Modeling the Dynamics of Ontological Reasoning in Physics

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Abstract: The form of learners' ontologies of physics concepts such as heat and electric current is a subject of current debate within the learning sciences. In one view, there is a cognitive barrier to transitioning between ontological categories; others argue that experts and novices transition flexibly between ontological categories. In this poster, we support the latter view through arguing that experts coordinate transitions between ontological categories for heat and electric current and discuss the instructional implications of these results.

Introduction

The form of learners' science knowledge has been a topic of much debate within the learning sciences, hinging on the level of coherence and fragmentation the different perspectives attribute to naive science knowledge (diSessa, 2006). One prominent perspective is that developed by Chi (Chi, 2005), in which experts' and novices' reasoning about a science concept is constrained by their ontological commitments (commitments about whether the particular science concept can be categorized as *matter/substance* or a *process*). Once formed, these commitments are difficult to change except through conceptual change processes, leading to the robustness of ontological misconceptions (defined as mis-categorizations by novices). In this view, concepts such as heat, light, electric current are *emergent processes* and classified as such by experts. Novices tend to mis-categorize these concepts in the *substance/matter* or the *direct process* categories either due to a commitment to these categories, or due to a lack of the *emergent process* schema.

Recently, however, this view has been challenged, showing evidence that novices can and do reason across ontological categories (Gupta, Hammer, & Redish, 2010; Hammer, Gupta, & Redish, 2011) and that novices do not lack the emergent process schema (Levy & Wilensky, 2008). In this poster, we argue against the notion of ontological commitments: we present evidence that graduate students reasoning about heat often switch from speaking in terms of one ontology to another. We investigate the fine-timescale dynamics of such switching and posit that cues from the problem statement or interviewer, explanatory demands, learners' in-the-moment epistemological stances, and how they view the purpose of their explanation can contribute to the ontology underlying their reasoning as well as to transitioning to a different ontological description of heat.

Methods: Data Collection, Selection, and Analysis

The data comes from five one-hour videotaped interviews of physics graduate students from a previous project. The interview protocol followed Chi's and Slotta's tasks (Slotta, Chi, & Joram, 1995) to examine physics novices' and experts' ontologies of electric current, heat, and light. As part of the first author's high school magnet research internship, the heat and electric current sections of three of the interviews were selected for this analysis. Selection size was based on considerations of a high-school student research project.

The analysis occurred in two phases. First, transcripts of Sam's utterances in the selected portions were divided into 30 second segments and each segment was coded as reflecting *matter* or *emergent-process* ontologies using the predicate analysis method (Slotta & Chi, 2006). Instead of doing summary counts of predicate use for a topic, we plotted the predicate use *over time*. Second, we did a fine-grained analysis of the interviews, focusing more on segments where we noted category transitions (identified from the predicate plots). Loosely drawing on tools from knowledge analysis (Parnafes & diSessa, 2013) and discourse and framing analysis (Gee, 1999; Tannen, 1993), we aimed at a fine-timescale account of the transitions in the use of ontological categories, taking into account the content of talk as well as gestures, gaze, and tone of voice to infer the conceptual knowledge, epistemologies, and framings in use in the moment.

Analysis

We present excerpts of our analysis of one of the interviews. Figure 1 shows the graph for Sam's (pseudonym) use of matter and emergent process predicates.

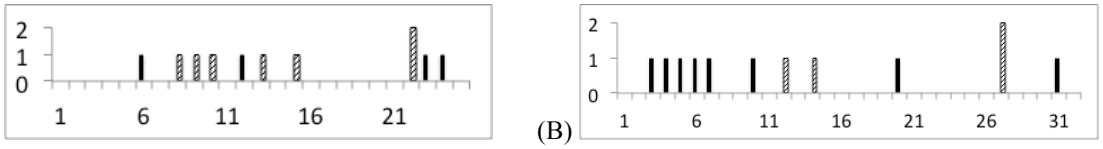

Figure 1 Predicate use for Sam for the interview sections on (A) Electric Current and (B) Heat. 30-second interview segments are marked on the horizontal axis. Frequency of predicate use within a 30-second segment is marked on the vertical axis. Striped bars represent *emergent-process* predicates. Solid Bars represent *matter* predicates.

In this poster paper, we present the story of how one ontological transition plays out from the electric current section of the interview at the 22-nd segment. At this point, Sam was answering a question about two circuits each with one bulb attached to a battery, identical except that one has a longer wire and so the bulb is farther away from the battery. Sam stated that this is similar to an earlier question when she had to decide if "the current starts at the battery and has to travel to the light bulb." However, she rejected that idea, saying instead, "The potential for current is everywhere in the wire at the same time (gestures in circular motion with arms to show the circuit). There are electrons scattered throughout that, or, not scattered. but spread throughout that wire, so as soon as one starts moving, they all move. So they are both gonna illuminate at exactly the same time." Following this, the interviewer asked her which bulb is glowing more brightly. First, Sam posed the question "Are we assuming resistance-less wires?" to which the interviewer said, "You tell me why that would matter." Sam explained how resistance affects brightness when the wires are different lengths because "resistance saps away" voltage as "current goes through the length of wire" and so "less voltage getting put into your light bulb." Her gestures confirm that she is thinking of an entity physically moving through the wire.

Sam, contrary to the ontological framework of Chi and Slotta, showed no cognitive resistance to switching between *matter* and *emergent process* categories: in the first segment, talking about long and short wires, Sam's explanation relies on an emergent-process understanding of current resulting from the simultaneous motion of electrons everywhere in the wires. Moments later, explaining resistance Sam's speech and gestures reflect a *matter*-view of current flow in a circuit. Also, notable is Sam's awareness, in each segment of the kinds of knowledge resources available to her and carefully chooses how to answer: she explicitly discusses the alternative way of reasoning and rejects in the earlier segment; later, even before answering she is aware that her answer would depend on whether wires have resistance or not and seeks to clarify that. Her responses here indicate some level of metacognitive awareness (what kind of knowledge is available to me) and epistemological evaluation (what kind of knowledge is relevant in this particular context).

Summary and Implications

In this poster, we present our results (using fine-grained video analysis as well as verbal protocol analysis) that graduate students in physics can and do transition between ontological categories in their explanations of phenomenon related to heat and electric current. We show that such transitions are often influenced by the particular problem context (the specific phenomenon being explained within the larger category of heat and current) as well as metacognitive and epistemological evaluations. We argue that the target of ontological expertise should not be ontological conceptual change, where a concept is supposed to be re-categorized within it's correct ontological category. Our results indicate that there might not be one "correct" ontological category (at least as reflected in experts' behaviors); nor do we see a cognitive barrier to flexibly transitioning between categories. Rather, the target of ontological expertise might lie in an awareness of all the knowledge resources that could potentially be relevant to a particular situation and in developing metacognitive and epistemological resources to figure out what is the most productive way to reason in a given context.

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Acknowledgments

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