Epistemological resources and framing: A cognitive framework for helping teachers interpret and respond to their students' epistemologies

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Previously, we have argued that an account of personal epistemologies based on *epistemological resources* shows generativity and explanatory power, especially for understanding variability in a student's behavior. In this chapter, we argue that a resources framework is generative for instruction and is therefore worth teaching to teachers. Using for illustration a case study of middle-school Earth science students learning about the rock cycle, we argue that the resources framework (1) includes coherent networks of resources that correspond to what teachers can recognize, and what novice teachers can learn to recognize, in students' approaches to learning; (2) invites close attention to context when evaluating whether a given student utterance or behavior reflects a productive stance toward knowledge, leading to more nuanced assessments of the student's approach to learning; and (3) provides guidance about how to foster epistemological sophistication over both short and long time scales. To support these points, we first extend the resources framework to address a challenge it presents: epistemological resources are rarely apparent in isolation. Instead, the main observable grain-size of student epistemologies corresponds to an *epistemological frame*, a locally coherent activation of a network of resources that may look like a stable belief or theory. A particular

epistemological resource, we argue, can play different roles in different frames, and this feature of our framework has instructional implications.

Introduction

A growing body of research on personal epistemologies contends that how students understand the nature of knowledge, knowing, and learning affects how they reason and learn (Hammer, 1994; Hofer & Pintrich, 1997; Hogan, 1999; May & Etkina, 2002; Sandoval, 2005; Schommer, 1993; Schommer, Crouse, & Rhodes, 1992).[1] Readers of this volume will not find it controversial to conclude that K-12 teacher education and professional development should address the notion of personal epistemology.

In this chapter, we argue that the resources perspective is particularly useful and generative for K-12 teachers. To make this argument, we first review and extend the resources perspective to include *epistemological framing* (Hammer, Elby, Scherr, & Redish, 2005; Redish, 2004), which corresponds closely to the phenomena of coherent personal epistemologies documented in the literature (Hofer & Pintrich, 1997). We then offer three reasons why this perspective is particularly productive for teachers.

Epistemological resources and framing

We first review our cognitive framework for describing personal epistemologies in terms of epistemological resources. Then we extend that framework to account for the coherent, belief-like epistemologies that students often display (diSessa, Elby, & Hammer, 2002; Hammer, 1994; King & Kitchener, 2002; Lising & Elby, 2005). Our framework,

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[1] Like Schommer-Aikins (2004), and unlike Hofer & Pintrich (1997) and others, we include views about learning in our definition of *personal epistemology*. We have both theoretical (Elby, submitted, 2007) and practical reasons for this choice, as discussed below.

however, predicts that epistemological coherence is often local rather than global, i.e., that students manifest different coherent epistemologies in different contexts.

Review of epistemological resources

Cognitive *resources* are fine-grained knowledge elements that a student possesses, the activation of which depends on context (diSessa, 1993; Hammer, 2000). To see how resources differ from the "beliefs" or "conceptions" that researchers often attribute to students (Carey, 1992; Hewson, 1981; McCloskey, 1983), consider an example: Many students expect that an ice cube wrapped in cloth melts more quickly than one left out in the air. One interpretation of the students' thinking would be to attribute a misconception that some materials, such as blankets, jackets, and gloves, are inherently warm. But ask those same students to think about removing a hot pan from the oven, and they would view that same cloth as something that can protect their hands by "blocking" the heat. The resources framework invites an explanation of these different patterns of reasoning in terms of the context-dependent activation of cognitive resources. From their experiences associating blankets and gloves with warmth, students may have formed mini-generalizations about cause and effect — that *softness means warmth*, perhaps. The cloth-wrapped ice cube triggers this resource. Other contexts, however, turn on different resources. When reasoning about the cloth and hot pan, students may activate their intuitive idea of *blocking* (diSessa, 1993) but not *softness means warmth*.

In our framework, context-sensitive activation of fine-grained knowledge elements also describes students' cognition concerning the nature of knowledge, knowing and learning (Louca, Elby, Hammer, & Kagey, 2004). A college student we described in a previous paper illustrates what we mean (Hammer et al., 2005). When asked how he prepared for his physics test, Louis said that he "studied every word of those homework solutions…I was memorizing

the book, too." This response reflects a view of knowledge as something absorbed from an authoritative source. By contrast, talking about his strategies for tutoring other students, Louis said, "what I like to do is build on what they already know instead of introducing a totally new concept," reflecting a view of knowledge as something constructed out of prior knowledge.

