Epistemological Considerations in Teaching Introductory Physics

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Epistemological beliefs are beliefs about knowledge and learning. In a physics class, for example, some students might believe learning consists of memorizing facts and formulas provided by the teacher, whereas others might believe it entails applying and modifying their conceptualizations of phenomena. This article explores, in the context of a debate about velocity from the author's high school physics class, how a perspective of students as having epistemological beliefs might influence a teacher's perceptions of students and intentions for instruction. © 1995 John Wiley & Sons, Inc.

INTRODUCTION

Physics teachers tend to speak about students and instruction by reference to an established body of knowledge: "This course covers classical kinematics and dynamics"; "The students confuse voltage and current"; etc. Our intentions for instruction and perceptions of students, at least those we articulate, are mostly *traditional content-oriented*, that is, oriented with respect to what is traditionally described as the "content" of a physics course. We often speak in the abstract of more general goals—such as that students should develop as independent, creative thinkers—but these goals do not necessarily influence day-to-day classroom pedagogy.

A similar emphasis is evident in the research literature, which is dominated by articles pertaining to students' understanding of physical concepts and phenomena. There have been numerous studies to identify student conceptions about dynamics (e.g., Halloun & Hestenes, 1985), electricity (McDermott & Shaffer, 1992), and optics (Galili et al., 1993); as well as more general analyses of the structure of students' knowledge and the dynamics of conceptual change (Carey, 1992; Chi, 1992; diSessa, 1993; Strike & Posner, 1985). Projects in instructional design have focused on developing students' knowledge of particular content through progressions of conceptual models (White, 1993), useful "anchoring" analogies (Clement et al., 1989), and hierarchical structuring of knowledge (Eylon & Reif, 1984). Research has suggested general techniques for drawing out and addressing students' prior conceptions (Dykstra et al., 1992; Minstrell, 1989) as well as specific interventions to address particular, known difficulties (Camp et al., 1994; Shaffer & McDermott, 1992). Larger scale projects in curriculum reform usually take as primary tasks the selection and ordering

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of topics (Rigden et al., 1993; California Curriculum Framework and Criteria Committee for Science, 1990).

Teachers and researchers are fairly rich with conceptual tools for thinking about students' knowledge at the level of content. First, we have for reference the extremely well-articulated, standard body of physics knowledge. If a student gives an explanation about the motion of a tossed ball, for example, it is relatively straightforward to assess whether that explanation agrees with Newton's laws. Second, the research cited in the previous paragraph provides an abundant collection of ideas, strategies, and materials concerning student knowledge and reasoning about physical phenomena, supporting what has come to be known as "pedagogical content knowledge" (Shulman, 1987). We are thus well equipped for anticipating how a student might predict the motion of a tossed ball, for inferring the knowledge that might underlie that prediction, as well as for making instructional decisions with the intention of helping the student move closer to understanding Newton's laws.

To be clear, this is not to argue that it is a simple matter either to compare students' conceptions to physicists' or to influence their knowledge in instruction—indeed it is not. This is to argue that, with respect to traditional content-oriented objectives, we have many tools available to help us conceptualize what we hope to achieve, how we might proceed, and how to assess whether we have been successful. Some may question whether particular tools are valid or effective, but I will not enter those debates here. I assert only that the tools exist.

It is broadly acknowledged, meanwhile, that there are other aspects of students' knowledge and reasoning beyond their conceptions of physical phenomena, such as their understandings of themselves and their place in society, of school, of physics and of physics classes. There is also more to being a scientist than knowledge of phenomena and concepts. If a purpose of science instruction is to help students move toward becoming scientists, it is essential to recognize that this entails much more than learning facts and established theories (Duschl, 1990; Roth & Roychoudhury, 1993). It means developing habits and attitudes for inquiry, refining reasoning practices and abilities, and adopting the generally tacit assumptions and values of a community. It means change in a complex system of knowledge and abilities at multiple levels and in multiple forms (Baron, 1985; Niedderer & Schecker, 1992; Schoenfeld, 1983).

This article concerns one aspect of this system of knowledge and abilities beyond traditional content: beliefs about knowledge and learning, or *epistemological beliefs*. We can expect students to come to a physics course, not only with prior conceptions of physical phenomena, but also with beliefs about what will constitute understanding in the course and how best to achieve it.[1] A student's prior physics knowledge, for example, might include a conception that *heavier things fall faster* or that *forces cause motion*. A student's epistemology, on the other hand, might include a belief that *understanding physics means knowing formulas* or that *learning physics means receiving and storing information*. Such beliefs can affect how students approach learning and how they benefit from instruction (Carey & Smith, 1993; Collins &

[1] In order to be clear about the distinction between conceptions of physical phenomena and beliefs about the nature of physics knowledge, the term *beliefs* in this article will refer only to students' epistemologies.

Ferguson, 1993; Dickie & Farrell, 1991; diSessa, 1985; Donald, 1993; Gunstone, 1992; Hammer, 1994a and b; Songer & Linn, 1991).

The problem is that, although we may feel it is important to consider students' beliefs in instruction, we have relatively little on which to base that consideration. There is no well-articulated, standard epistemology against which to compare students' views. Moreover, although there are some broad points of consensus regarding reasonable epistemological goals, there is only a very small body of "pedagogical epistemology knowledge" concerning the nature and phenomenology of these beliefs, with a literature far less developed than that on knowledge at the level of content. We are not well equipped for anticipating what students' might believe about knowledge and learning, for inferring beliefs from their work, or for making instructional decisions with the intention of influencing beliefs.

It is not surprising that traditional content-oriented concerns dominate physics teachers' day-to-day perceptions and intentions, because there is a significant bias toward such concerns in the conceptual tools we have available. If we want seriously to consider other aspects of students' knowledge and reasoning, we need to develop conceptual tools to support that consideration, and we need to study how these tools might be involved in day-to-day classroom instruction (Hammer, in press).

The purpose of this article is to explore how an epistemological perspective might influence a teacher's perceptions and intentions. The following section describes a framework for characterizing epistemological beliefs. "Epistemological considerations" illustrates epistemological perceptions and intentions in the context of a class discussion about velocity graphs.

EPISTEMOLOGICAL BELIEFS

In earlier work (Hammer, 1994a and b), I analyzed interviews of introductory physics students to show that it was possible, using the framework shown in Figure 1, to characterize individual students as having tacit beliefs about knowledge and learning.

