On the Form of a Personal Epistemology

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Introduction

Research on "epistemological beliefs" has made important contributions to education, most fundamentally in identifying epistemology as a category of informal knowledge that may play a role in students' knowledge, reasoning, study strategies, and participation. A perspective on students as having epistemological beliefs can provide an alternative interpretive lens for teachers to use in understanding their students' ideas and behavior, in assessing students' abilities and needs, and in adapting their plans and strategies for instruction.

This value of the perspective in opening a new category of instructional perception and intention has not been sensitive to the details of the perspective. At this point, however, further progress will depend on those details. In this chapter, we contend that current perspectives on epistemologies are problematic in their form, or "ontology." We will focus our arguments primarily on epistemological beliefs about science and science learning, specifically in introductory physics, but our contentions apply to beliefs in other disciplines as well.

The study of epistemologies has largely emulated the study of "conceptual understanding," which has established that students have informal knowledge, about physical phenomena for example, that strongly affects what they learn. It is not clear, however, with respect either to epistemological beliefs or to conceptual understanding, how best to model what takes place in an individual's mind. What is the internal form of an informal epistemology? In other words, tolerating a cumbersome alliteration, what *ontology* should we ascribe to epistemology?

For the most part, researchers have presumed an ontology of "beliefs" as essentially unitary components of essentially stable epistemologies. By “unitary,” we mean that each belief corresponds to a unit of cognitive structure, which an individual either does or does not possess. Construed in this way, epistemological beliefs are analogous to the "concepts" or "conceptions" posited as elements of cognitive structure. Just as cognitive science has understood naïve physics to be made up largely of "misconceptions" (e.g. "motion requires force") that differ from expert conceptions ("acceleration is caused by force"), research on epistemologies has understood students to have "misbeliefs" (e.g. "scientific knowledge is certain") that differ from expert beliefs (e.g. "scientific knowledge is tentative"). It follows that, just as developing an understanding of Newtonian physics requires "conceptual change," developing a more sophisticated epistemology requires changing beliefs. In neither case could the naïve constructs – the misconceptions or misbeliefs – be understood to contribute to that development, because they are inherently inconsistent with expert thought.

Therein lies a fundamental theoretical difficulty, as Smith, diSessa, & Roschelle (1993/1994) have argued with respect to the misconceptions perspective: Although couched as "constructivist," it offers no account of productive resources for the construction of more sophisticated understanding. If conceptions are unitary elements of cognitive structure, then student conceptions must be replaced by expert conceptions. To suppose that they could evolve in some way is to suppose, at least, that they have some underlying structure, that they contain productive elements at a finer grain-size; but the misconceptions perspective has not described what that underlying structure might be. Similarly, in considering naïve epistemologies to be made up of constructs such as "knowledge is certain," current perspectives on epistemology offer no account of what may be the raw material from which students could develop new structures, such as that "knowledge is contingent on context and perspective."

There is an empirical difficulty as well. To model students' understanding of physical phenomena in terms of misconceptions is to imply a consistency in their reasoning that is contradicted by evidence from interview protocols (Viennot, 1985; diSessa, 1993; Smith, diSessa, & Roschelle, 1993/1994). Similarly, to presume students' epistemologies exist in the form of beliefs as stable structures is to presume a consistency across contexts: If a belief such as "knowledge is certain" exists as a unitary component of a stable epistemology, an alternative component to an expert's "knowledge is tentative," then this difference between the student and the expert should be consistently evident.

This ontology, which we will refer to as "unitarity," has not to our knowledge been explicitly defended in the literature on epistemologies. It is a default presumption, not the result of a deliberate process of investigation, and we contend it is inadequate. We will argue in the following section that researchers are presuming unitarity, more specifically the consistency it implies, in studying students' beliefs through questionnaire and clinical interviews that are far removed from the contexts of learning in which the beliefs are supposed to apply. This assumption of consistency across such diverse contexts is neither evident nor, when made explicit, plausible. We will then sketch a framework of epistemological resources at a finer grain-size than unitary beliefs, analogous to diSessa's (1993) account of phenomenological primitives at a finer grain-size than unitary (mis)conceptions.

By "unitarity" here, it is important to specify, we are not refering to the idea that epistemological thinking develops in unidimensional stages, advanced by Perry (1970), King and Kitchener (1994), and others. Schommer (1990), Hofer and Pintrich (1997) and others have challenged this assumption, arguing that epistemologies are better modeled along multiple dimensions. We concur. However, as we now elaborate, even authors who reject stage theories of epistemological development continue to assume unitarity in the sense we are using the term, the idea that personal epistemologies take the form of theories or traits.

Theories and Traits

There are two (sometimes undifferentiated) versions of the presumption of unitarity in the literature. The first, most common and most closely aligned with the usual connotation of "beliefs," is that individuals hold epistemological beliefs in the form of declarative knowledge to which they can have conscious, articulate access. Thus Hofer and Pintrich (1997b, p. 117) suggest these beliefs be seen as "epistemological theories," following research on conceptual understanding. If students are not ordinarily aware of their theories, they may become aware of them and report on their substance through well designed questionnaires and interviews.