Louis's variability can be understood as arising from the different contexts activating different resources, in this case resources for understanding the nature of knowledge and how an individual comes to have it. Note that "different contexts" includes but is not confined to different disciplinary domains (Muis, Bendixen, & Haerle, 2006). As a physics student, Louis activated *knowledge as propagated stuff*, a resource for understanding knowledge as passed from a source to a recipient. This attribution does not contradict an explanation of Louis's behavior in terms of long-established habits and expectations about school. Those expectations and habits, in our framework, are likely to activate and to be activated by a network of epistemological resources that includes *knowledge as propagated stuff.* As a tutor, by contrast, Louis activated *knowledge as constructed*, a resource for understanding knowledge as built from other knowledge. That activation may have been more likely because Louis was focused on his tutee's knowledge rather than his own, or because he was familiar with the academic material.

We need to clarify how the *knowledge as propagated stuff* and *knowledge as constructed* resources differ from the transmissionist and constructivist beliefs often discussed in the personal epistemology literature (Hofer & Pintrich, 1997). In earlier work (Hammer & Elby, 2002), we posited *knowledge as propagated stuff* as a little piece of knowledge about knowledge that enables a kindergartener, when asked how she knows what is for dinner, to answer, "because Daddy told me!" This epistemological resource enables her in some

circumstances to view knowledge as a kind of thing than can be passed from source to recipient, even if she cannot articulate this view or apply it consistently. Similarly, the kindergartener possesses *knowledge as constructed*, a resource that enables her to view knowledge as something that can be figured out. For instance, when her birthday arrives and her mother walks in holding something behind her back, the kindergartener might squeal, "a present!" When asked how she knows, she might say, "It's my birthday and I saw you holding something — I figured it out." We use a kindergartener to emphasize that these resources are not beliefs; a kindergartener's "transmissionist" and "constructivist" views almost certainly lack the robustness or stability of beliefs. However, these and other epistemological resources can form coherent, stable networks that constitute the epistemological beliefs observed in older children and adults.

Before discussing the role these networks play in our framework, we briefly mention two other characteristics of epistemological resources. First, in both children and adults, the activation of a resource can occur beneath the subject's awareness. When we say "Louis activated *knowledge as propagated stuff*," we do not imply that he consciously chose to use that resource. Second, these resources cut across the categories of "knowledge" and "learning." For instance, *knowledge as propagated stuff*, functioning as an element in a cognitive model of intuitive epistemologies, contributes to a view of knowledge as a kind of shareable stuff and to a view of learning as receiving information. We include views about learning within our definition of personal epistemology not for disciplinary or other *a priori* reasons but because, in the cognitive models we are building, views about learning are inextricable entangled with views about knowledge and knowing (Elby, submitted, 2007).

Epistemological framing

Our view is not that personal epistemologies are haphazard and incoherent. Rather, we expect local coherences, including belief-like consistencies and stabilities, within a given context (Hammer, 1994) and sometimes across contexts (Lising & Elby, 2005). We now explain how the resources framework accounts for epistemological coherence.

Framing. Epistemological resources do not generally turn on or off in isolation; the activation of one resource can promote or inhibit the activation of others. We lack a precise developmental story, but we subscribe to a dynamic systems view (Thelen & Smith, 1994) of development as a progressive construction of patterns of resource activation.

In some cases, a network of activated resources will be unstable and perhaps turn off quickly. In other cases, the network of resources will be *locally coherent*, by which we mean the activations of the individual resources are mutually reinforced by each other and by contextual cues and other features of the environment, leading to stability. A locally coherent activation of a network of epistemological (and perhaps other) resources is an *epistemological frame* (Hammer et al., 2005).

Louis, for example, recounted succeeding in science classes by memorizing information:

> Because in all, especially in my like chemistry classes, the way I did well on the exam is like flash cards of different reactions and memorize it and the better I memorized it the better I did on those exams. (Hammer et al., 2005).

He assumed that Physics 122 would be similar. So, for him, features of the context as filtered through his previous experiences tended to activate *knowledge as propagated stuff*,

accumulation (a resource contributing to a view of learning as accumulating information), and other resources. Resources in this network probably cue each other. For instance, thinking of *knowledge as propagated stuff*, passing from a source to a recipient, coheres with thinking of learning as *accumulation* of that stuff. These mutual cueings produce local coherence: Louis in physics class is stable in framing learning as memorization. (Notice that this "memorization" frame includes views about knowledge and views about learning, deeply entangled.)

Redish (2004) proposed the term "epistemological frame" to connect the study of personal epistemologies to the notion of *framing* from anthropology and sociolinguistics, particularly Tannen (1993). In Tannen, framing is the set of expectations an individual brings to a social situation, expectations that affect what she notices and how she thinks to act. Roughly speaking, in Tannen (1993), a framing is a person's generally tacit answer to the question, "What sort of activity is this?" For instance, a father at his child's soccer game can frame his activity as rooting for a sports team or as nurturing children. Those two different framings lead the father to notice different things (e.g., who is winning vs. who is happy) and to behave in different ways (e.g., partisan cheering and jeering vs. general encouragement). Tannen's (1993) conceptualization of framing corresponds in our perspective to an individual's forming a locally coherent activation of resources (Hammer et al., 2005). In particular, epistemological framing is the cognitive activity underlying a student's sense of "what is going on here" with respect to knowledge.