The framework consists of three dimensions. The first dimension, *Pieces* ↔ *Coherence*, describes a range of beliefs about the structure of physics knowledge. At one end, *Pieces*[2] describes a belief that physics is made up of a collection of isolated pieces of information, such as particular formulas and facts. At the opposite end, *Coherence* is a belief that physics knowledge constitutes a coherent system and that a grasp of that coherence is essential.

The second dimension, *Formulas* ↔ *Concepts*, is a range of beliefs about the content of physics knowledge. *Formulas* is a belief that physics knowledge is made up of formulas. *Concepts* is a belief that physics knowledge involves a sense of mechanism or structure; in this view, the formalism is a useful tool for expressing or applying conceptual understanding, what students often refer to as "intuition" or "common sense." *Apparent Concepts* is an important intermediate position, describing a belief that physics knowledge is made up of a formalism that one can often, but need not,

[2] Italics here denote the name of a category of beliefs. Thus, *Pieces* refers to the belief that physics is made up of pieces.

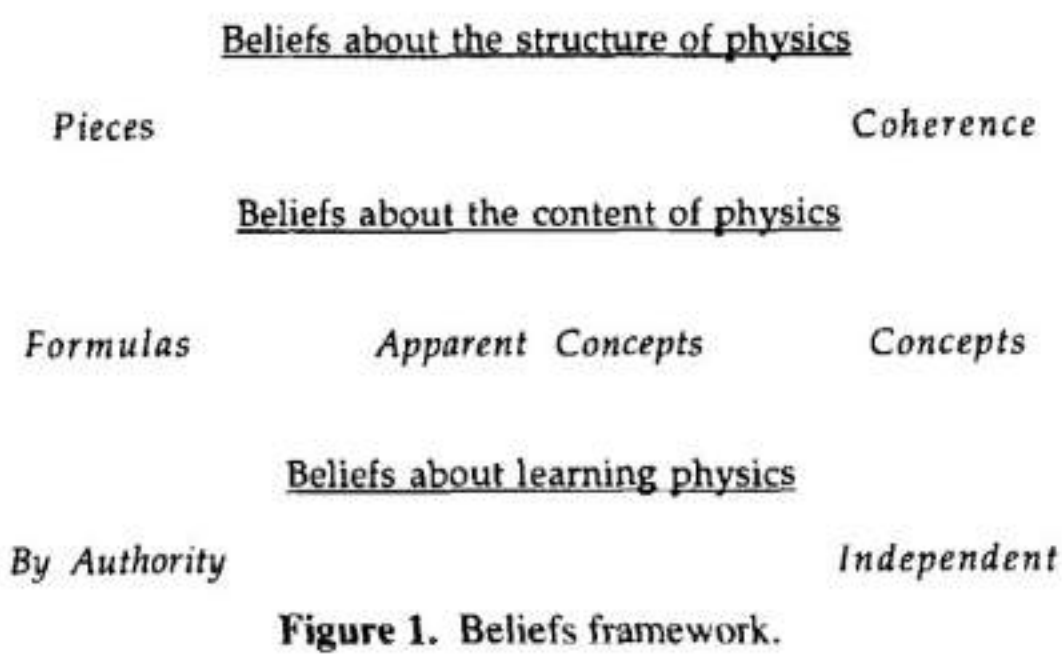

Figure 1. Beliefs framework.

associate with conceptual content. Students characterized as having an *Apparent Concepts* view of physics are casual about forming or breaking conceptual associations with the formalism. Daniel, for example, showed an *Apparent Concepts* view in choosing simply to dismiss his intuition when it disagreed with a calculation, saying "Of course I have to trust my answers that I calculated better than intuition, so, I'm more than willing to accept this . . . as a better answer." Tony, in contrast, showed a *Concepts* view in taking such disagreement as reason either to check his calculations or to "modify [his] common sense" (Hammer, 1994b).

The third dimension, *By Authority* ↔ *Independent*, describes beliefs about how, as a student, one develops an understanding of physics. *By Authority* is a belief that learning physics is a matter of storing knowledge delivered by the teacher or the text. *Independent* is a belief that learning physics is a matter of applying and developing one's own understanding.

The study (Hammer, 1994a) showed that differences in initial conceptual knowledge, general intellectual ability, and motivation would not be sufficient to account for differences in students' success at developing robust understanding of classical mechanics. Part of the distinction was epistemological: the more successful students could be characterized by *Coherence*, *Concepts*, and *Independent*.

It is important to emphasize that these are tacit beliefs and not articulate philosophies. Students do not generally express these beliefs; and what they might say in the context of a discussion of epistemology may not correspond with what they implicitly assume in a context of a discussion of physics. As well, to suggest that *Coherence*, *Concepts*, and *Independent* describe productive beliefs is not to suggest that they constitute an appropriate philosophy of science. In other words, the claim that any beliefs are *useful*, for students, or scientists, is not a claim that the beliefs are *true*. There are good reasons, for example, to dispute the notion of scientific understanding as constructed or possessed by individuals (Latour, 1987; Lave & Wenger, 1991), but these reasons do not contradict the claim that it is productive for students to see themselves as responsible for their own learning.

A number of studies have made claims similar to those above regarding the role of epistemological beliefs in science learning. Kuhn's (1993) discussion, of students' abilities to coordinate theory and evidence, and Schauble et al.'s (1991) account, of students' goals in laboratory tasks, bear on beliefs about scientific knowledge and in-

quiry. Songer and Linn (1991) argued that students' views of science as "static" or "dynamic" significantly influence their learning. Hodson (1988) and Duschl (1990) suggested a set of conceptualizations of scientific theory to guide curriculum development. Reif and Larkin (1991) highlighted differences in tacit epistemologies between scientific and everyday domains. Morrison et al. (1994) suggested "epistemic fluency" as an objective for science instruction. diSessa (1985) and Gunstone (1992) reported on students' epistemologies specifically in introductory physics classes, and Niedderer and Schecker (1992) included beliefs as one component of a "matrix of understanding." Although the details and methods of these studies vary substantially, they present a fairly consistent view of productive beliefs about knowledge and learning in science.