Most studies of epistemologies proceed in this way, by asking subjects direct questions about their beliefs, often by presenting epistemological statements and asking subjects to rate their agreement or disagreement on a Likert scale. Students are asked, for example, whether they agree or disagree that "the best thing about science courses is that most problems have only one right answer" (Schommer 1990); whether “the science principles in the textbooks will always be true (Songer and Linn 1991); whether “knowledge in physics consists of many pieces of information, each of which applies primarily to a specific situation” (Redish *et al.*, 1998).

It is only by a presumption of unitarity that the results of these studies may be seen as applying to contexts of learning. Students do not typically reflect directly and explicitly on the nature of knowledge and learning in their science classes, where their attention is almost always focused on concepts and phenomena. Questioning students in these ways about their epistemologies may be, to borrow an old joke, like interviewing golfers about their swings, off the course and away from their clubs: "Do you inhale or exhale when you swing the club?" It is not something they think about, ordinarily, and they may not know the answer. There would probably be a correlation between what golfers say and what they are observed to do when they play, but the former would probably not reliably indicate the latter.

That is, it is at least plausible that students' epistemologies might not be accessible to conscious reflection and articulate reporting, and their epistemologies as revealed on surveys and questionnaires may not be reliably indicative of their epistemologies in contexts of learning. To expect that students' responses to direct questions accurately represent their epistemologies in the classroom is to presume a consistency across these very different contexts.

The second version of the presumption of unitarity is that individuals have epistemological beliefs as constitutional attributes, akin to "learning styles" or "personality traits." Seen in this way, students may not be aware of or able to discuss their epistemologies explicitly, but they could have access to other aspects of their preferences and habits from which one may infer these aspects of their personalities. Thus some studies of epistemologies pose subjects questions about their much more general tastes and attitudes, deliberately shifting to contexts that may be more accessible to reflection than those of learning science, such as whether they "like movies that don't have endings," or whether they agree or disagree that "people who challenge authority are overconfident" (Schommer 1990).

Again, to treat students' responses to these questions as reliably indicative of their beliefs about knowledge and learning is to presume a consistency across contexts. In this case, it is a consistency not only with respect to the context of the interview, but also with respect to the target of reflection. This is analogous to asking golfers about their techniques in other activities and using their responses to infer how they play golf. In some cases, no doubt, that would be a reasonable assumption: Someone who is right-handed on the guitar would be very likely to be right-handed with a golf club; there is a strong basis for attributing handedness as a trait.[1]

However, while most people can be characterized consistently as right or left handed across a wide range of contexts, there is not a basis for a similar claim regarding their epistemologies. There is no reason to expect that what an individual believes about knowledge in the realm interpersonal relations, for example, about knowing and learning how to get along with others, must be consistent with what she believes about knowing and learning in an introductory physics course.

Reasons to Doubt Unitary Consistency

In fact, there are good reasons to expect that beliefs about knowledge and learning vary with both domain and context. Most people would agree that what makes someone a good dancer need not make him a good scientist, that the nature of expertise in the one is quite different from the nature of expertise in the other. That this bit of epistemology seems a matter of "common sense" is reason in itself to doubt that epistemologies are consistent across domains. There is formal evidence as well, such as Stodolsky, Salk, & Glaessner's (1991) study, which showed differences between middle-school students' beliefs about learning in math and in social studies, and Hofer and Pintrich's (1997a) study, which showed differences between students' epistemological beliefs about psychology and science.

There must also be at least some variation with context, even holding the putative topic fixed. It would be strange to suppose that the beliefs a subject would express about the certainty of knowledge would not depend, for example, on whether the context is that of a philosophical discussion, a scientific debate, or an everyday exchange of information. The same person who adopts a critical stance toward claims made in the academic context of a psychology course may be inclined to accept without question the advice of a therapist. Such variation with context belies either theory-like or trait-like unitarity for a belief such as "knowledge is certain."

Again, there are indications from research that epistemologies may be sensitive to context. In their review, Hofer and Pintrich (1997b) point to a variety of inconsistencies within and between various measures of epistemologies, citing Moore (1991), for example, who found low correlations between scores from different epistemological assessments of subjects' beliefs along Perry's (1970) scheme, and noting that few subjects showed consistent epistemological reasoning across the different questions in Kuhn's (1991) study. Leach, Millar, Ryder, and Séré (1999) gave evidence of the sensitivity to context of high school and university students'

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[1] Even in that case, however, it is clear that for individuals who are ambidextrous it is necessary to think of handedness as context-dependent. Moreover, even people who are clearly "right-handed" are likely to have specific tasks they perform best with their left hands. To account for these phenomena, an adequate theory of handedness must address context dependence, and a simple ontology of traits will not suffice.

epistemological reasoning, arguing that it would not be well understood as reflecting a consistent framework of beliefs.

We are not suggesting there can be no consistency in students' reasoning or epistemologies. Clearly there can be, as a number of studies have shown (King and Kitchener, 1994; Schommer, 1990). One of us has presented evidence to show that students in an introductory physics course could be characterized as having consistent epistemological beliefs *within the context of the course* (Hammer, 1994). The data for those characterizations came from series of interviews of six students. These interviews, following Perry (1970), had an open format and a conversational tone, in an effort to keep the context of the interviews close to the context of the course.

