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Misconceptions or P-Prims: How May Alternative Perspectives of Cognitive Structure Influence Instructional Perceptions and Intentions?

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The notion that students come to science courses with misconceptions has become quite widely accepted by those who follow or participate in education research. DiSessa and his colleagues (diSessa, 1988, 1993; Smith, diSessa, & Roschelle, 1993/1994) have challenged the theoretical and empirical validity of this perspective and offered an alternative account of cognitive structure in *phenomenological primitives* or *p-prims.* The purpose of this article is to further clarify and contrast the two accounts: in particular, to consider their utility and generativity as conceptual tools for teachers. How may each perspective influence instructional perceptions and intentions? The article recounts a discussion about forces and motion from a high-school physics class, analyzes how a teacher may perceive students' participation in that discussion from either perspective, and considers what, based on those perceptions, the teacher may see as tasks for instruction.

It has become widely accepted as a truth, among those who follow or participate in science education research, that students come to science courses with conceptions about the world that differ from scientists', and that these misconceptions need to

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be addressed in instruction. This view frames research designed to identify misconceptions and instruction designed to reveal, confront, and replace them.

The wide acceptance and application of this perspective warrants concern, because there remain a number of reasons to question its validity and completeness. Smith, diSessa, and Roschelle (1993/1994) argued, on theoretical grounds, that the misconceptions perspective contradicts constructivism: If student conceptions are deeply and fundamentally different from experts', then from what can they construct expert conceptions? On empirical grounds, they argued that intuitive reasoning is not as consistent or stable as the misconceptions perspective implies.

Smith et al. (1993/1994) built their arguments from diSessa's (1988, 1993) earlier work, and they compare the misconceptions perspective to his "knowledge-in-pieces" view of intuitive knowledge. In diSessa's model, intuitive physics is made up of smaller, more fragmentary structures diSessa called *phenomenological primitives,* or *p-prims* for short. The misconceptions perspective, diSessa argued, confuses emergent knowledge, acts of conceiving in particular situations, for stable cognitive structures.

As in Smith et al. (1993/1994), my purpose is to compare the misconceptions perspective to diSessa's p-prims account. However, rather than compare the perspectives on theoretical or empirical grounds, I compare them in regard to their potential utility and generativity as conceptual tools for teachers. How may each of these perspectives influence teachers' perceptions of students and intentions for instruction? In other words, I am not asking which view is more valid; I am asking what each view may do to shape a teacher's awareness and objectives.

The context for this comparison is a class discussion about forces and motion from a physics course I taught during the 1992 to 1993 school year at a public high school in Massachusetts. In that discussion, the students expressed a number of views inconsistent with the standard, Newtonian account. I consider two interpretations of these views as (a) involving stable misconceptions or (b) situated acts of conceiving involving p-prims. In general, perceptions of stable misconceptions suggest tasks for instruction of weakening and replacing elements of students' prior knowledge; perceptions of acts of conceiving suggest tasks of modifying the use of prior knowledge.

The article is organized in three sections. First, "Alternative Perspectives on Students' Knowledge" reviews misconceptions and p-prims as models of cognitive structures. "A Class Discussion About Forces and Motion" then presents an account of a physics class discussion, offers alternative ways in which a teacher may perceive the students' views, and considers what a teacher may suppose instruction should accomplish. The closing section, "Research Perspectives and Instructional Practice," summarizes the analyses and reflects on the contributions of these perspectives from research to instructional practice.

ALTERNATIVE PERSPECTIVES ON STUDENTS' KNOWLEDGE

Misconceptions[1]

As Smith et al. (1993/1994) noted, there are many versions of the perspective that students' conceptions are different from scientists'. The students' conceptions are referred to variously as *preconceptions, alternative conceptions,* and *misconceptions,* but the core idea is of *conceptions* that

1. are strongly held, stable cognitive structures;
2. differ from expert conceptions;
3. affect in a fundamental sense how students understand natural phenomena and scientific explanations; and
4. must be overcome, avoided, or eliminated for students to achieve expert understanding.