There is also is a growing literature on curricula, materials, and methods motivated by epistemological and other metacognitive objectives. These include Novak and Gowin's (1984) concept-mapping and "vee" diagram techniques; the Project to Enhance Effective Learning (Baird, 1986; White & Gunstone, 1989); Bereiter and Scardamalia's 1989) intentional learning environments; Brown and Campione's (1990) communities of learning; and LabNet's (Ruopp et al., 1993) "project enhanced science learning." Whereas these articles draw implications from research for instructional design and study the effectiveness of particular strategies, the emphasis of the present article is on understanding how an epistemological perspective might contribute to teacher awareness and judgment.

The following section presents a detailed account of physics instruction. The subsequent analysis asks: (1) what does the student participation in the class look like when seen through an epistemological lens; and (2) how might the view through this lens influence a teacher's decisions?

EPISTEMOLOGICAL CONSIDERATIONS

After giving some background about the class and describing general epistemological objectives, this section presents a detailed account of a class debate that began from students' solutions to a homework problem, contrasting what one might perceive in that debate from an epistemological perspective with what one might perceive from a traditional content-oriented perspective.

Background about the Class

There are about 2000 students at the school, the single public high school for a city near Boston, mostly from "working class" families. I was there as a guest, during the 1992–1993 school year, teaching one physics class. I videotaped every session from the third week of school through April 1, after which a student teacher took over, except when there were exams or occasional technical problems. In addition, I recorded daily, detailed notes on the class sessions and on any meetings I had with students. Finally, I saved samples of students' work throughout the year.

The class was the more "accelerated" of the school's physics offerings. It met every morning from 9:18 to 10:00, except on Monday when it met for a double period. There were 22 students, 16 seniors and 6 juniors, divided evenly by gender.

The school is well run with a very traditional style in almost all respects, including discipline, class scheduling, and pedagogy: in a typical class, students sit in rows watching and listening to a teacher's presentation. This course was a significant change from the familiar, and many of the students found it disconcerting, especially those who had been successful with traditional pedagogy.

Epistemological Objectives and the First 3 Weeks

I had several epistemological objectives in the course, which during the first 2 weeks I emphasized strongly over traditional content-oriented objectives.

First, I wanted to work immediately toward students' believing they should participate in the course as sense-makers. Based on what science teachers at the school described, as well as on my own observations, the bulk of the students' experience was consistent with a belief that learning science constitutes receiving information from the teacher or text. The students needed to learn that, in this course, not only would they have to find answers for themselves, but they would often ask their own questions. In the language of the Beliefs Framework, I wanted to promote *Independent* and challenge *By Authority* beliefs about physics learning.

I began the course by giving the students problems, with the purpose of engaging them in inquiry: *that* students were thinking was more significant at this point than *what* they were thinking. It was important to include some problems the students would be able to solve with confidence, because if the students did not experience success in thinking for themselves they could learn precisely what I hoped to avoid, namely that thinking for themselves is not productive. For example, they successfully determined how to roll a marble between two curved, parallel lines; and they concluded that if one drops a ball while running the ball will continue to move forward.[3] But it was not important for the students to solve all the problems correctly: most felt that the dropped ball would slow down and fall behind the runner.

My second epistemological objective, in the language of the Beliefs Framework, was to promote *Concepts* and avoid *Formulas*. Physics courses typically begin with a review of mathematical formulas and procedures. To begin in this way may reinforce, if not produce, a belief that physics reasoning is symbol manipulation. I hoped instead that the students would come to see their own knowledge and experience as relevant to physics or, more precisely, to see much of their knowledge *as* physics.

Thus I chose problems I expected would connect with the students' experience. They mostly involved familiar objects, such as marbles, balls, coins, and wheels. One homework assignment, for example, had them study the motion of shoes suspended by their laces (pendula); another was to decide whether heavy things fall faster than light things. None of the problems included a formula in its presentation, although in several cases students found it useful to invoke formal tools themselves.

Finally, my third objective was to work toward students' expectation of coherence in their understanding of physical phenomena. In the language of the Beliefs Frame-

[3]The curved, parallel lines are drawn so that there is a straight line path between them (McCloskey, 1983); the dropped ball would continue to move forward at the same speed as the runner.

work, I wanted to promote *Coherence* over *Pieces*, and *Concepts* over *Apparent Concepts*. The students should learn to look for connections between different aspects of their knowledge and to identify and resolve inconsistencies. They should see the need to explain, not only the answer they think is right, but also the answers they think are wrong: Why might someone take that alternative position; and what would be wrong with that reasoning?

To that end, I presented several problems during the first 2 weeks that had "tempting wrong answers," and I introduced a three-part structure for answering questions we would follow for the entire year: (a) *Answer what you think is correct and explain*; (b) *identify a tempting wrong answer, and explain why it is tempting*—that is, *argue for an answer someone else might think is correct*; and (c) *explain why the way of thinking you described in part (b) does not work for this problem.*

In sum, I had three closely related epistemological objectives: The students should believe they need to think for themselves; they should understand physics as involving their own knowledge and experience; and they should believe it is important to coordinate and reconcile alternative ways of thinking. For the first two weeks, I focused strongly on these objectives, putting little emphasis on traditional content. I did not expect to achieve these objectives in those 2 weeks however; I hoped for gradual progress over the course of the year.

There were other considerations, to be sure, for beginning in this way rather than with a math review. One was that, in my experience, students take very little from decontextualized math reviews to the contexts in which the mathematical techniques apply. Others may be seen as affective: I hoped to pique the students' interest; I wanted to develop a respectful environment in which students could express their views without fear of derision. These are extremely important considerations, but they are not the focus of this article.

At the beginning of the third week, I began to pursue traditional content-oriented objectives. On Monday, to introduce ideas of displacement, velocity, and acceleration, I assigned a lab exercise in which the students rolled steel balls down inclined tracks. The students placed small pieces of tape along the track so that, when a ball rolled over a piece of tape, it made a soft click. I challenged them to place the bits of tape so that the clicks would come at an even rate. I also asked them to draw two graphs of their results, assigning for the first time the use of a formal representation. One graph was to show the total distance the ball rolled, the other the distance between consecutive pieces of tape, each as a function of the number of clicks.

All of the groups discovered that the distances between the pieces of tape had to increase, in order to make clicks at an even rate, because the ball was speeding up; some concluded that the distances should increase in a uniform pattern. Graphing and interpreting the graphs, however, proved difficult for most of the students. We spent some time the next day talking about how a graph of the distances between pieces of tape, the *displacements* of the ball over roughly uniform time intervals, showed that the ball was speeding up.