To claim, however, that an epistemology is consistent within a given context, in this case that of a traditional introductory physics course, is not to claim that the consistency derives from a unitary ontology. We contend that it need not.[2] For instance, it would be a mistake to attribute someone's raucous behavior as a spectator at football games to an inherent "raucousness," even if their behavior is consistent in that context; in other contexts the same person's conduct may be reliably proper. Similarly, a student's epistemology as revealed by their filling out a survey or in a "Reflective Judgment Interview" (King and Kitchener, 1994), even if it is consistent in that context, may not coincide with that student's tacit epistemology in the context of a science class.[3]

Of course, classroom contexts may also vary. For us, the most compelling reasons to doubt unitarity come from our informal experience as teachers. It is possible to change, very quickly, how students participate in our physics classes. Students who arrive on the first day expecting a blackboard lecture replete with equations, who would appear to hold beliefs that scientific knowledge is formal, absolute, and received from authority, may by the end of the period be participating in heated debate, behaving as if they believe their own ideas and experiences matter. This does not reflect a sudden, global change in their epistemological beliefs; it reflects a local change in the context of the classroom, which engenders in students a more productive epistemological mode.

That this mode is available to students, even temporarily, implies that they have the epistemological resources needed to enter that mode. An adequate theory of epistemologies must account for those productive resources and for the contextual dependence of their activation.

An Alternative Framework

Krieger (1992) described the development of theory in science as analogous to the design and production of machines: A scientific model is like a machine scientists assemble, from the various "parts" they have available, to produce the same phenomena they observe in the physical world. On this analogy, theoretical advances often come from new choices of parts, or from the creation of new kinds of parts, just as technological advances often come from selection or development of new materials. Several hundred years ago, for example, physicists were trying to assemble a model of light out of conceptual parts they had available from their observation of balls and other bits of solid matter, namely small hard, solid particles. Much effort went into contriving different ways to assemble these parts into a model that would produce phenomena such as diffraction and interference. In the end, however, progress resulted from the use of different conceptual parts, namely "waves."

To frame our criticism in Krieger's language, we are questioning the use of "theories" and "traits" (or "styles") as the parts from which to assemble models of students' epistemologies.

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[2] Indeed, a standard topic in psychology texts (e.g. Wortman, Loftus, and Marshall, 1988) is the "fundamental attribution error," the tendency to attribute a person’s behavior to a general trait when contextual factors play a role.
[3] King and Kitchener, in fact, advise caution in applying the Reflective Judgment Interview on an individual basis (1994, p. 115).

Certainly there have been advantages to their use. Notions of theories and traits fall within everyday lexicon, and that familiarity facilitates discussion. This is especially important in the case of students' epistemologies, where for many audiences the idea that students might have epistemological orientations in any form may be unfamiliar. "Theories" and "traits" are effective means of introducing epistemological considerations, just as "alternative conceptions" are effective means of introducing consideration of students' intuitive content knowledge.

With respect to advancing beyond these first models, however, they are limiting progress, making what Minsky (1985) called the "single-agent fallacy" in presuming epistemologies are comprised of unitary beliefs. Dennett (1991) has similarly described it as a fallacy to attribute the experience of consciousness to an ontological unitary, a mistake similar in kind to that of understanding complex behavior such as bird flocking as having a single, central, organizing source (see, e.g., Wilensky and Resnick, 1999). Our purpose in this section is to propose an alternative, manifold ontology, in the general class of models that has developed from Minsky's notion of multiple "agents" acting in a "complex society of processes" (Minsky, 1985).

diSessa (1993) has proposed such an ontology in his account of "phenomenological primitives," or "p-prims," the parts he proposed to assemble into a model of intuitive physics. To see how p-prims differ from “theories” or “alternative conceptions,” consider a specific well-studied student difficulty. When asked about the forces involved in pushing a desk across the floor, many students say that there must be an overall forward force, i.e., the forward force must “beat” any backward ones, and as soon as the forward force turns off, the desk stops moving. Generally, this is explained by attributing to students the stable, context-independent *misconception* that motion requires force.[4] In other contexts, such as when asked about a ball being thrown, students correctly answer that the ball continues to move in the absence of the forward force of the hand. On the misconceptions perspective, students must then be thinking of an internally stored force as responsible for the continued motion of the ball.

Rather than describing students' knowledge in terms of conceptions inherently inconsistent with experts', diSessa posited elements that, appropriately organized, contribute to expert understanding. By his account, attributing to students the unitary conception that *Motion requires force* confuses emergent knowledge, an act of conceiving in a particular situation, for a stable cognitive structure. On this view, students’ reasoning about the desk and the ball can be understood in terms of the context-specific activation of the following p-prims. *Maintaining agency*[5] is an element of cognitive structure useful for understanding any continuing effect maintained by a continuing cause, such as a light bulb needing a continuous supply of energy to stay lit. *Actuating agency* is another p-prim, an element of cognitive structure involved in understanding an effect initiated by a cause, when the effect outlasts the cause, such as the strike of a hammer causing a bell to ring. The desk question tends to activate *Maintaining agency,* and hence, the idea that a continued net forward force is needed to keep the desk moving forward. By contrast, the ball question tends to activate *Actuating agency*, and the idea that the ball's motion can outlast the force exerted by the thrower.[6] Unlike the misconception *Motion requires force,* the p-prims *Maintaining agency* and *Actuating agency* are not "incorrect." Neither are they correct; they are resources that can be activated under various circumstances, sometimes appropriately, sometimes not. Furthermore, whereas the misconception is an element of cognitive structure specifically tied to motion and force, the p-prims also apply to light bulbs, bells, and numerous other situations. In this sense, p-prims are both smaller and more general than unitary conceptions.