Not all authors would agree with this set of properties. In particular, some consider the term *misconceptions* to refer only to the phenomenology of patterns in students' responses that are inconsistent with expert understanding. This use of the term does not posit cognitive structures or any other explanation for the observed patterns; it simply notes the patterns' existence (D. Hestenes, personal communication, January 21, 1994). Following Smith et al. (1993/1994), I do not intend to attribute the list to any particular authors, but I suggest it is consistent with common usage of the various terms (preconceptions, etc.) in the science education community. For the purposes of this article, I use the most common term, misconceptions, and I take these four properties as its definition.

The misconceptions perspective reflects the constructivist tenet that people perceive and interpret the world through their current knowledge structures. It is an alternative to the naive, generally tacit view that students are "blank slates," according to which instruction constitutes a transfer of information from the teacher (or textbook, or demonstration, etc.) to the students. The core idea is that students' prior knowledge includes quite reasonable conceptions that are not consistent with expert understanding. These misconceptions affect in a fundamental way how students perceive and interpret what they see and hear. For this reason, instruction

[1]Refer to Smith et al. (1993/1994) and Carey (1986) for more extensive discussions of the misconceptions perspective.

cannot be a straightforward exchange of information. It is not sufficient simply to tell students or to show them; teachers must help students change or replace their misconceptions. It is thus essential for educators to take seriously the alternative and intelligent conceptions that underlie students' "mistakes," rather than simply to convey scientists' knowledge.

Misconceptions About Forces and Motion

By a Newtonian account, forces do not cause motion (velocity); they cause change in motion (acceleration). If there is no net force on an object, it moves at a constant speed in a constant direction; if there is a net force, the object's speed, direction of motion, or both changes. Students often have difficulty understanding this account, due, from the misconceptions perspective, to their misconceptions about forces and motion.[2] I note several that are relevant to the analysis of the class discussion later in the article.

McCloskey (1983) described students as having an intuitive *impetus theory* similar to the impetus theories articulated by medieval physicists. Students see the motion of an object as caused by an internally stored impetus, which they typically call *force* or *energy*. As the impetus runs out, the object stops moving. McCloskey identified two variations of the impetus theory, one in which the impetus runs out on its own and another in which the impetus is drained by gravity, friction, or both.

Other researchers have identified similar misconceptions without attributing to them the coherence of a theoretical framework. Clement (1983) described students' use of a misconception that "motion implies a force" in a range of situations. This is a misconception that the motion of an object indicates the presence of a continuing force causing that motion.

Hestenes and his colleagues (Halloun & Hestenes, 1985; Hestenes, Wells, & Swackhamer, 1992) have provided the most complete taxonomy of misconceptions related to mechanics. They use the term *impetus* to describe several misconceptions related to an internally stored cause of motion. Their list also includes the misconceptions that motion implies an active force on an object, exerted by some external agent, and that motion ends when the active force "wears out." Similar misconceptions, of motion as caused by an externally applied force, have sometimes been described as Aristotelian (Champagne, Klopfer, & Anderson, 1980; diSessa, 1982; Whitacker, 1983), although these authors have been careful to note that the students' conceptions do not have the coherence or logical structure of Aristotle's account. Other misconceptions in Hestenes et al.'s (1992) taxonomy include the conception

[2]More extensive accounts of misconceptions in mechanics can be found in Arons (1990), Camp et al. (1994), and Halloun and Hestenes (1985).

that the strength of gravity increases as an object falls (Champagne et al., 1980), that obstacles (e.g., a table) do not exert forces (Minstrell, 1982), and that motion occurs when the motive force is larger than the resisting influences.

Challenges to the Misconceptions Perspective

The purpose of this article is not to debate the validity of the misconceptions perspective. However, because of its wide acceptance in the science education community, it may be important to review some of the criticisms of the misconceptions perspective to motivate the consideration of an alternative.