For the remainder of the week, we worked on defining and graphing position, displacement and velocity, building in various ways from the inclined plane lab. I assigned corresponding problems from the textbook (Haber-Schaim et al., 1976), one of which, on Friday, became the focus of the following debate.

A Debate about Graphing Velocity

I have chosen to discuss this session in part for its traditional organization: A student presented his solution to a homework problem on the blackboard, and the teacher directed the discussion from the front of the room. Over the year, the students spent much of their time working outside of this familiar structure. However, to discuss epistemological concerns in the context of an alternative structure may obscure the central focus of this article, which is to explore, not alternative pedagogy, but how an alternative perspective on students' knowledge and reasoning might influence a teacher's perceptions and intentions. Epistemological considerations need not be associated with any particular methods of instruction.

The debate, which took place Friday of the third week of school, pertained to the following problem. Figure 9-34 from the textbook is shown here as Figure 2.

> John rode his bicycle as fast as he could from his house to Tom's house. After a short time he rode back as fast as he could. Figure 9-34 shows a position–time graph of his trip. Plot the velocity–time graph of John's trip. From the information given and your graph, what would you give as a plausible description of the road between John's and Tom's houses? (Haber-Schaim, et al., p. 191, problem #14)

I asked for a volunteer to draw the velocity graph on the blackboard, expecting it to have been fairly straightforward. No one offered, probably in part due to the presence of the video-camera. Jack said that he had been able to describe the road but not to draw the graph. I called on Harry, a confident, immodest student, in part because he was needling Jack to go to the board. He agreed, on his way to the board revealing that he had not done the homework.

Harry worked quietly at the board for several minutes, and I moved around the room to find that roughly half of the class had drawn one kind of graph and half had drawn another. I asked other students to give Harry some help and feedback.

> Teacher: So listen folks. Watch what he's doing and help him out. How does this look so far? Do you have concerns or is he doing all right?

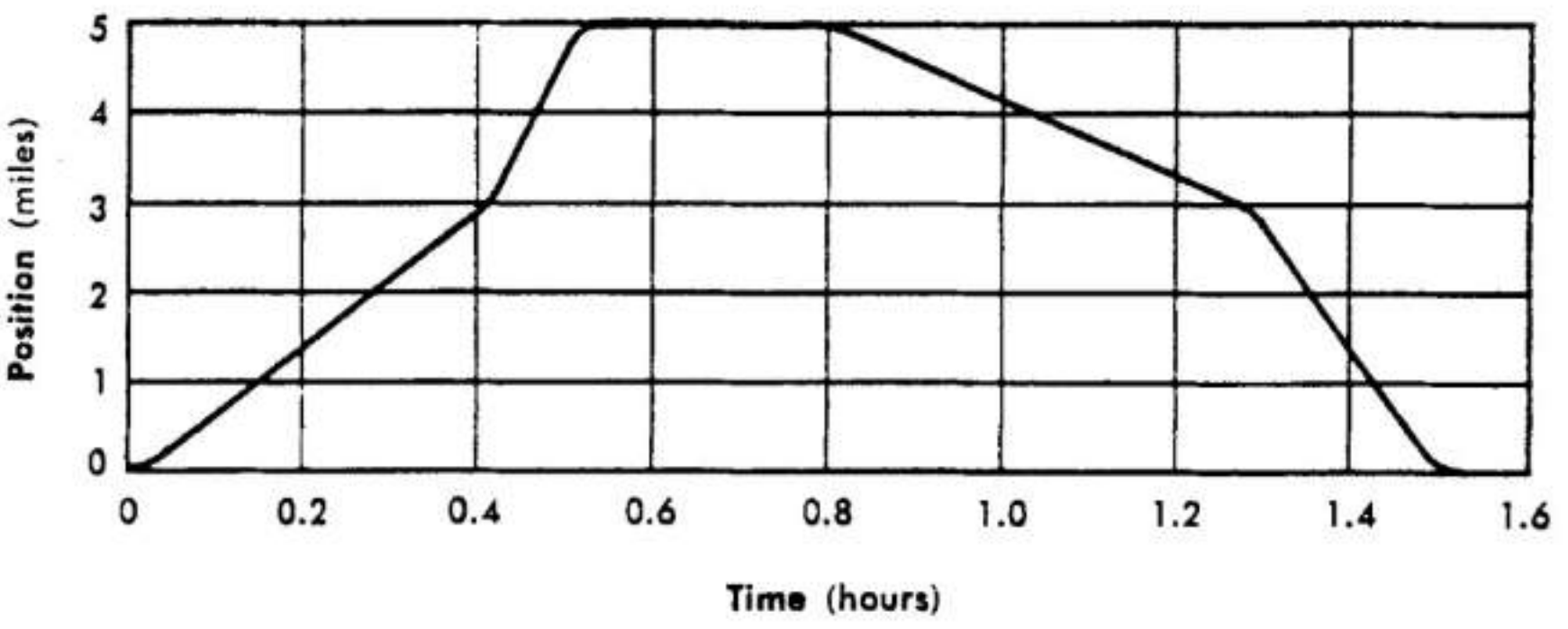

Figure 2. Figure 9-34 from the textbook (Haber-Schaim et al., p. 193).

