at

> the very heart of the definition of ontological categories: What makes them ontologically distinct is that one cannot gradually or radically change a concept's ontological attribution from one category to another. The only way to change the ontology of a conceptualization is to develop a completely new conceptualization.

Ontologies, according to this view, have the form of discrete categories in the mind, as fixed structures that constrain reasoning. It is in this sense that we described them as static in contrast with dynamic.

We gave evidence of dynamism in both experts' and novices' ontological attributions. It is not, however, simply that they move between ontological categories; it is that in many situations the simple categorical distinctions do not apply. Our disagreement is with the idea that the ontologies are *parallel*, that they are distinct and independent, in experts or in novices. Thus, we showed experts and novices *blending* conceptualizations of matter and process or, as we also put it, *straddling* those categories in their reasoning.

Regarding experts, the disagreement centers on the veridical nature of concepts, again reflected in Slotta's (this issue) description: "In the scientifically normative view, the concept of heat is actually associated with an *emergent process* ontology" (emphasis in the original) and emergent process attributes are "fundamental characteristics" of science concepts such as heat and light. This is, again, a static interpretation, that each scientific concept *correctly* belongs to a *single* ontological category (e.g., the emergent processes category for diffusion). We have not seen evidence that expert reasoning holds to that normative view. In our article (Gupta et al., 2010) we gave evidence that it does not, using Slotta and Chi's (2006) methods of predicate analysis to analyze samples of professional discourse from colloquia, journal articles, and textbooks.

Regarding novices, by the view we attributed to Chi and Slotta, which we read Slotta (this issue) to have expressed again, difficulties in learning arise from (a) commitment to substance-based reasoning and (b) novices' "little or no psychological representation of [the emergent process category]." We disagree in these respects as well. In our original article, we documented flexibility in the ontologies emergent in novice reasoning about electric current, heat, and waves—in data we collected from classroom discourse as well as in reanalysis of novice reasoning in published literature—again using Slotta and Chi's (2006) predicate analysis. We also cited Levy and Wilensky (2008), who gave compelling evidence of novice resources for understanding emergent processes in familiar contexts, such as the spread of rumor or the movement of students in a classroom.

EXPLAINING STABILITIES

As Slotta (this issue) rightly argues, our account of ontological flexibility needs to explain the results Chi, Slotta, and their colleagues have richly documented, that novices in a variety of situations hold to substance-like views of science concepts. We were remiss not to give this greater attention in our original article.

The core of our assertion is that intuitive ontologies arise from the dynamics of a complex system composed of manifold cognitive resources. Stability, in such a view, need not reflect the properties of a fixed structure. In other work (Hammer, Elby, Scherr, & Redish, 2005), we discussed how stabilities can arise in several ways within a resources-based account. That work focused on intuitive epistemologies rather than ontologies, but the same reasoning applies. Most relevant here is *contextual stability*, in which the stability of a pattern of resource activations involves features of the situation. That is, given a situation, patterns may arise and be robust that would not form in other situations.[1]

Our perspective draws from work in cognitive psychology, especially work by Thelen and Smith (1994), that gives evidence of and pursues dynamic systems accounts of the formation of stable patterns of cognition and action on local and ontogenetic time scales. The field of developmental psychology has been moving in this direction more broadly (Lerner, 2006; Siegler, 1996), as has research on conceptual change (Brown & Hammer, 2008). (This shift, from accounts of fixed, constraining cognitive structures to accounts of more flexible, adaptive dynamics, is, to be sure, much like a shift from matter to process.)

In all, the cognitive flexibility of a complex systems view does not rule out the observed stability of matter-based reasoning—just as an emergent process view of electrons moving randomly in a wire does not rule out the possibility of an overall drift pattern, a steady current—but reconceptualizes it as a dynamic stability.

[1]For a simple example, we discussed one student who, like many students, was stable to the point of adamancy in her belief that she would need a mirror as tall as she was in order to see her whole body reflected in it. That pattern of thinking did not occur at all in her home, where everyday she looked at her reflection in a mirror about half her height (Hammer et al., 2005).

Most important, we do not need a fixed unitary category as the cognitive substrate for the emergence of such stability in reasoning, and we expect to find multiple coherences in student reasoning.[2]

The question we raise in return is this: How is it that, as Slotta and Chi (2006) showed with convincing evidence, students are able to develop "a completely new conceptualization" (Slotta, this issue) through only 2 hr of exposure to a training module? We argue that a flexible systems view provides an explanation: The module taps into resources students have from the outset, and it creates a situation in which emergent process–like reasoning is locally stable.