The soccer example illustrates a crucial point about framing, namely context dependence and shifting. The father might frame his child's soccer game differently in different contexts, such as an unscored scrimmage versus the league championship, and he might shift frames in response to contextual cues, such as his child getting hurt or other parents

reminding him it is just a game. Similarly, although Louis initially framed tutoring much differently from the way he framed learning physics, an intervention helped him enact a shift (Hammer et al., 2005). When Louis visited office hours after failing the first midterm exam, the professor advised him "when you study, try to explain it to a ten-year-old." In Louis' recollection, this advice led him to approach the rest of the course in a different, more sense-making way, more like the way he approached tutoring. His performance improved dramatically, and he ended up with a B+.

We have evidence that supports Louis's explanation of his improvement (Hammer et al., 2005). First, in an interview with another researcher (not the professor), Louis not only stated how he changed his study strategies but also gave specific examples, including an analogy he generated for understanding electric charges moving through wires based on trucks driving on roads (with obstacles as resistors, etc.). Second, Louis contacted the professor after the semester and spontaneously attributed his success specifically to the professor's intervention as opposed to the professor's lectures, labs, and so on. That success, Louis recounted, extended to other courses—his GPA had increased—which he again attributed to a general shift in how he approached learning. For these reasons, we find it plausible that the intervention helped Louis epistemologically reframe his approach to learning, activating a locally coherent network of resources — a frame — similar to the one he activates while tutoring, a frame that includes *knowledge as constructed* and related resources.

Regrettably, such one-time interventions rarely work so well. One possible explanation for why it helped Louis is that he had already formed that productive frame in another context.

Framing is believing. From a resources perspective, the coherent epistemological "beliefs" that researchers observe in their subjects reflect stable epistemological frames. That

stability could arise in a variety of ways. Elsewhere we described three mechanisms of stability: contextual, deliberate, and structural (Hammer et al., 2005).

Contextual: The stability relies on persistent cueing by features of the context. For example, a student might adopt an active approach to learning, treating knowledge as personally constructed, in a setting where reformed curricular materials and instruction prompt and scaffold that framing. But the student might shift back to rote learning, treating knowledge as information received from authority, when those cues are removed.

Deliberate: The stability of the epistemological frame relies on the individual's deliberate attention toward maintaining a consistent stance. Louis, for example, said his choice to treat physics knowledge as built out of everyday ideas competed against his established routines. At first, he had to keep reminding himself to explain ideas in simple terms rather than revert to rote memorization, an example of epistemological volition (Bendixen & Rule, 2004; Corno, 1993) relying on metacognitive monitoring in an epistemological context (Hofer, 2004).

Structural: A coherent pattern of resource activations can become stable over time, as it is used and reused. In that case, the network of resources turns on as a compiled, robust unit of cognitive structure; that is, it becomes a resource in its own right. Louis' success may have stemmed in part from his needing to keep his "constructivist" framing stable by *deliberate* means for a comparatively short time before it compiled in that context into a *structurally* stable cognitive unit. A contextually and/or deliberately stable epistemological frame can develop, through repeated use, into a structurally stable frame.

In summary, from the resources perspective, an epistemological "belief" professed or enacted in a given context — a physics class, an interview about controversial topics, an epistemological survey given in psychology class — corresponds to an *epistemological frame*

that may be more stable or less stable by any of these three mechanisms. Only the last of these mechanisms corresponds to the general use of "belief" in the literature. For example, personal epistemology researchers typically describe a belief as something an individual "holds" (Hofer & Pintrich, 1997). When an epistemological frame is only contextually stable, however, the observed pattern of epistemological thought persists only in particular contexts, making it problematic or misleading to speak of that pattern as belonging entirely to the individual.

Methodological implications. By this account of epistemologies, researchers cannot assume that the "belief" a subject exhibits in one context is a global or even domain-specific epistemological belief. Only by probing the subject in different contexts doing different activities, within or across domains, can we determine the generality of the "belief." Tweaking the experimental conditions in various ways would also provide insights about the mechanism underlying whatever degree of stability is observed. For instance, changing the location of an interview from the Physics building (with the interviewer introduced as a physicist) to the Education building (with the interviewer introduced as a psychologist), while otherwise keeping the protocol the same, could uncover contextual stabilities and instabilities. Changing the ordering of the questions, from a random jumble to a more ordered progression that invites coherence, could shed light on deliberate stabilities and instabilities.

Our framework also suggests the need for new models of epistemological change. In Bendixen & Rule's (2004) model, which synthesizes recent theoretical and empirical work, such change generally involves epistemic doubt and/or volition and results in new epistemological beliefs. In our model of Louis' epistemological change, by contrast, volition plays a role but the end result was not a new epistemological belief; it was the redeployment of an *old* "belief." More generally, in our framework, much epistemological development and

change consists of the co-activation and stabilization of epistemological resources the student already possesses.