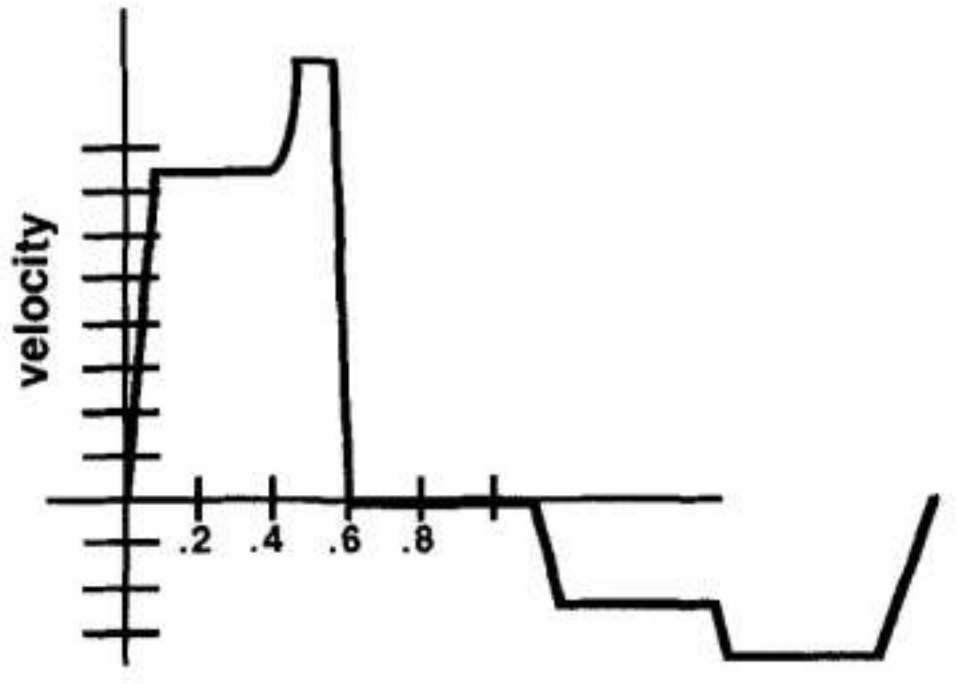

Figure 3. A schematic sketch of Harry's graph, at one stage of its evolution.

Several students (Ricky, Steve, and others): It's wrong. Sit down!

Teacher: Well what's the problem?

Several students: It's just wrong.

Harry was about to give up and sit down, but I encouraged him to stay and asked him to talk about the beginning of his graph. He explained that from 0 to 0.4 hours the bicycle "picks up speed [and then] starts going at a constant speed."

Julie and Jean had done something similar, but they thought the speed was constant between 0 and 0.4 hours, so that the graph should start at 7.5 miles per hour, instead of at 0 miles per hour as Harry had drawn. Greg argued "yeah, but you have to pick up speed," and Harry pointed out a small curve at the start of the position graph in the textbook that showed an initial gain in speed. I remarked that my graph was like Julie's and Jean's, but that I understood what Harry and Greg were saying. We decided to have the graph show the increase in speed.

Harry stayed at the blackboard; other students and I helped him continue. Figure 3 is a sketch of Harry's graph after about 10 minutes of this collaborative work.[4]

A number of the students were perplexed by what was going on. At one point Steve interrupted to say that "if you just find all the displacements by, like, subtracting, and you just graph them that's not what you get." Camille agreed.

Camille: There's a couple of us that subtracted the points and you get—do you understand what I'm saying?

Teacher: Mm-hm? [asking Camille to continue]

[4]There were several errors in Harry's graph at this point, most of which the students corrected by the end of the period. One error may be particularly confusing: the graph showed the bicycle's velocity as zero between 0.6 and 1.0 hours, while Harry was careful to explain that the velocity was zero between 0.5 and 0.8 hours. The graph also did not show the appropriate magnitudes of the velocities. In part this was because there was not room at the bottom of the blackboard, given the placement and scale of the vertical axis.

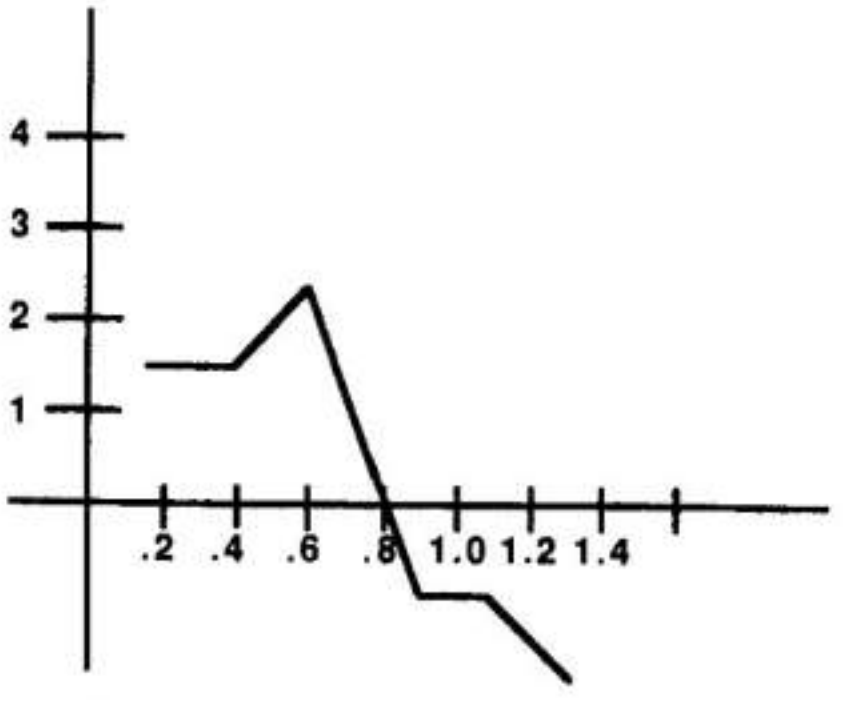

Figure 4. A schematic sketch of Camille's graph, at one stage in its evolution.

> Camille: You're supposed to subtract the distances and plot those points, and that's what we did, and we got different graphs.

I asked Camille to put her graph on the board. As she did, Harry corrected a mistake on his that Jack had noticed, and others discussed the matter among themselves. When Camille had drawn the graph shown in Figure 4, I asked her to explain.[5]

> Camille: The first point I subtracted, I said well 1.5, you started at zero and went to 1.5 so the distance is 1.5. . . . Then at .4 it's about 2.8, 2.9 somewhere around there. And I subtracted 1.5 from that, and I graphed, and I got 1.3, so I plotted that.[6]

Thus, Camille explained, she found the first point to plot on her graph by subtracting 0 miles, the bicycle's position at 0 hours, from 1.5 miles, the position at 0.2 hours; she found the second point by subtracting the position at 0.2 hours from the position at 0.4 hours, and so on, over intervals of 0.2 hours as marked on the time axis of the position graph in the textbook. Several other students in the room agreed with her general method, although some noted specific mistakes.

Scott, who like Harry had not worked on the problem before class, suggested they divide the position graph into time intervals according to the straight line segments, in other words, into segments of constant velocity:

> Scott: Instead of using the time intervals, can you use the slopes, the change in the slopes, make the point at the end of each of those slopes; like x1 at zero, x2 just after the .4, and then at .5 at the top where, the change in that slope, and then from .5 to .8 . . .