Some accounts of particular misconceptions have been criticized as inappropriately framed within the scientists' position, using scientists' terms and meanings, rather than within the students' (Viennot, 1985). For example, if a student says a moving object "has a force in it," researchers may interpret a misconception about force. It is a mistake, by this line of criticism, to interpret the student's use of the word *force* as corresponding to a physicist's use of the term. Students may have an entirely different schema for the word *force* (Carey, 1986), or several competing schemas (Maloney & Siegler, 1993), or their concept of force may be vague in a fundamental sense (McDermott, 1984). A similar criticism holds that some of the differences inferred between students and scientists are a matter of terminology. Schuster (1993) showed that changing the wording of certain questions can have a dramatic effect: "Which object's speed is changing more quickly?" elicits very different—and to a physicist more appropriate—responses from "Which object has a higher acceleration?"

Smith et al. (1993/1994) and diSessa (1988, 1993) challenged the idea of a discontinuity between student and expert knowledge, arguing that it conflicts with the constructivist account of how we develop new understanding:

> In focusing only on how student ideas conflict with expert concepts, the misconceptions perspective offers no account of productive ideas that might serve as resources for learning. Because they are fundamentally flawed, misconceptions themselves must be replaced. ... An account of useful resources that are marshaled by learners is an essential component of a constructivist theory, but the misconceptions perspective fails to provide one. (Smith et al., 1993/1994, p. 124)

That is, although the misconceptions perspective presents a need for conceptual change, from the students' misconceptions to the expert's appropriate conceptions, it does not provide an account of how that change may take place.

Finally, a number of researchers have questioned whether student reasoning is as consistent as the misconceptions perspective implies. Most of this criticism has been directed at views of student reasoning as based on coherent, alternative frameworks. A number of authors take the position that naive reasoning in physics lacks the coherence of expert reasoning (Hestenes et al., 1992; Huffman & Heller, 1995; Minstrell, 1989, 1992; Viennot, 1985). Some of these accounts not only challenge the view of students' having alternative, coherent frameworks, but also question the view of incoherent collections of stable, individual cognitive structures (diSessa, 1988, 1993; McDermott, 1984; Viennot, 1979). These authors point to a malleability in the conceptions attributed to students, evident in the variation of students' reasoning across different contexts.

P-Prims

Not all thoughts students express need to be understood as directly reflecting stable, stored knowledge structures. What the misconceptions perspective treats as a stored construct may alternatively be treated as an act of construction.

For example, in one popular demonstration of misconceptions, students were asked to explain why it is hotter in the summer than in the winter (Sadler, Schneps, & Woll, 1989). Many responded that this is because the earth is closer to the sun. To see this response as a misconception is to understand it as part of the students' knowledge system: The question accessed that stored (and faulty) element of knowledge about why it is hotter in the summer. Another interpretation would be that the students constructed that idea at the moment. This construction would be based on other knowledge, such as the (appropriate) knowledge that moving closer to the sun would make the earth hotter, but it is not necessary to assume that the idea itself existed in some form in the students' minds prior to the question.

DiSessa (1988, 1993) developed an alternative account of students' intuitive physics knowledge, positing the existence of more fundamental, more abstract cognitive structures he called phenomenological primitives or p-prims. By this view, how students respond to a question depends on which p-prims are activated.

For example, the question of why it is hotter in the summer may activate for them a p-prim connecting proximity and intensity: *Closer means stronger.* This p-prim is an abstraction by which one may understand a range of phenomena: Candles are hotter and brighter the closer you get to them; music is louder the closer you are to the speaker; the smell of garlic is more intense the closer you bring it to your nose. It may be through the activation of *closer means stronger* that students generate the idea that the earth is closer to the sun in the summer. That most people would have this primitive in their knowledge system, and that it has a high probability of being cued in the seasons question, is an alternative explanation for why many students give such a response.

Moreover, because *closer means stronger* is encoded at an abstract level, in other words because it is not directly linked to any surface features of experience, different entrances to the same topic would likely yield different responses. For example, if the question were to arise in the context of a discussion about the tilt of the earth, *closer means stronger* may never be activated or the p-prim may be activated but applied in a different way, leading the student to reason that the tilt of the earth pushes one hemisphere closer to the sun. By the misconceptions perspective, what is stored in some form is directly the notion that "it is hotter in the summer because the earth is closer to the sun." By that perspective, it is difficult to understand how any discussion about why it is hotter in the summer would not invoke the misconception.