Connections to teachers' professional knowledge

We have argued that a resources-based account draws on and may contribute to teachers' professional knowledge (Hammer & Elby, 2003). Our experiences as instructors informed our development of a resources-based perspective. In particular, those experiences concerned students' approaches to learning and how they may shift, depending on how they understand (frame) the task.

Here, we refine that argument to focus on framing, following Redish (2004). To review, an epistemological frame, at the level of experience, is an individual's sense of "what is going on here?" with respect to knowledge. At the level of cognitive structure, it is a locally coherent activation of a network of epistemological and associated resources. We argue that

(1) Epistemological frames correspond to what teachers can recognize, and novice teachers can learn to recognize, in students' approaches to learning;

(2) The possibility that a given resource can participate in multiple frames invites close attention to context when evaluating whether a given student utterance or behavior reflects a productive stance toward knowledge, leading to more nuanced assessment of the student's approach to learning; and

(3) The resources perspective provides guidance about fostering epistemological change over both short and long time scales.

Rather than draw again on our own teaching experiences, we develop our arguments with respect to a case study from an eighth-grade science class taught by Jessica Phelan (in Hammer & van Zee, 2006; also Rosenberg, Hammer, & Phelan, 2006). To be clear, we are not making an empirical case for our claims; we are illustrating them with an example from a case study.

Epistemological frames correspond to what teachers can recognize in students' approaches to learning

We illustrate this first claim with an example of Ms. Phelan's diagnosis of student difficulties as they worked to develop a model of the rock cycle.

The students had completed worksheets addressing the formation and properties of igneous, sedimentary, and metamorphic rocks, but had received no formal instruction on the rock cycle, the physical processes by which those three kinds of rocks turn into each other. Ms. Phelan split the 25-person class in half and instructed each group to make a model of the rock cycle.

One group sat in a circle on the floor in the hallway. This is how they began their work.

Lisa: I need to get out the papers.

Bethany: OK, so what is the rock cycle?

Ben: Well, it starts out as an igneous rock. Right? And then it um-and then it like-

Johanna: An igneous rock forms, weathering occurs.

Bethany: OK, wait…Igneous rock.

Johanna: [sing-song voice, reciting] Igneous rock forms, weathering occurs…weathering.

Ryan: I have all of my sheets if we're allowed to go back in the room.

Bethany: OK, what happens next? Lisa? [Lisa has her papers out.]

Lisa: Igneous rock…it forms from magma (inaudible) lava. First we have to start with the plates running into each other, and the lava going up.

Tracy: It's either erosion (inaudible) or sediments are formed.

While Lisa is speaking several other students chime in with comments about the "deposits." Tracy decides erosion comes first, and tells Bethany to record that.

Ben: The deposit goes through erosion, and settles at the bottom of the sea.

Lisa: First we have to start with uh first we have to start with the plates – underground.

Bethany: Oh wait, so what happens?

Tracy: (inaudible) plates underground.

Bethany: So, the Teutonic (sic) plates move, and-

Lisa: Yeah, that's the very beginning.

Bethany: OK. [Starting to write] Teutonic plates…

The conversation stops as Bethany writes, and she motions for the group to continue: "You guys can talk while we're writing." At this moment, Ms. Phelan came out to check on their progress, in time to hear Bethany reading back a summary to the group of what they had accomplished thus far:

Ben: And then, after that happens, the sediment goes to the bottom of the ocean, and then it compresses to form…

Bethany: [reading] So, the Teutonic plates move and create rock, and then I have the igneous rock forms. Is that wrong? [Pause. Ben and Ryan both start to say something but hesitate.]

Lisa: No, there's something. There was like de-desa-whatever.

Johanna: Deposit (inaudible)

Lisa: Yeah, deposition.

Tracy: We're not there yet.

Ben: The deposit comes after that.

Rosenberg et al. (2006), analyzing the conversation line-by-line, argued that the students were organizing their efforts around information retrieval rather than sense-making, focusing on terminology, and creating a formal ordering rather than a causal story. Their analysis included the conversation that took place before Ms. Phelan entered the hallway, but there is evidence in the segment she overheard: The students discuss terminology (Teutonic plates, deposition) and temporal ordering ("So, the Teutonic plates move and create rock, and then I have the igneous rock forms. Is that wrong?" and "the deposit comes after that"), but they do not consider causal mechanism. Rosenberg et al. (2006) modeled the students' framing as a locally coherent activation of five epistemological resources including *knowledge as propagated stuff* and *accumulation*.

Overhearing part of this conversation, Ms. Phelan arrived at an interpretation similar to that of Rosenberg et al. (2006). Here is her entire intervention:

Ms. Phelan: Can I make a suggestion?