[5]There were also errors in Camille's graph at this moment. One of these was that the point she plotted below the axis at 0.8 hours should have been at 1.0 hours, and this error threw off the later times as well. Again, by the end of the period, Camille's graph had been modified and corrected.

[6]The numbers "1.5" and ".4," for example, indicate student utterances of "one point five" and "point four."

Nancy objected that Scott's idea would produce time intervals of varying length:

> Nancy: For the first time the time change is 2 [i.e., 0.2 hours]. And the second time it takes 1 and 1/2. So it changes the time.

Camille elaborated on Nancy's point, arguing that to use Scott's idea would be to leave out information. Jack claimed that Camille's graph did not accurately depict intervals of constant speed. Harry pointed in particular to the time from 0.5 hours to 0.8 hours, over which, he argued, the velocity should be 0, because the position graph showed that the bicycle was not moving. Steve rebutted that Camille's graph showed "where [the bicycle] went" over the time interval between 0.6 and 0.8 hours:

> Camille: If you do that you're not going to see what's shown right there, what's between them, what's going on.
>
> Teacher: What's between them. [asking for clarification]
>
> Steve: You have different sizes for the intervals and—
>
> Jack: But in your graph there's only two spots that are constant speeds, but on here there's one, two, three, four spots that are constant speeds, and you only show two on your graph. And on the graph in the book there's four sections that have constant speeds.
>
> Harry: From .5 to .8 the guy is not moving anywhere, so why are you having him move down to .8? Because he went to Tom's house and stayed there for awhile. He didn't go right back.
>
> Steve: From .6 to .8 that's where he went.
>
> Harry: That's when he stopped.
>
> Steve: Well it doesn't show what happens in between; it shows what happens from .6 to .8.

I challenged students on either side of the debate to explain the other side's reasoning, but everyone felt the other side was just "confused":

> Teacher: [to Jack and Harry] What's wrong with the way that they [Camille and others] did it? I mean they used a good, I mean it seems like a good way to do it—they just found the intervals and they subtracted the points.
>
> Camille: That's the way you told us to do it!
>
> Scott: They're confused.
>
> Joanne: I know [agreeing]. All they did was [sweeping arm gesture indicating nonchalance].
>
> Amelia: David, I think they have the idea, but they messed up on the calculations. Because I have almost the same graph.
>
> Teacher: Wait, which one messed up on the calculations?
>
> Amelia: This one [Camille's].
>
> Teacher: This one [Camille's] messed up the calculations.

> Amelia: That one [Harry's] I don't have anything to say about, I don't think it's right.

Amelia went to the board to fix what she felt was a mistake in Camille's graph. Watching her, Sean asked, "If we graph one of the odd ones [0.1, 0.3, 0.5 . . . hours] don't we have to graph all of them?" (Amelia had plotted points at 0.5 and 0.7 hours, but not at 0.1 or 0.3 hours.) Sean's argument was similar to what Nancy, Camille, and Steve had already said, that the time intervals should be uniform, but it raised the possibility of using an interval of 0.1 rather than 0.2 hours. Camille and others agreed that it was a reasonable option to use intervals of 0.1 hours.

I noted "We only have a couple of minutes left." Sean, speaking over several side discussions, asked, "Are you going to tell us what the right answer is?"

Epistemological and Traditional Content-Oriented Perceptions

To review the substance of the debate, the problem asked students to infer the velocity of a bicycle from a graph of its position over time. Harry found the velocity by calculating the slopes of straight sections of the position graph, each of which corresponded to a section of constant velocity.[7] He joined the constant sections of the velocity graph with steep lines to indicate rapid changes in velocity. In a physicist's terminology, Harry's was a graph of the bicycle's *instantaneous velocity*.

Camille found the changes in position, or *displacements*, of the bicycle over 0.2-hour time intervals, by subtracting its position at the beginning of each interval from its position at the end. She plotted these displacements as points on her "velocity" graph. Because she used constant time intervals, it was reasonable for her to treat displacement as measures of the bicycle's velocity. More precisely, the displacements were proportional to the bicycle's *average velocity* over the 0.2-hour time intervals.

Each technique was valid, in its own sense, although most physicists would find Harry's graph more appropriate. Errors notwithstanding,[8] it gave a continuous record of the bicycle's speed and direction of motion. In contrast, although she drew lines to connect them, Camille's graph had meaning only at the points she plotted: each point showed the distance and direction the bicycle had traveled over a 0.2-hour interval of time. This technique corresponded closely to what the students had done earlier in the week for the inclined plane lab and on some homework problems.

Traditional content-oriented perceptions of the students' participation in this debate pertain to their understanding of the kinematics concepts and representations. Harry, and others on his side of the debate, showed at least the beginnings of a conceptual understanding of velocity. Their graph, by the end of the period, was essentially what a physicist would produce, and they defended it largely by reference to a narrative account of the bicycle's motion: "From .5 to .8 the guy is not moving anywhere . . . he went to Tom's house and stayed there for a while."

Camille, and others on her side, did not show a conceptual understanding of veloc-

[7] A straight line segment on a position graph indicates constant velocity and, therefore, a horizontal section of the corresponding velocity graph.

[8] See footnote 4. The final version was still only qualitatively correct with respect to velocity magnitudes.

ity. They generated and defended their graph by reference to a formal procedure ("You're supposed to subtract the distances and plot those points, and that's what we did. . ."), and their graph was not well connected to a narrative account of the bicycle's motion. That they drew lines to connect the points they plotted raises the question of whether they understood that the graph had meaning only at those points.

None of the students in either group observed that Camille had actually graphed distances (miles) and not velocities (miles/hour); and no one thought to label the dimensions of either graph. No one saw the validity of both approaches or understood how they could be related, thus none of the students showed an understanding of the distinction and relationship between the concepts of displacement, average velocity, and instantaneous velocity. Since many of them were concurrently enrolled in calculus, I had hoped they would find the bicycle problem fairly straightforward.[9] It was disappointing that it raised such difficulties. On the other hand, almost all of the students in the class had taken one of two reasonable and technically valid approaches to the problem.

Epistemological perceptions pertain to the students' beliefs about knowledge and learning. Harry's group approached the problem based on their sense of the bicycle's motion, as they could infer it from the position graph. For example, Harry, Jean, Julie, and Greg debated about the bicycle's motion in order to decide how to plot the beginning of the graph; Jack argued for their graph based on his knowledge of when the bicycle was moving at a constant speed. These students were not, and did not claim to be, following a procedure specified by the instructor. They were thus behaving as if they believed that physics knowledge is conceptual and that they should solve problems for themselves. In the language of the Beliefs Framework, their behavior in this respect indicated *Concepts* and *Independent*.