In short, context sensitivity is easier to understand from a p-prims perspective than it is to understand from a misconceptions perspective, because p-prims are encoded at a more abstract level. The p-prims perspective does not attribute a knowledge structure concerning the closeness of the sun and the earth; it attributes a knowledge structure concerning proximity and intensity. Moreover, the p-prim *closer means stronger* is not incorrect.[3] Its activation in the situation of trying to explain the seasons is incorrect, but the knowledge element itself is not. This difference has practical relevance for instruction: A teacher would not try to eliminate the p-prim.

Similarly, rather than understanding students as having a misconception that *motion implies a force,* one may understand them as generating such responses from more fundamental knowledge elements. DiSessa described a p-prim, which I call *maintaining agency,*[4] that is related to the misconception, except again it is encoded at a more abstract level. *Maintaining agency* is involved in an understanding of a continuing cause that maintains motion, such as an engine maintaining the motion of a car, but it can also be involved in understanding that a supply of energy is necessary to keep a bulb lit or an oven hot, or that continuous encouragement is needed to keep a student motivated. Like *closer means stronger, maintaining agency* is not incorrect in and of itself; its activation in certain contexts is inappropriate.

Other primitives in diSessa's framework include *actuating agency, dying away, resistance, interference,* and *Ohm's p-prim. Actuating agency* is involved in understanding an initial cause of some effect, when the effect outlasts the cause, in the way that a toss causes the motion of a ball, the strike of a hammer causes a bell to ring, or, perhaps, a traumatic event causes anxiety. *Dying away* is an abstraction from experiences, such as the fading of the sound of a bell, a decay in time analogous to the decay with distance of *closer means stronger. Dying away* may underlie students' understanding of why a tossed ball returns to earth, as the influence of the *actuating agency* fades over time. *Resistance* and *interference* are two p-prims

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[3]I use *correct* and *incorrect* in this article to describe consistency and inconsistency with accounts that are established within the physics community.

[4]DiSessa (1993) called this p-prim *continuing push,* but the word *push* in that name may be misleading. I also use the name *actuating agency* instead of diSessa's *force as mover.*

pertaining to causes that impede an effect. *Ohm's p-prim*[5] is an abstraction from experiences involving an agency, an effect, and an impediment: The stronger the agency, the greater the effect; the stronger the impediment, the weaker the effect.

These two perspectives on students' knowledge thus posit different kinds of cognitive structures—misconceptions and p-prims—and these different models of knowledge point to different interpretations of students' reasoning. The following section presents a class discussion about forces and motion in which students express a number of views that are inconsistent with the standard, Newtonian account. In the subsequent analysis of the discussion, I describe how one may understand these views either as indicating misconceptions or as events of reasoning that involve the activation of more fundamental knowledge elements.

A CLASS DISCUSSION ABOUT FORCES AND MOTION

The purpose of this article, again, is to consider how alternative perspectives on student knowledge may influence instructional perceptions and intentions. The context for this comparison is a class discussion about forces and motion: How may a teacher perceive the students' reasoning in this discussion, and what may the teacher then see as tasks for instruction?

I first give some background about the class, and then I present an account of the discussion based on multiple viewings of the videotape, multiple readings of the transcript, and notes I recorded that day.

Background on the Class and Setting

There are about 2,000 students at the school, the single high school for a mostly working-class city in Massachusetts. I was there as a guest, teaching one physics class during the 1992 to 1993 academic year. The class met daily, for 42 min, except on Mondays when it met for a double period. I videotaped every meeting from the 3rd week of school through April 1st, except for occasional technical problems. In addition, I recorded daily, detailed notes and collected samples of students' work. There were 22 students in the class, divided evenly by gender. Sixteen were seniors, and 6 were juniors.