A flexible systems view also provides an explanation of how, as in the history of physics, a "wrong" idea such as the Bohr atom or the matter-based caloric theory of heat can be productively generative for students. Thus, the idea of heat as a weightless substance called "caloric" can activate resources for reasoning about a conserved, extensive quantity, resources that contribute to understanding the first law of thermodynamics. That is, what begins as matter-based reasoning need not remain there. It is true that matter-based reasoning readily comes to mind; for that reason it is likely to arise in classes in which students are afforded agency to invent and pursue ideas. It is not true, however, that matter-based reasoning cannot lead to process-based reasoning.

METHODOLOGY

Our final point concerns divergences in research methods. We were struck by Slotta's (this issue) contention that we offered "no evidence" to challenge the idea that an analogy between the flow of electricity in wires and the flow of water in pipes would reinforce student commitments to a matter-based ontology. This raises a final aspect of our disagreement that we believe deserves mention: What should count as evidence?

From our perspective, we provided evidence. The student Kimberly from Ayush Gupta's physics course, in which students invented and made significant use of analogies to blood flow for electric current, moved easily between using matter-based and process-based predicates for electric current; at times her reasoning evidently straddled the categories. The data clearly show that the analogy to blood flow supported her construction of a correct understanding of current. This directly contradicts the incompatibility hypothesis,[3] but Slotta (this issue) does not consider it evidence. Perhaps that is because it is in the form of a case study?

[2]We are currently preparing a manuscript that analyzes multiple ontological coherences in graduate students' reasoning about heat.

[3]Slotta and Chi (2006, 286) consider "the flow of blood in veins [to be] a substance-based concept," like the flow of water in pipes, incompatible with the flow of electrons in wires.

Evidence supporting the account of static ontologies, in contrast, is primarily from aggregate data across many subjects. Although that evidence can certainly establish statistical trends, it does not afford analyses of the dynamics within subjects' reasoning, and it does not attend to the variability among or within subjects. From the static ontologies perspective, the variations are statistical noise; from ours they are phenomena of central interest.

There are clear similarities between the divergences in our methods and findings and the divergences Dunbar (2001) identified in research on analogical reasoning. He discussed the "paradox" of why people seem quite able to generate and understand analogies in naturalistic settings, but when psychologists try to isolate those abilities in clinical settings they find severe limitations. Dunbar argued for the need to combine in vivo and in vitro methods of research to make progress in understanding analogical reasoning and showed how insights from one can inform work in the other. We believe the same will be true here. Our studies have been almost exclusively in vivo, Chi's and Slotta's have been primarily in vitro; we should be in conversation.

CLOSING NOTES

There has been little challenge to the account of static ontologies in the research literature, although it is widely cited and applied. That, we believe, has been a problematic state of affairs. Challenges to a perspective can not only reveal its flaws and limitations, if it has them, but draw out its strengths; challenges provide authors insight into how others are interpreting their work and the opportunity to address misunderstandings. We thank the editors of the *Journal of the Learning Sciences* for publishing our original article, as well as, again, for providing space for this exchange.

There are implications of this debate, including for instruction. The strongest pragmatic point on which we depart from the account of static ontologies is with respect to its contention that educators should avoid

> any form of instruction that could reinforce novices' existing ontological commitments. The theory suggests that instructors should first help students establish the target ontology, then explicitly link any instruction of the concept to that target ontology while explicitly avoiding the original ontology. (Slotta, this issue)

Neither expert nor novice cognition in vivo, we argue, supports this position, and, as we argued in our article (Gupta et al., 2010), instructors following that advice could do harm they do not intend. Students in Gupta's class invented the analogy to blood flow and made productive use of it in explaining and predicting phenomena; by the static ontologies view he should have guided them away from that reasoning.

Still, although we disagree with their perspective, we should have done more to emphasize our belief that Chi's and Slotta's work has been productive and generative. We assign it in our seminars for doctoral students and for teachers not simply as a foil but because it raises awareness of learners' reasoning in productive ways. We see its value for instruction not as a means of delineating correct and incorrect teaching methods but of helping to identify patterns of reasoning instructors could recognize and consider in their students.

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