Bethany: Yeah.

Ms. Phelan: You're looking at a lot of papers and using a lot of words that you don't know what they mean.

Gustavo: Sure we do (?). [Ryan laughs].

Ms. Phelan: And if you're doing that, for your model, it's not going to be very good. So, I want to start with what you know, not with what the paper says.

Note that she says nothing about rock concepts or the group dynamics; her intervention consists entirely of pointing out to students how they are framing the activity and suggesting that they frame it differently. Specifically, she diagnoses the students to be framing knowledge as words to be retrieved from worksheets without comprehension, and she responds by suggesting that they reframe their activity to "start with what you know." She implicitly expects that the students can keep their (re)framing stable by deliberate means, by monitoring their thinking to make sure they are starting with what they know and not just regurgitating vocabulary. In brief, Ms. Phelan aimed her intervention at students' approach to knowledge generation, and she expected that students could shift to a different approach. Her reflections on the lesson confirm this interpretation:

> Hearing this bit of conversation made me think the students were not making sense out of the problem….They were using lots of big words, without understanding their meanings. This wasn't what I had in mind with the assignment! And it wasn't close to what these students were capable of doing. I had seen them use reasoning skills to solve problems before…I felt that they

> had everything they needed to solve the problem of the rock cycle in their heads. It was just a matter of getting them to really think (Phelan, 2006).

We continue the case study below. But first, we discuss two ways in which Ms. Phelan's diagnosis and intervention align with the notion of epistemological frames: her expectation that students have multiple epistemological stances available to them, and the grain size of what she attended and responded to in her students' thinking.

Expectation of epistemological variability. Ms. Phelan's diagnosis and intervention reflect an intuitive understanding of student epistemologies that, like the resources perspectives, expects students to be capable of treating knowledge and learning in multiple ways, such as focusing on worksheets or "starting from what you know." From attending to her students' thinking in this episode and in previous classes, she knows her students' abilities and factors that may affect their reasoning.

We note, too, that this interpretation is continuous with laypersons' everyday expertise about other people's mind states. People with no teaching experience can recognize when a friend is getting bogged down in terminology and technical details rather than stepping back and making sense of the situation. Consider, for example, this discussion between two introductory college physics students answering a question about light and shadows. The four-person group which included Jan and Veronica was videotaped with no researcher present (Lising & Elby, 2005):

> Jan: So the light is like that and these are the rays, and the vector points that way….All the rays are going like this. So, it's kind of like polarized

> Veronica: Mmm, not really. It's just, well, it's just…you're making it, you're trying to make it more difficult. It's just, the light goes out... [common-sense explanation follows].

Veronica's interpretation of her fellow student's reasoning is similar to Ms. Phelan's and Rosenberg et al's interpretation of the eighth graders: She sees Jan as taking a counter-productive stance toward the ideas in the lab, and she expects it is possible for Jan to adopt a different stance.

Grain size of the epistemological "unit." Elsewhere we have argued that a resources-based account of student epistemologies aligns with teachers' professional knowledge (Hammer & Elby, 2003), giving examples from our own teaching. The refinement of that argument offered here applies to those examples as well: What a teacher can see of student epistemologies in the classroom corresponds to the grain-size of an epistemological frame rather than of an isolated epistemological resource. In Ms. Phelan's (and our) interpretation, the students are framing their epistemic activity as retrieving information from authority. Although as researchers we view that framing as comprised of resources at a finer grain-size, as teachers we notice the pattern (framing) as a whole.

The grain size of what Ms. Phelan notices and responds to aligns equally well with the notion of an epistemological belief (Hofer & Pintrich, 1997). Ms. Phelan's interpretation and resulting intervention, however, align more closely with frames than beliefs: Rather than think of students as holding beliefs or theories about the nature of knowledge, we think of students as *framing* epistemic activities in different ways at different times. There is coherence to their framing, but it may be local to the context. This was Ms. Phelan's interpretation, and she acted

accordingly: Rather than elicit and confront an epistemological belief that the relevant knowledge comes from authority (the worksheets), she simply noted the difference between focusing on "what the paper says" and "start[ing] from what you know." The students' adoption of a particular stance may be local to the circumstances, and a teacher making that diagnosis might expect that interventions aimed at changing those circumstances could result in substantial shifts. As we recount below, that is what happened with Ms. Phelan's students.

Finally, we note our practical reason for including views about learning along with views about knowledge and knowing in our definition of personal epistemologies: What we see students doing in class, at the grain-size of framing, almost always involves aspects of both. Because we are ultimately interested in how students approach knowledge and learning in situations such as these, it serves us to treat knowledge and learning together as part of epistemic cognition. If our aims were otherwise — for example, if we were ultimately interested in students' making progress as philosophers — we might find it more useful to tease apart students' views about knowledge and knowing from their views about learning.