The discussion detailed later took place on Thursday, November 5th, about 2 months into the school year. With respect to the traditional content of a physics course, to this point in the year the students had been exploring various aspects of

[5]This name is due to the similarity between the p-prim and intuitive understandings of Ohm's law relating electrical potential difference, resistance, and current.

one-dimensional kinematics (see Hammer, 1995a, for further discussion of activities early in the year). During the week that preceded this discussion, they used microcomputer-based lab materials (Thornton, 1987). The final activity with that equipment was to examine what happens to the speed of a cart when it is pushed with a constant force, as measured by a spring scale attached to the cart. Most students predicted that the cart would move with constant speed, but they all found that the speed increased. We discussed these results for the first part of the period on Wednesday, November 4th. Some students suggested that the acceleration of the cart was constant, under constant force, but at that time we only reached a general consensus that the speed increased.

With about 15 min remaining on Wednesday, I brought out some metal tracks and rolled a steel ball on them to present two arguments by Galileo that "any velocity once imparted to a body will be rigidly maintained as long as there are no causes of acceleration or retardation."

The first argument is as follows. If a balls roll down one ramp and then up another, it will roll up the second ramp until it reaches the height from which it started, as long as the ramps and the ball are smooth enough so that the effect of friction on the height the ball reaches is negligible. Thus, if the up ramp has a shallower slope than the down ramp, the ball travels farther on the up ramp than it did on the down ramp. The more shallow the slope of the up ramp, the farther the ball travels to reach its original height (see Figure 1). By this reasoning, if the second ramp were horizontal, the ball would have to roll forever, because it would never reach its original height.

The second argument starts from the observation that a rolling ball gains speed if it is rolling downhill and loses speed if it is rolling uphill. If uphill loses speed

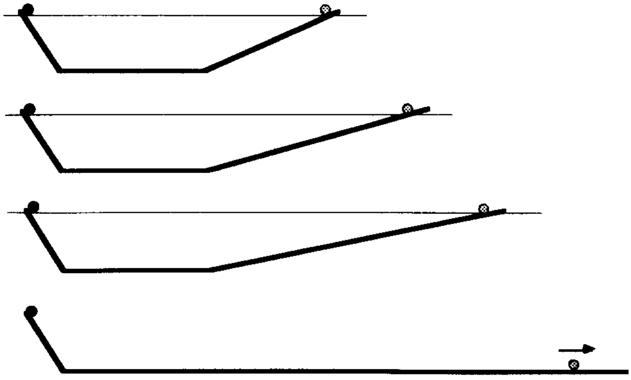

FIGURE 1 As the slope of the ramp becomes more shallow, the ball must travel further to reach its original height.

and downhill gains speed, then on a smooth, level surface the speed should be constant.[6]

The students accepted these arguments readily; in fact, a few students helped me complete the explanations. I assigned homework for the next day, first, for the students to read the textbook's (Haber-Schaim, Cross, Dodge, & Walter, 1976, pp. 224–226) account of Galileo's arguments and, second, for them to come up with arguments against Galileo's view that a ball will roll forever at a constant speed unless there is some force on it to make it speed up or slow down. Several students protested, saying they could not argue against what they thought was true. I explained that my reasons for this assignment were that I suspected they had other ideas "lurking around in [their] heads" and that it is important to consider alternative positions thoroughly.

An Account of the Discussion

At the beginning of class on Thursday, I drew on current events for further motivation, asking: "How many of you supported for president the same person your parents supported?" I asked whether they supported one or the other because they had thought carefully about both sides of the issue or whether it was just their upbringing.[7]

Teacher: My parents voted for the same person I voted for for president. I have to say, well wait a minute, did I just get it from them? I grew up in a family that had certain ideas that they think, and then I think them. Does that mean that those ideas are right, or does it just mean I grew up in that family.... If you're going to vote for Bill Clinton, you better know why somebody would want to vote for George Bush. Because if you don't know why anybody could ever vote for George Bush, you haven't thought it through. ... I know yesterday I gave this argument about Galileo, and everybody said "Yeah, it makes sense. Sure, it seems right." [But] if you don't seriously consider the other answer, how can you be confident about this answer? Maybe you just haven't thought it through.