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[4] On a Newtonian account, a force is required to *initiate* or *change* an object’s motion, but not to *maintain* motion.
[5] diSessa (1993) called this p-prim *Continuing push*, but the word *push* in that name may be misleading, as the agency need not take the form of a force. We will also use the name *Actuating agency* instead of diSessa's *Force as mover*.
[6] In many contexts, the ball question may also activate *Maintaining agency*, which students attribute to an "internal force" that was impressed into the ball by the hand.

The ontology of p-prims has several advantages over the ontology of conceptions. First, it provides theoretical structure to account for the sensitivity to context of students' reasoning, as different p-prims are more and less likely to be activated in different circumstances. Second, it provides an account of productive cognitive resources from which students may construct more adequate understanding. Development toward expert understanding involves modifying which p-prims get activated in which situations, rather than replacing p-prims with other structures.

We seek, similarly, a framework of epistemological resources, smaller and more general than theories or traits, that can accommodate contextual dependence and provide an account of productive resources. For example, many students appear to view scientific knowledge as coming from authority. At the same time, it is clear even small children have epistemological resources for understanding knowledge as invented ("How do you know your doll's name is Ann?" "I made it up!") or knowledge as inferred ("How do you know I have a present for you?" "Because I saw you hide something under your coat!").

Following Minsky (1985) and diSessa (1993), we are looking for epistemological resources that are naturally invoked in familiar circumstances, and for which we can describe plausible developmental origins. For now, we have focused on identifying resources that may reasonably be attributed to young children, and that have an everyday face-validity. In other words, when described appropriately, they should be recognizable as part of common sense. We do not consider this set of resources to be established; it is certainly not complete. These are tentative ideas as we begin a new program of research. We cannot emphasize enough that the knowledge elements presented here are intended to demonstate the *kind* of epistemological resources we view as alternative to unitary beliefs. Future research will undoubtedly reveal that many of the *particular* elements we list are not part of an adequate theory of naïve epistemology.

As we currently conceive it, the framework has four categories of epistemological resources. The first is of resources for understanding the general nature of knowledge and how it originates, beginning from a notion of "knowledge as stuff" (Lakoff and Johnson, 1980). The second and third categories are of resources for understanding epistemological activities and forms, such as *Brainstorming* and *Lists* respectively,[7] these following the notions of "epistemic games" and "epistemic forms" as developed by Collins and Ferguson (1993). The fourth category is of resources for understanding stances one may take toward knowledge, such as *Doubting* or *Accepting*.

We consider these categories to be useful in describing these resources, and useful at this stage of theory building, but we do not consider them to have ontological significance. The activation of a resource does not preclude the activation of other resources within that same category or, certainly, in other categories. In fact, as will be clear, there are close links between resources in different categories. It may well be that, in some cases, these close links would be better understood as single resources that lie across the categories we have drawn.

Resources for Understanding the Nature and Sources of Knowledge

In different contexts, children as young as three years old can be heard to speak of knowledge in several different ways, reflecting different resources for understanding what sort of thing knowledge is and how it arises. The following are examples of resources in this category.

Knowledge as propagated stuff: The first of these is to treat knowledge as a kind of stuff that can be passed from one person to the next. Knowledge understood in this way has a source and a recipient, although it is not "conserved," because the source does not lose any knowledge in the process. Knowledge is not, in this sense, like money or material; it is more like fire, or the flu, or a state of dirtiness or contamination (as in, for example, the child's notion of "cooties"). Small children can understand the question "How do you know we're having soup for dinner" and respond "Because Mommy told me."

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[7] We will use italics and capitalization in this way to denote epistemological resource. Thus *Lists* refers to a resource for understanding lists as an epistemological form.

Knowledge as free creation: Children also have other resources for understanding how knowledge may arise. Invention is a routine experience for children, and "I made it up" a routine explanation for the origin of many of their ideas, including stories, imaginary characters, and games. Knowledge by this resource, like the pictures a child draws on a blank page, does not have any source other than the child's own mind, where it arose spontaneously. Again, we are not claiming that this is correct – we would expect that children's creations arise from other knowledge they have. We are claiming only that this is an element of the children's epistemologies, a resource they invoke to understand how some of their ideas come to be.

Knowledge as fabricated stuff: Children may also think of knowledge as inferred or developed from other knowledge. This resource may be a metaphor for knowledge as a more familiar sort of stuff, something one creates, but out of other material. Thus it is not a free creation; it is constrained by the nature of the material. Thus the answer to the question "How do you know?" is "I figured it out from [the source material]." For example, asked "How do you know that 3 x 5 = 15?" a child may answer "Because I added 5 + 5 + 5," rather than "I made it up" or "my teacher told me." In this way, asking a child "how do you know this?" is analogous to asking "how did you make this?" about a physical object. To understand knowledge in this way, moreover, is to think that others can create the knowledge for themselves, as long as they have access to the same raw material. (By contrast, knowledge generated by *Free creation*, must be divulged by the creator.)