These arguments have implications for teacher education and professional development. We urge teacher educators to focus not just on the default epistemological "beliefs" students most commonly exhibit, but also on the multiplicity of approaches to knowledge and learning that a student can display when nudged appropriately. And we urge that these discussions about epistemology be grounded in real classroom data, such as Ms. Phelan's case study.

We turn now to consider how teachers assess the productivity of student epistemologies.

The framing perspective invites attention to context in assessing whether students are taking a productive stance toward knowledge

We argue here that, because a given resource connected to a particular behavior can participate in multiple frames, the resources perspective invites attention to how students frame the overall activity in which a particular behavior is embedded, leading to more nuanced judgments about the epistemological productivity of that behavior.

In previous work (Elby & Hammer, 2001) we argued that a resources-based view belies simple characterizations of epistemological sophistication. For example, while viewing scientific knowledge as tentative is often sophisticated, in some contexts it is counterproductive, such as in popular treatments of evolution as "just a theory" or in offhand dismissals of global warming as "controversial." In this and other ways, our notion of epistemological sophistication aligns with the Evaluativist epistemological stage discussed by Kuhn (1991).[2]

The notion of epistemological frames as locally coherent activations of finer-grained resources enables us to refine and extend our arguments about the nuanced, contextual nature of epistemological sophistication, and this refined argument has pedagogical implications. The key idea is that different epistemological frames draw upon overlapping rather than disjoint sets of epistemological resources. So, a particular epistemological resource such as *knowledge as propagated stuff*, which can drive a specific behavior such as retrieving information from worksheets, participates in multiple epistemological frames. Consequently, when judging the sophistication of a particular epistemological resource and of the behaviors it helps to drive, we must attend to the overall frame of which it is a part. A given behavior such as information

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[2] But we contest Kuhn's (1991) stage-based conceptualization.

retrieval may be epistemologically productive or unproductive, depending on how students frame the activity in which it is embedded.

To illustrate the importance of this idea for instruction, we return to the rock cycle discussion. After the teacher's suggestion to "start with what you know, not with what the paper says," the students shift how they frame the activity. Still, they continue to retrieve information from the paper (worksheets), which one might construe as not following the teacher's advice. However, they now *use* the retrieved information in a different, more epistemological productive way.

We pick up the conversation several minutes after Ms. Phelan's intervention. Gustavo and Ben have been talking about how layers of sedimentary rock "[go] up and up" until there is a "big sedimentary rock" that is compressed by all the layers. Soon, the group turns to the question of how the sedimentary rock layers become metamorphic:

> Lisa: We need heat and pressure…Where [do] we get more heat and pressure from?
>
> Johanna: [singsong, reciting] A metamorphic, a metamorphic rock forms from heat and pressure…applied to [pause] a rock. [laughter] To any rock. To any rock, and it makes it-it changes the grains, because the heat and pressure changes the crystal structure, the texture, the, appearance, an-and so-and so because-because it's an immen-immense amount of heat or pressure, it can change any rock, and like the grains are changed, so it's foliated or non-foliated.

While Johanna is speaking, Lisa and Bethany try to interrupt to ask where the heat and pressure come from. Ryan tries to answer, "from the lava of course, " and Lisa refines her question.

Lisa: Pressure I can understand where from, but the heat?

Bethany: Wait, where does it get heat and pressure?

Ryan: From the earth's core.

Johanna: From well--'cause it--'cause it's underground, so it's closer to the core.

Lisa: How did it get underground?

Several students speak at once to answer, with Bethany saying, "there's layers and layers and layers on top" and Ryan saying that they "make it go closer to the core, the pressure from all the other layers." Johanna asks "Couldn't it have started underground?"

After another brief exchange, the students wait for Tracy (the new recorder) to finish writing, and she says that the last thing she has is "Sediment rock is formed." Bethany asks, "What happens after that?" and begins to read.

Bethany [reading from a worksheet]: Immense heat and pressure, deep beneath the earth's surface, change the rock into a metamorphic rock.

Ben and Gustavo immediately return to explaining how the heat arises. They say it's because "so many layers makes it closer to the magma" at the core. Johanna points out the inconsistency: The group's account of sedimentary rock layers building up from the bottom does not explain how the resultant sedimentary rock gets closer to the Earth's core.

In some sense the students did not follow all of Ms. Phelan's advice; both Johanna and Bethany read from the worksheets, and the group continues to use them as authoritative sources of information. Although Ms. Phelan missed this segment of the conversation during the class, she viewed it while preparing her case study, and she was not concerned about the students' reliance on authority. She points to this fact in her case study, specifically with respect to vocabulary:

> Here and later, it's interesting to notice that they were still using big words, such as *igneous*, but now they were using those words in ways that made sense to them (Phelan, 2006).