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[6]George Smith has called to my attention the fact that physicists' practice of attributing these arguments to Galileo is misleading, because Galileo himself did not believe them. Galileo presented these arguments in his *Dialogues Concerning Two New Sciences,* but he went on to refute them. In this article, as in the class discussion, I continue the physicists' practice and attribute the view that the ball will continue moving at a constant speed to Galileo. To physicists, these arguments are valid motivation for Newton's first law of motion, the law of inertia, that an object with no force acting on it will move in a straight line at constant speed.

[7]In the dialogue excerpts, ellipses and brackets denote where the transcript deviates from direct quotation; dashes denote points of interruption. All students' names in this article are pseudonyms.

I argued that it is important not only to know reasons for your side, but also to understand and be able to respond to reasons for the other side. Tina helped me make a comparison between what I was asking them to do and what lawyers often have to do: "Whether they believe it or not, they have to argue for their client."

The students seemed convinced of the value of the exercise, so I solicited arguments against Galileo. Ning was the first to volunteer. She asked me to walk across the room and look at her as I sped up and slowed down. From my perspective, she explained, she was speeding up and slowing down, but there was no force on her to make her speed up or slow down. This brought an admiring murmur around the room, and, from this point on, there was a high level of engagement, with many side discussions and debates. No one had a response to Ning's argument, so I asked for other arguments. We did not return to Ning's until the next day.

Jack, referring to an experiment we had done earlier, said that a pendulum does not swing back up to the same height from which it was released, so the ball in Galileo's first argument should not come back up to the same height either. Other students said they thought the pendulum did swing back to the same height, but Scott convinced everyone by pointing out that the pendulum eventually stops, so it must lose a little height on each swing. Steve claimed that the pendulum lost height in its swing because of friction, and, he said, Galileo was talking about "an ideal environment with no friction." Jack asserted that a "pendulum has no friction."

I wrote Jack's point, that the ball would not roll to the same height, on the blackboard, and I asked for other arguments against Galileo. Penny was next.

1	Penny:	For the pendulum the reason it didn't go up to the same height was because of gravity. So why can't you think of the ball rolling on the flat surface stopping because of gravity too. It's going to slow down in a really small difference, so you can't even notice the difference, but eventually it's going to stop because of that little difference adding up.
2	Teacher:	So your argument is that the ball is slowing down, but it's just slowing down slowly enough that you can't really notice?
3	Penny:	Yeah because of gravity.
4	Teacher:	Because of gravity.

Several students responded; Amelia's voice was the loudest.

5	Amelia:	Yeah, but Galileo was talking about no gravity.
6	Harry:	If there's no gravity then how can the ball roll down the slope?
7	Steve:	No he was talking about gravity, he was just talking about no friction.
8	Nancy:	No friction, yeah.
9	Teacher:	So Galileo was talking about gravity.

10 Nancy: Gravity's a kind of friction, though.
11 Teacher: Gravity's a kind of friction?
12 Nancy: Yeah, because if you roll a ball down it speeds up because of gravity. And if you roll a ball up, it slows down because of the gravitational pull. So if you're rolling a ball horizontally the gravitational pull is pulling it down and it slows it down, you just can't notice, but eventually it will stop.

I intervened at this point, trying to curb the idea that "Galileo was talking about 'no gravity.'"

13 Teacher: I don't think he was thinking of "no gravity." It's like Harry said, how could it have rolled down the hill if there was no gravity? Why would he even have it roll down the hill? So he wasn't thinking of "no gravity."
14 Scott: It wouldn't roll down the hill, it would just float.

I reiterated Penny's argument and wrote it on the board: "The ball slows down gradually, so you don't notice, because of gravity." Steve contradicted that view, and Nancy and Jack contradicted his.

15 Steve: Well see the ball's not slowing down because of gravity, it's slowing down because of friction. So it—

Several voices, including:
16 Jack: But gravity is there, gravity stops it.
17 Nancy: But the gravity's pulling it down—

18 Steve: But if there was no friction and there was still gravity then it wouldn't slow down, because the ball wouldn't have any friction. It doesn't matter, gravity doesn't make it slow down. The thing that makes it slow down is the friction, not the gravity.
19 Jean: Gravity is the same as friction.