Other resources in this category would include *Knowledge as direct perception*, ("How do you know I'm in the room?" "I see you!"); and *Knowledge as inherent* ("How do you know this color is red?" "I just do!").

To be clear, we are not describing a progression of stages of increasing sophistication. We are describing a set of resources that are available from an early age for use, as needed, in various contexts. Moreover, these resources may be invoked in combination with each other. For example, an adult would be likely to invoke *Propagated stuff* to understand the spread of a rumor, in conjunction with *Fabricated stuff* to understand its evolution along the way. Or, a child who invokes *Free creation* to understand her authorship of a story would invoke *Propagated stuff* to understand how others come to know that story.

Resources for Understanding Epistemological Activities

Our principle strategy in the preceding category was to consider what resources may underlie children's various responses to the question "How do you know ____?" Here, our principle strategy is to consider what resources may underlie their responses to the question "What are you doing?", to identify resources that allow children to understand and engage in familiar activities, such as telling and listening to stories, playing and inventing games, asking questions and guessing at answers, all of which involve the creation, manipulation, or application of knowledge.

As before, it is important to remember that what we are describing are not *activities* but *resources for understanding* activities. Thus one may disagree over whether knowledge is ever simply "accumulated" but nevertheless agree that *Accumulation* is a resource people invoke in some contexts to understand what they are doing.

Accumulation: When asked "Is Mommy in the yard?" and not knowing the answer, a child could easily respond "I'll go find out." This reflects an understanding of "finding out" as a simple activity, the retrieval of information. *Accumulation* probably develops very early from experience with ordinary objects, with "get the toy" the basis for "get the piece of information." It is reflected in everyday language, when we speak of "gathering" or "retrieving" information, and it may be invoked by children or adults to understand learning in many contexts.

Formation: Children also understand activities in which they construct ideas for themselves, whether in writing stories, composing songs, devising rules or inventing games. There may be a resource of *Formation* they invoke in all of these contexts; but perhaps this is better described as a collection of more specific primitives, for example with *Forming-rules* a distinct primitive from *Forming-stories*, or *Guessing* and *Brainstorming* distinct from *Crafting* and *Adjusting*. In any case, it is clear that children have resources to understand the differences between *Accumulation* and what they are doing with knowledge in these more creative contexts. Again, *Formation* may develop, in conjunction with *Fabricated stuff*, from experience of making things out of everyday material.[8]

Checking: A child would also understand, for example, a request to "Check to make sure you put your book away," reflecting an understanding of "making sure" as an epistemological activity. *Checking* may evolve in response to early experiences of error, in conjunction with *Doubting* as a stance (see below). In various contexts *Checking* may be invoked in conjunction with *Accumulation*, such as when the child goes to re-retrieve information regarding the location of the book, or in conjunction with *Formation*, such as when checking the conclusion that 3 x 5 = 15 by counting.

There must also be a resource, or set of resources, of *Application*, invoked in situations that involve using a piece of existing knowledge, such as in singing a song, telling information, or in following or enforcing a rule; other resources for understanding epistemological activity may include *Comparing*, *Sorting*, *Naming*, *Counting*, *Adding*, and so on. See Collins and Ferguson (1993) for a more detailed list.

Again, this is not a hierarchical list of greater and lesser sophistication. These resources are all available from an early age. Therefore, “development” would primarily consist of changes in their activation. In this way, a framework of this sort allows modeling of epistemological development as more "unique" to a context than "universal" (Feldman, 1994). For example, what the literature describes as the counter-productive epistemological belief that knowledge is received may be understood instead, roughly, as an overuse in the given context of some resources (*Accumulation*, *Propagated stuff*) and an underuse of others (*Formation, Checking*, *Fabricated stuff*). An epistemological intervention, then, could be conceived as modifying the activation of epistemological resources in that context, rather than as disestablishing an epistemological theory.

Resources for Understanding Epistemological Forms

Resources for understanding epistemological activities are not sufficient, inasmuch as these activities invariably involve epistemological forms. Thus the activity of writing a story requires resources for understanding the activity of writing, some version of *Formation* in conjunction with *Free Creation* or *Fabricated stuff*, as well as a resource for understanding the form of a story, which we will call, simply, *Stories*. The latter resource may of course also be invoked to understand the activity of listening to a story, in conjunction with *Application* and *Propagated stuff*,

In addition to *Stories*, we can also identify *Rules* as an epistemological resource available to young children, which they may invoke in activities of formation (inventing a new rule to a game) or of application (enforcing an existing rule). Both of these resources, *Stories* and *Rules* seem to be primitive notions in the sense that, within informal epistemology, they cannot and do not need to be defined in any more basic terms.

Rule system is a resource for understanding a coherent set of rules that define a game, such as checkers or tic-tac-toe. *Facts* is a resource for understanding a piece of information, such as a phone number or an address. Other resources in this category would include *Songs*, *Lists*, *Pictures*, *Categories, Statements*, *Words*, *Names*, and *Numbers*; again, Collins and Ferguson (1993) provide a more detailed list.