In this episode, the way in which students use the worksheets supports rather than suppresses their sense-making (Rosenberg et al., 2006). Instead of focusing mostly on vocabulary and instead of simply recording what the worksheets say, the students try to incorporate that information into the causal story they are telling. Specifically, when Johanna announces from the worksheet that a metamorphic rock arises from "heat and pressure," Lisa and Bethany immediately wonder where the heat and pressure come from. Ryan provides an answer ("the Earth's core"), and Johanna herself builds on Ryan's answer ("it's underground, so it's closer to the core."). The sense-making discussion continues, and a minute later, when the students find themselves stuck, Bethany asks "what happens after that" and reads from the worksheet, "Immense heat and pressure, deep beneath the earth's surface, change the rock into a metamorphic rock." The argument about the source of that heat then reignites, with Johanna pointing out a possible contradiction in Ben and Gustavo's account.

In summary, during both this conversation and the earlier one before Ms. Phelan's intervention, students retrieve information from the worksheets. In the latter conversation, however, the information feeds into the students' collaborative knowledge generation, while in the earlier conversation, the information retrieval *is* the knowledge generation. This distinction illustrates the following point: when judging whether a behavior such as retrieving information from worksheets is productive for students' learning, teachers (and researchers!) need to look not just at the behavior but at the overall pattern of activity.

The resources perspective invites and buttresses this conclusion. In the earlier conversation, students frame knowledge as bits of information to be retrieved from authority, an epistemological frame that undoubtedly includes *knowledge as propagated stuff* as a hub in the network of resources. During the latter conversation, the students' epistemological frame still includes *knowledge as propagated stuff*; they continue to view the worksheets as a source of knowledge that can be transmitted to them. But *knowledge as propagated stuff* no longer functions as a central, hub resource in the network. A dynamic model of this epistemological frame might have *knowledge as propagated stuff* becoming active only when the student cannot fill in the next causal link in the story she is constructing. In this way, the idea of multiple epistemological frames drawing upon *overlapping* sets of resources provides a framework for describing how transmissionist ideas can be part of a productive constructivist stance.

This analysis has implications for both researchers and teachers trying to identify what counts as evidence of productive versus unproductive epistemologies.

First, probing students' epistemologies as part of formative assessment, either through formal written instruments or informal observations, a teacher should fight the general

tendency to decompose the desired attitudes/beliefs/behaviors into pieces that are separately "tested." Instead, the teacher should look more holistically at how students frame their activity.

Second, viewing frames as composed of finer-grained resources allows analysis of the cognitive dynamics of epistemological "beliefs," of what holds different frames together in different moments. For example, in the rock cycle episode, the teacher's invocation to "start with what you know" pressed on one sort of resource, maybe including *knowledge as constructed*, leading to a locally stable epistemological frame that also afforded the retrieval of information from worksheets.

Third, epistemological frameworks that stand transmissionist views in stark opposition to constructivist views support overly simplistic characterizations of progressive instruction; teachers are exhorted "not to tell" (Chazen & Ball, 1999), so that students will figure things out for themselves. The framing perspective affords more nuance of interpretation and intervention. It can be perfectly appropriate for students to seek information from authority, and for teachers to provide it; the issue is how students frame what they are doing with that information.

The framing perspective provides guidance about fostering epistemological change

In this section we argue that the resources perspective provides guidance about how to foster epistemological change over both short and long time scales. These instructional implications stem from (i) a view of frames as composed of finer-grained epistemological resources, and (ii) the three mechanisms of frame stability discussed above.

According to our perspective, a teacher wishing to initiate the process of epistemological change might first try to unearth and activate productive sets of

epistemological resources that the students already have but currently fail to activate consistently in that teacher's classroom. Sometimes, a small epistemological "nudge" is enough to start the process. Here, that nudge was "start from what you know," a brief intervention that was, evidently, sufficient to prompt the students' reframing. For another example, in our experience as physics teachers, we have found that telling a student to "pretend you don't know any physics" when answering a given question can (temporarily) make the student stop framing knowledge as facts and formulas to be retrieved from authority and start framing knowledge as something that can be figured out and made sense of (Hammer & Elby, 2003).

In general, a frame induced in this way will not be stable. To facilitate contextual stability of a productive frame, a teacher can tweak aspects of the classroom environment: providing opportunities for students to figure out concepts and problem-solving approaches for themselves, rewarding sense-making even when it leads to an incorrect answer, and otherwise creating a classroom culture that bolsters the productive epistemological frames the teacher is trying to induce (Hammer & Elby, 2003).

The teacher can reinforce this contextual stability by trying to induce deliberate stability, helping students to monitor their views of knowledge and learning as part of an attempt to maintain a productive framing. For example, having students reflect upon their learning *during* the learning process, and not just at the end, can help them monitor their framing of the activity (Elby, 2001). At a deeper level, the teacher can involve students in the process of changing the classroom culture. For instance, in mathematics classes studied by Cobb and collaborators, the teacher and students jointly construct *sociomathematical norms*, expectations about what counts as good mathematical knowledge generation and argumentation

(Yackel & Cobb, 1996). These norms have a strong epistemological orientation toward sense-making. As students begin to monitor their own adherence to these norms, they are among other things monitoring their epistemological framing of their classroom activity, which can help to stabilize a productive frame.