Camille's group, in contrast, applied a formal procedure, subtracting positions over 0.2-hour intervals; and they followed this procedure at least in part because they thought it was what they were "supposed to" do. They defended their approach largely by reference to that procedure, such as in Nancy's and Steve's insistence that the time intervals be constant, and by reference to authority, such as in Camille's (inaccurate) claim that they were following my instructions. Their behavior thus indicated beliefs that physics knowledge consists of formulas and procedures, or *Formulas*, and that learning physics is a matter of receiving information from the teacher, or *By Authority*.

None of the students, on either side of the debate, seemed interested or willing to consider the alternative perspective. Each side called the other's approach "just wrong" or "confused." This was directly relevant to my agenda that the students come to believe it is important to identify and reconcile alternative ways of thinking, rather than see physics learning as simply a matter of finding out the right answers. In the language of the Beliefs Framework, the students' behavior was consistent with *Apparent Concepts* and *Pieces* rather than with *Concepts* and *Coherence*.

[9] At the time, about a month into the year, I was not familiar with most of the students' standing in the school. Looking back, it is interesting to note that most of the students enrolled in calculus (including Camille, Amelia, Nancy, Steve, Joanne, and Bruce) had followed an algorithmic method for producing their graphs. The students who took a more intuitive approach (including Harry, Julie, Ning, Greg, and Jack) were mostly enrolled in precalculus and tended to have lower academic status.

Finally, Sean's question at the end—"Are you going to tell us what the right answer is"—echoed numerous discussions over the first 3 weeks of the course, in which the students complained that I would "never tell them the answers." In fact, I did very often "tell answers," which is to say I provided information or explained my own understanding of a situation.[10] Evidently the students were so accustomed to teachers providing answers that they noticed when it did not happen much more than when it did. This expectation indicated beliefs that knowledge comes in "answers" (*Pieces*), and that answers are provided by teachers (*By Authority*).

How to Proceed?

The options available at this point in the class were, of course, innumerable: to press the students to identify the dimensions of their graphs and label the axes; to lecture on displacement, average velocity, and instantaneous velocity; to have students experiment with microcomputer-based lab materials (Laws, 1991; Thornton, 1987) or computer simulations (Trowbridge, 1989); to organize them into groups and assign the task of producing explanations for both graphs; to initiate a concept-mapping exercise (Novak & Gowin, 1984), and so on. How any teacher chooses to proceed depends critically on how she or he perceives the students' work.

Traditional content-oriented perceptions of this class session concern strengths and weaknesses in the students' understanding of the concepts and representations of displacement, average velocity, and instantaneous velocity. As asserted at the outset of this article, such traditional content-oriented perceptions tend to be most salient for physics instructors, and traditional content-oriented intentions—those of moving students closer to correct understanding—tend to dominate our decisions.

Epistemological perceptions of this session concern strengths and weaknesses in the students' beliefs about the status of formulas and procedures as knowledge, about their roles as students and mine as teacher, and about the need to address alternative ways of thinking. *If we hope to promote epistemological objectives, we need to make epistemological perceptions part of routine instructional awareness.*

There is no reason to expect that a strategy based exclusively on one set of considerations would further the other set of objectives. For example, based on traditional content-oriented considerations, one might choose at this point to explain the concepts of average and instantaneous velocity and to prescribe specific procedures for generating the two kinds of graphs. Such an approach may well help students produce correct solutions to homework problems, but it may also support beliefs that learning physics is a matter of receiving information and that reasoning in physics means following procedures.

The remainder of this section describes my choices as the teacher in this situation. The purpose here is not to promote any instructional technique. I am not presenting my decisions as ideal or even as appropriate. Indeed, reflecting on the class, there is much I would change. The purpose is to illustrate how epistemological and traditional content-oriented concerns might be coordinated in a teacher's in-class percep-

[10]Gunstone (1992) reported a similar phenomenon, of students perceiving that the instructor provided no information when the data clearly showed otherwise.

tions and intentions. It is also important to note that my knowledge about my perceptions and intentions during the discussion is limited: this is not a complete, faithful depiction of my thought processes.

Prior to and at the outset of the lesson, my objectives for the day had been mainly traditional content-oriented. What I saw happening, however, drew my attention to epistemological concerns, and I chose to focus the entire period on epistemological objectives. Thus, for this session, I concentrated on drawing out the students' thinking, on facilitating an exchange of ideas, rather than directly on promoting a physicist's understanding of velocity graphs.

When Sean asked his question, I had already been vacillating between two strategies. One was to say that both answers were right, each in its own way, and to ask the students to figure out why. The second was to insist that each side try to explain, first, why someone might believe the other side's answer and, second, what would be wrong with that reasoning. To tell them that both answers were right, I hoped, would challenge (somewhat dramatically) the belief that there should be one right answer; as well, it might promote a belief that it is valuable to consider alternative ways of thinking. However, to provide that information would be to adopt the familiar teacher's role, shifting the focus from their reasoning, where it had been, to mine.

I chose the first strategy and answered Sean, "Today I'm going to tell you what the right answer is." This drew joking exclamations of surprise. I took a final poll and confirmed the students' unanimous sentiment that the other side's view did not make any sense. Their eagerness to hear the answer from the teacher had me both questioning my choice of strategies and convinced that it was too late to change. I went ahead, telling them it was essential for each side to understand the other's reasoning, because both sides were correct. This brought a loud, exasperated reaction, including Joanne's question: "How are those two graphs the same?!"

I acknowledged that the two graphs were not the same, but, I hinted, they might not be graphs of the same thing. I modified the assignment I had planned for Monday to include a written explanation of each of the two graphs, telling the students they needed "to sort out how these two graphs can both be right." I also assigned reading from the textbook, which, I said, might help them do this.

I later regretted the reading assignment, which probably worked against my epistemological objectives, supporting *By Authority* and, perhaps, *Formulas*: the textbook was quite formal in its presentation. These considerations contributed to my eventual decision to stop assigning reading from the textbook.