In this respect as well, an account of resources allows a reinterpretation of evidence from existing studies. Rather than attribute results of surveys and interviews to, for example, the presence of one unitary belief ("knowledge is simple") and the absence of another ("knowledge

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[8] Here, then, is an example of a pair of closely-linked resources, *Formation* and *Fabricated stuff*, that may be better understood as two views of the same resource.

is complex"), we can view the results as evidence of the *activation*, in the context of that survey, of some resources (*Facts*, *Rules*, *Names*) and deactivation of others (*Categories*, *Rule systems*).

Resources for Understanding Epistemological Stances

We describe only briefly this fourth category of our draft framework of epistemological resources, those for understanding the stances one may take toward an epistemological form. Hearing something that does not seem reasonable, a child can say "I don't believe that," reflecting an understanding of *Belief* and *Disbelief* as alternative stances one can adopt toward a piece of information. *Doubting* seems another resource that is likely part of a school-age child's repertoire, to understand a stance one adopts toward a piece of information one has neither accepted nor rejected. There should also be resources for understanding experiences of an idea seeming right or making sense, *Understanding*, and experiences of an idea not making sense, *Puzzlement*. *Understanding* would generally trigger *Acceptance*, although perhaps not always: Someone may understand the experience of an idea seeming right but knowing it to be false. Educational problems may arise when, in the context of a course, *Acceptance* triggers *Understanding*, in other words when students understand the experience of believing an idea is correct as implying that they understand the idea.

Implications for Instruction and Research

The above list of epistemological resources illustrates the shift in ontology we are proposing from unitary beliefs, attributed to students as traits or theories, to manifold resources, seen as activated within particular contexts. To reiterate, we are not arguing here for this particular list of resources; we are arguing for the shift in ontology they illustrate. However, this shift in itself has implications for instruction and for research.

Instructional Diagnoses and Strategies

These ontological considerations affect how we, as physics teachers, diagnose our students' strengths and needs. For instance, to understand their epistemologies as *traits* is to understand them, in some sense, as parts of who they are as people. In this case, we should try to accommodate different epistemologies, just as many teachers try to accommodate different learning styles. Expecting that epistemologies are general characteristics of students' personalities, we should have only modest hopes of inducing change. By contrast, if we understand students to have epistemological *theories*, then our approach to instruction should include some effort to disestablish theories that disagree with what we hope them to believe. Following the literature on conceptual change, we would likely pursue this by drawing out students' theories, trying to challenge or refute them, and finally offering better theories in their place.

An ontology of manifold resources affords a different perspective on students' epistemologies and a different approach to fostering epistemological change. If we understand students' epistemologies as specific to a context, we may expect that they have other resources tied to other contexts. Rather than think in terms of accommodating their traits or refuting their theories, we may think in terms of finding and animating the more productive epistemological resources the students invoke in other situations.

On this view, much may be achieved by manipulating the context of learning. If in class debates among students are more typical than lectures by the teacher, the class may become a context in which students naturally consider it important to explore a variety of perspectives. Therein may lie much of the benefit of innovative pedagogical approaches: They change the context in such a way as to invoke more productive epistemological resources. Another manipulation of context is to engage students in more activities of design and construction, such as building gadgets or writing computer programs that will accomplish some task. Contexts of design and construction are more likely than traditional classroom contexts to activate epistemological resources productive for learning (Harel and Papert, 1991).

Clement, Brown, and Zeitsman (1989) described one strategy instructors have for helping students draw on productive conceptual resources, that of "bridging analogies" to productive "anchoring conceptions" in more familiar situations. For example, students often have difficulty understanding how a "passive" object, such as a table, can exert an upward force on a book. Students do not, however, have trouble understanding how a hand, or a compressed spring, can exert a force. By helping students to think of the table as a very stiff spring, instructors can help them understand it as exerting an upward force (Minstrell, 1982).

Instructors may employ similar strategies to help students activate productive epistemological resources. In these cases, the analogies form a bridge from target, less familiar activities of learning to what we may call "epistemological anchors," familiar activities in which the productive resources are likely to be invoked.

One common example is the analogy many instructors draw between learning and physical exercise, comparing the mental benefits of thinking to the physical benefits of exercising. This bridge between exercise and learning helps students to think of knowledge and ability as developed through effort.

Another example is the following story we have used to promote metacognitive reflection in our physics students, a bridging analogy to what we expect are familiar experiences in context of interpersonal relationships:

> "Imagine you have met a new person and he irritates you for some reason you can't put your finger on. So you think about it, trying to figure out what it is about him that bugs you, and eventually you realize that it's because he looks and sounds a bit like a character in a movie you saw recently. Having figured that out, you know that it's not really this new guy who irritates you, but that movie character, and you don't have to worry about it any more. In another instance, you may realize that you've met him before and had an unpleasant interaction, in which case there's good reason for that feeling of irritation."

This may serve as an epistemological anchor to help students understand the phenomenon of having an intuitive sense that a physical object will behave in a certain way, but not being able to explain why. For example, although Newton's First Law says that an object moves at a constant velocity if there are no forces acting on it, most students have the intuitive sense that the motion will die away. The movie character analogy may help students understand the importance of looking into the experiential bases for that intuitive sense, to articulate them and assess how they might reconcile those experiences with Newton's laws.