In the longer run, a frame repeatedly stabilized by contextual and deliberate means can become structurally stable, a compiled cognitive structure that turns on as a unit. For example, many students studied by Yackel and Cobb (1996) eventually learned to engage in mathematical sense-making and argumentation without needing constant reminders from themselves or from others about the classroom norms. For those students, the epistemological frame(s) associated with the sociomathematical norms may have become structurally stable. Explicit reflection upon their framing can perhaps speed up the development of structural stability.

Structural stability, though, does not mean global applicability. It is possible that the same students who engage in deep sense-making in math class "revert" to rote learning in their traditionally taught classes. To develop a fully sophisticated epistemology, a student would need to have developed multiple structurally stable epistemological frames and the ability to consciously manipulate and choose between them.

Notice that, in the resources perspective, naive epistemological "beliefs" do not always need to be confronted and dismantled. Instead, the activation conditions of the frames corresponding to those stances could gradually evolve so that activation occurs —consciously, as described by Kuhn's (1991) Evaluativist stage, or unconsciously — only in appropriate contexts. For instance, when learning the State capitols, it *is* appropriate to view knowledge as stuff transmitted from authority and learning as accumulation of that stuff.

Are these resources and frames epistemological?

Given the above arguments, a critic could argue as follows:

> Sure, Ms. Phelan's intervention helped students reframe the activity, from recording information drawn from authority to constructing a causal story. But there's no evidence that students' *epistemologies* shaped their pre-intervention or post-intervention behavior. It's more likely that their pre-intervention behavior stemmed from expediency (the worksheets were readily available) and/or habit and expectations about what Ms. Phelan wanted. And it's likely that their post-intervention behavior stemmed from their revised expectations and/or from a classroom routine that Ms. Phelan had previously established. They were just following her directions, not activating an epistemology.

We agree that habits and expectations play a role here and that students are following Ms. Phelan's directions when they shift their approach. Our argument is that epistemology plays a role in their shift from one behavior to the other. Our evidence is that students are able to understand and respond appropriately to the epistemological component of Ms. Phelan's intervention. Part of her suggestion could be taken as referring purely to students' behavior: stop looking at your papers and instead do something else. But the "something else" she suggests is not a specific behavior or activity; she doesn't instruct students to tell a story or explain the rock cycle in everyday language. She just suggests, "start with what you know, not with what the paper says." For students to understand and act upon that suggestion in the way they do, not only starting with what they know but also *using* what they know to construct a

causal story, they have to understand knowledge as something they have in their heads and as something that can be built upon, not just as information on the worksheets.

This insight about knowledge is not deep; we expect almost any eighth grader to believe that they have knowledge in their heads and that in some cases they can build upon that knowledge. Nonetheless, this insight is epistemological in the sense that it is a view about knowledge. Furthermore, despite the seeming triviality of this epistemological insight, it was apparently dormant during the students' pre-intervention discussion of Teutonic plates and the like. A purely non-epistemological explanation of the students' behavioral shift is implausible. The students could not have understood which habits/routines Ms. Phelan's expected of them without understanding the epistemological insight that they have knowledge in their heads to be built upon.[3]

Conclusion

We argued that the resources perspective on personal epistemology is particularly productive for teachers to learn, for three reasons. First, epistemological frames correspond to what teachers can recognize, and novice teachers can learn to recognize, in students' approaches to learning. Second, the possibility that a given resource can participate in multiple frames invites close attention to context when evaluating whether a given student utterance or behavior reflects a productive stance toward knowledge, leading to more nuanced assessment of the student's approach to learning. Third, the resources perspective provides guidance about fostering epistemological change over both short and long time scales.

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[3] We note, too, that the students do not "blindly" follow Ms. Phelan's instructions; they continue to use the worksheets, as documented above. This counts as further evidence against the claim that students were simply following Ms. Phelan's directions.

Although the general warrant for "knowledge in pieces" frameworks stems from cognitive theory and clinical experimentation (diSessa, 1993; Karmiloff-Smith, 1992), many of the emerging details of the resources perspective *as applied to personal epistemologies* come from mining the knowledge and actions of teachers (Hammer & Elby, 2003). This theory-building design principle stems from our conviction that, when it comes to understanding students' approaches to knowledge and learning, the (tacit) practitioner knowledge underlying productive instructional moves such as Ms. Phelan's rock cycle intervention is often "ahead" of researcher's theories. Just as teachers learning about resources and framing can unearth, build upon and refine their practitioner knowledge, we as theorists unearth, build upon and refine teachers' practitioner knowledge in generating our theoretical perspective.

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