Although my thinking about how to proceed on Friday stressed epistemology, I was not abandoning traditional content. Over the weekend, I developed a worksheet to guide the students through successive modifications of a graph like Camille's to produce a graph like Harry's.[11] Other activities the next week included qualitative discussions about velocity, another worksheet that challenged the students to derive position graphs from velocity graphs, and a short lecture on the value and possibility

[11] To convert Camille's graph to Harry's, the students could divide each of the displacements in Camille's graph by 0.2 hours to produce a graph of the bicycle's velocity averaged over 0.2-hour time intervals. They could then produce a sequence of such graphs using successively smaller time intervals. The smaller the time interval, the more the graph would resemble Harry's.

of students' figuring things out for themselves based on Wertheimer's (1945/1982) account of students' inventing ways to find the area of parallelograms. The following week, the students showed substantial progress toward a physicist's understanding of velocity in their performance on a short quiz. Later still, the school's six Apple IIe computers became available, and the students spent time exploring kinematics graphs with microcomputer-based lab materials developed by Thornton (1987).

DISCUSSION

By and large, the emphasis in drawing implications for practice from research on students' knowledge and reasoning has been on instructional methods and curricula. Researchers make general recommendations (e.g., teachers should engage students in active exploration; teachers should adopt constructivist principles), and they design specific materials and methods (e.g., computer software; prescriptions for arranging cooperative learning groups).

These researchers are often frustrated and disappointed by what they see happening as a result, ostensibly based on their ideas. They see teachers as misinterpreting the recommendations and designs; as teaching in ways that are not consistent with the new philosophies they profess; as not following prescriptions precisely or as following them in letter but not in spirit. Teachers, in turn, are often frustrated and disappointed by what the research community offers. General recommendations often seem platitudinous, divorced from authentic classroom situations. Specific curricula and methods do not accomplish what the researchers described, or they do not address the teachers' objectives

Every classroom—and every student and every teacher—is in some sense unique, and how instruction evolves in a classroom depends on its particular circumstances. Curricular and methodological prescriptions cannot anticipate the students' educational and cultural backgrounds, the values and needs of the community, the teacher's interpretations of the materials or the students' responses to them. The concepts of *curriculum* and *method* as developed in advance to be applied in instruction are misconceived. It is more appropriate to think of curricula and methods as constructed in the situation of the class by the teacher and students. Certainly that construction is largely influenced by materials and procedures designed in advance, but, also certainly, what happens in class is not *determined* by those materials and procedures.

For this reason, there needs to be an increased emphasis on teachers' conceptualizations in our thinking of how research should inform instructional practice (Peterson et al., 1992). How a teacher perceives and responds to students' work depends on how she or he conceptualizes that work and the tasks of instruction.

This article opened with the claim that physics teachers' perceptions of students and intentions for instruction are dominated by traditional content-oriented considerations, in other words that we attend mainly to the correctness of students' understanding with respect to an established body of physics knowledge. Physics educators have a variety of reasons for other than traditional content-oriented objectives. Some argue that achieving other objectives, such as students' engagement in inquiry, are prerequisites for substantive traditional content-oriented progress; some argue that other objectives, such as students' becoming independent learners, are ultimately

more important than any particular content (Marx, 1989). For whatever reasons, if we want to promote such objectives, we need to learn how to think about them in authentic contexts of instruction.

The Perspective of Epistemological Beliefs

This article has explored how a perspective of epistemological beliefs might influence a teacher's perceptions and intentions. The perspective sees students as having beliefs about the nature of physics knowledge and learning, and it points to objectives regarding those beliefs. Students should expect physics knowledge to be coherent, rather than a collection of pieces of information; they should believe it is made up of conceptualizations of phenomena, rather than of formulas; and they should believe physics learning is a matter of applying and developing one's own understanding, rather than simply of receiving and storing information.

As general statements, these objectives may seem obvious and uncontroversial. But specifically how might they inform teaching practice? If we cannot use these objectives to make specific statements in the context of particular classroom events, then we do not understand them in a way that can actually influence instruction.

In this article's examination of a physics class debate, an epistemological perspective showed merits and raised concerns about students' beliefs about knowledge and learning. These considerations motivated a shift in instructional intentions toward epistemological objectives, a temporary subordination of traditional content-oriented plans. To pursue epistemological objectives, it may sometimes be necessary to press students in ways other than directly with respect to their understanding of physical concepts and phenomena.

Epistemological considerations can also inform decisions of whether and how to provide information. It is disturbing how often educators caricature alternative pedagogy as a matter of not answering students' questions. It is essential to consider how the students would understand a decision to withhold information and how they would understand the value of the information if it was provided. For students with mature epistemological beliefs, refusing to answer a simple question may serve no purpose; it may only communicate disrespect. On the other hand, for students who understand arrival at the answer as the ultimate goal, telling an answer can stop a process of inquiry. These are epistemological considerations, and they point to an instructional agenda: Students should come to see value in finding answers for themselves, and they should come to see information from the teacher as a means to support their own inquiry, rather than as ending the need for inquiry.

Questions

Many readers will see epistemological considerations as part of what good teachers see and take into account intuitively. If these are intuitive aspects of good teachers' reasoning, it would be useful to develop a means by which to articulate them. An explicit vocabulary would help teachers express these considerations to each other as well as to students, parents, and administrators. Moreover, it may help the teachers to become aware of and develop their own ideas, and it may facilitate communication with teachers for whom such considerations are not intuitive.

In this regard, the arguments in this study are insufficient. I have suggested a possible role for an epistemological perspective in introductory physics teaching, but I have not provided a reliable account or evidence that it can actually play that role. My report of epistemological considerations in my own teaching is only plausible and illustrative. There is a need for research into whether and how this and other perspectives can influence teachers' work. Knapp and Peterson (1995) describe encouraging results in their study of the influence on elementary school teachers' practices of a cognitive perspective on children's arithmetic. Much further work of this sort is needed in regard to other perspectives from educational research.

Part of that work should involve exploration and comparison of a broad range of conceptual tools. There are accounts of reasoning as abstract or concrete, of learning styles, of social affiliation, and so on. How should we sort through all of these possibilities? How should we decide whether any particular perspective is useful? Discussions of different perspectives on students' knowledge and reasoning usually focus on supporting or challenging a view with respect to its adequacy as a theoretical account. I suggest that it is important to consider not only whether a perspective is theoretically defensible, but also what it says about specific classroom situations.

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