We are certainly not suggesting that these are new ideas for instruction. In our experience, effective teachers already know, if tacitly, that students have productive epistemological resources (as well as productive conceptual resources, emotional resources, physical resources), and that much of effective teaching is helping students find these resources and use them. However, this knowledge is not reflected in the *status quo* of formal research about epistemological beliefs.

Implications for Research

A shift in ontology from unitary theories or traits to finer-grained resources also has implications for research. We are proposing, first, a new emphasis in the study of personal epistemologies, the identification of naïve epistemological resources and the contexts in which they are invoked.

Like research on conceptions, research on epistemologies has focused almost exclusively on identifying the ways in which students' views differ from those educators wish them to develop. To understand epistemologies as made up of resources is to understand the need to develop an account of what those resources are. This is a more fundamentally constructivist agenda in that it aims to provide an account of resources from which students may construct more adequate epistemologies.

This is rich, relatively unexplored terrain. There are several ways to explore it; what we sketched above is at best a beginning. To date, we have worked primarily by reflecting on what we know children to be capable of understanding, based on everyday experience, supplemented by some informal interviews of a first-grade student. That a young child is capable of answering "how do you know that?" with a variety of different responses suggests the existence of a variety of different epistemological resources.

Of course, more can be achieved through careful interviews. For instance, by carefully designing the tasks children are presented, Samarapungavan (1992; Samarapungavan and Westby, 1999) has provided convincing evidence that first graders are richly equipped with epistemological resources for scientific thought: When told that a certain theory about tigers is true, and then presented with evidence that seems to a support a rival theory, most first graders concluded that *another person* looking at that same evidence would believe the false theory. That children and lay adults do not activate these resources in many contexts (Kuhn, 1989) may be understood in this way, rather than as a general developmental limitation.

Insights can also arise, we contend, through reflection on everyday adult activities. That an ordinary adult, for example, would be capable of understanding the notion that they may be irritated by someone they just met because that person reminds them of a movie character reflects epistemological resources for thinking about the existence and influence of inarticulate knowledge. No doubt there are many other examples of everyday competencies that suggest the existence of epistemological resources. It should also be possible to design tasks for formal protocols to reveal adult epistemological competence.

We have already alluded to methodological concerns regarding the use of large-scale questionnaire studies. Epistemology researchers should make greater use of naturalistic case studies, including open-format interviews (Perry, 1970; Belenky *et al*, 1986) as well as classroom observations (Hogan, 1999). If the activation of epistemological resources depends on context, then to determine a student's epistemological stance in introductory physics, for instance, a study must be conducted in a manner that remains as close as possible to the contexts of learning introductory physics (Hammer, 1994).

The particular value of case studies, as opposed to paper-and-pencil surveys, is that they provide a depth of information about a small number of subjects, instead of a thin thread of information about a large number. Depth rather than breadth of information is particularly important when identifying which cognitive structures should be attributed to individual minds. By analogy, a biologist studying *e coli*, who wanted to claim there are within *e coli* certain structures, would be obligated to identify the structures within individuals. To insist that studies involve a large number of subjects may hinder an understanding of the nature of those structures.

Songer's and Linn's (1991, 1993) work has been effective in bringing wide attention to secondary-school students' beliefs about the nature of scientific knowledge. However, their analysis illustrates how a commitment to unitary ontology can occlude alternative interpretation. In their framework, a “static” stance holds that scientific knowledge is certain and unchanging, mostly facts to be memorized. A “dynamic” stance holds that scientific knowledge stems from evidence, changes and expands, and relates to daily life. However, in response to seven survey questions, most students (63%) held “some static ideas, some dynamic ideas, and some ideas that were difficult to categorize” (Linn and Songer, 1993). In their 1991 article (Songer and Linn, 1991), the authors characterized these students as having *mixed beliefs*.

In a manifold ontology, the seemingly inconsistent and hard-to-categorize responses could indicate that different questions cued different epistemological resources. Researchers could explore these context-dependent patterns of activation using deeply-contextualized interviews. By contrast, Linn and Songer (1993) conducted short interviews (15 minutes), simply asking students to explain their answers to the survey items. Based on students' brief responses, such as the idea that scientists can reach different conclusions about experimental results because “because everybody has a different opinion” or because “they can find something in the experiment, and then a week later they can find something else,” Linn and Songer conclude that students with mixed beliefs are relativists, in some cases radical relativists: “Some students who abandoned a static view of scientific knowledge turned instead to a view that might be classified as radical relativism. These students had no criteria for comparing explanations and no ability to distinguish established and controversial ideas." We contend this is a non-constructivist interpretation, that students simply abandoned one set of ideas (static) for another (relativist). Furthermore, we doubt the students had "no ability to distinguish established and controversial ideas." Interview questions set in the context of discussing whether the heart pumps blood, or whether the Earth is round, would undoubtedly activate epistemological resources corresponding to static beliefs. Our point is that a unitary ontology pushes researchers to cubby-hole students into categories such as "relativist" or "radical relativist," rather than exploring the possibility that students' "beliefs" *really are* mixed, due to the activation of different epistemological resources by different questions.

We do not suggest researchers should abandon surveys, however, nor do we suggest that any case study approach is sufficient. King and Kitchener (1994) designed their Reflective Judgement Interviews to address context by focusing on rich issues, such as the conflict between creationism and evolution. We contend, however, that a unitary ontology distorts their analyses. In particular, their scoring scheme focuses on the abstract form rather than the context-dependent meaning of their subjects' responses, and this context-stripping leads to potentially misleading conclusions.

For instance, reflective judgment stage 2 corresponds to an absolutist stance; knowledge is certain but not immediately available, and it generally comes from direct experience or from authority. The authors cite the following as a *definitive* stage 2:

> Interviewer: How do you decide?
> Subject: I decide what goes with my views.
> Interviewer: Where do your views come from?
> Subject: My teachers and how I've been brought up. As you grow up, you automatically get certain views.

The subject may be more sophisticated than she appears. Her beliefs,[9] expressed in more academic language, could be

> When deciding what to believe about the origin of humanity, I take into account what fits with my religious beliefs. Those beliefs undoubtedly come from the way I was brought up, from my parents and teachers. When children are exposed to certain articles of faith over a long period, those beliefs get incorporated into the child's views.

If this rewording reflects the subject's views, then she holds some relativist ideas about the origin of religious beliefs, but it is a sophisticated relativism supported by developmental psychology. That is, we contend, this excerpt does not provide sufficient contextual information to characterize the subject's epistemology definitively.

These examples illustrate a further difficulty in the study of epistemologies. Within the literature on epistemologies in science education, there is the further, explicit consensus about what constitutes epistemological sophistication: beliefs that knowledge is tentative rather than certain, constructed rather than discovered, subjective rather than objective. We challenge this consensus elsewhere (Elby and Hammer, submitted), largely on the grounds that in considering "knowledge is tentative" to be a desirable epistemological stance, researchers are neglecting context. It is hardly sophisticated, for example, to consider it "tentative" that the earth is round, that the heart pumps blood, or that living organisms evolve. A manifold ontology affords a view of epistemological sophistication as sensitive to the nuances of context.

Summary

Studies of beliefs have found statistical patterns in students' responses to questions designed to assess epistemology, as well as correlations between epistemological sophistication

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[9] King and Kitchener did not specify the topic of discussion, but the interview snippet they presented immediately before this one concerned creationism vs. evolution.

(as measured by these instruments) and academic performance. Such studies strongly suggest that there should be an epistemological contribution to the ecology of mind researchers and teachers attribute to students. What remains unclear is the form in which these epistemologies reside in students' minds. How researchers and teachers answer this question, whether implicitly or explicitly, affects the methods they use to study or influence these epistemologies.

The methods used by most researchers reflect a tacit presumption of unitarity, that students hold epistemological knowledge either as theories, the content of which can be probed by direct questions, or as traits that manifest themselves in students' behavior and preferences. As theories or as traits, students' epistemologies are understood to be consistent across contexts; thus, inferences about epistemologies as drawn from questionnaires and surveys are expected to be relevant to contexts of instruction.

We have suggested an alternative view of students' epistemological knowledge as made up of a range of epistemological resources, the activation of which depends on context. These resources differ from unitary epistemological (mis)beliefs in the same way that diSessa's p-prims (cite) differ from unitary (mis)conceptions. Although the specific resources we presented here are tentative, we suggested heuristics for identifying promising candidates. Naïve epistemological resources should

- be possible to identify in young children;
- have plausible developmental origins;
- be recognizable, when articulated, as "common-sense" mini-generalizations about knowledge.

For instance, children's behavior suggests that they sometimes activate *Knowledge as propagated stuff*, understanding knowledge as something they receive ("I know the cat's name because Diana told it to me."). Other times, they activate *Knowledge as fabricated stuff*, understanding it as something they create from other knowledge ("I thought you had a present for me because I saw you hiding something under your coat!") Although *Knowledge as propagated stuff* seems to correspond to an authority-driven view of knowledge while *Knowledge as fabricated stuff* seems closer to a constructivist view, these epistemological primitives are not general beliefs. They are, in general, inarticulate and unstable in their activation, switching on or off beneath the child's conscious awareness.

This is not to disallow consistency, however. By this view, epistemological beliefs, when they exist within or across contexts, correspond to patterns of activation of epistemological resources, along with some kind of metacognitive awareness when the beliefs are articulate. A full-fledged authority-driven view of knowledge may well exist, in a given context, but it would also involve the sustained activation of other epistemological primitives beyond *Knowledge as propagated stuff*, such as *Accumulation* as a resource for understanding epistemological activity and *acceptance* linked tightly with *Understanding* as an epistemological stance.

This shift in ontology suggests new directions for teachers and researchers. Accounts of students as having unitary misconceptions suggest the need for instruction to elicit, confront, and replace students' misconceptions with more appropriate conceptions. In contrast, to understand students' conceptual understanding in terms of a manifold ontology of resources, such as diSessa's (1993) p-prims, offers the possibility for instructors to conceptualize their agenda in terms of helping students draw on those resources more productively (Hammer, 1996). Similarly, accounts of students as having "misbeliefs" suggest the need to elicit, confront, and replace those beliefs. An account of students' epistemologies as made up of resources would suggest a different agenda for instruction, of helping students draw on their epistemological resources more productively.

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