There were a number of voices at once, including Susan saying something about gravity getting stronger "farther away from the ground." I quieted others to give her the floor.

20 Susan: If you're farther away from the ground, the stronger the pull.
21 Teacher: The stronger the pull of gravity.
22 Nancy: It's just because you're right on the ground you can't feel it. You can't notice it.

23	Susan:	You can't feel it. You can't go any further. If you jump up in the air, right—
24	Teacher:	Yeah?
25	Susan:	It's gonna pull you right down. But if you're just standing there it's not going to pull you down.
26	Nancy:	Because you don't fall. It's just so small you [unintelligible].
27	Susan:	Because there's nowhere to go.
28	Teacher:	Okay. So how does that [relate to] the thing going sideways and slowing down?
29	Nancy:	Because it's still, it's pulling, here's the ball, and gravity's still pulling this, so eventually it's slowing it down.
30	Susan:	You don't see it.
31	Steve:	It's slowing down because of friction, if there was no friction then it wouldn't slow down.

Steve's comment led to another eruption of voices. I caught Amelia's saying that "if gravity doesn't pull us down, why wouldn't you keep moving all the time?"

32	Teacher:	[to Amelia, quieting other students] Why wouldn't we keep moving all the time?
33	Joanne:	It pulls us down, we're just saying it just doesn't you know—
34	Amelia:	It does make us stop.
35	Joanne:	—it doesn't say how fast and slow we're going to walk, [you're not going to be] floating in the air.
36	Amelia:	It's not friction, it's gravity. When you throw a ball, it does come down.

Amelia continued to argue her position, and the debate intensified, with many students speaking at once. Sean managed to win the floor to argue: "If you use a pendulum, does the string slow down the pendulum?" Ricky answered that "there is friction in the string where you're holding it," and Sean clarified his question.

37	Sean:	Well does the string itself slow down the ball. Because it's holding it at a certain distance. Sort of like gravity does with objects, holds it right onto the surface.
38	Teacher:	[gets a pendulum to help illustrate Sean's point]
39	Sean:	The string is the gravity. It's just keeping the pendulum where it's supposed to be.
40	Teacher:	The string is just keeping the pendulum in this [draws an arc on the board]. So the pendulum swings like this [gestures along the

arc on the board], and the reason the pendulum doesn't go past this is because the string is holding it along that path. Is that what you're saying?

41 Sean: [Yes.]

42 Teacher: And so, you're saying if you roll a ball along a track, gravity is just holding, making it so it moves along the track.

43 Sean: Yeah.

Susan asked why the two forces, gravity down and the string up, would not make the ball slow down; Sean answered that "what's slowing it down is the friction."

Ning came back into the discussion to say that "the Galileo theorem" concerned an "idealized" situation with no forces, which must mean no gravity and no friction. This brought us back to the question of whether gravity is present, but Bruce took the discussion in a new direction.

44 Bruce: If there is no gravity and no friction, and there is a force that's making it move, it's just going to go in a straight line at a constant speed.

45 Teacher: Okay. Penny—

46 Penny: If there's no gravity the ball wouldn't stay where it is.

47 Teacher: If there's no gravity, Penny says, if there's no gravity the ball wouldn't stay on the track. The ball wouldn't stay where it is. So [to Bruce] do you have a, what do you say to that?

48 Bruce: What's making the ball move?

49 Amelia: [over several other voices] The forces behind it.

50 Susan: He said there was no force.

51 Bruce: If there's no force pulling it down, and no force slowing it down, it would just stay straight.

Several voices at once, including:

52 Harry: The ball wouldn't move.

53 Jack: There's no force that's making it go.

54 Steve: The force that's pushing it.

55 Bruce: The force that's pushing it will make it go

56 Jack: Where'd that force come from, because you don't have any force.

57 Steve: No there is force, the force that's pushing it, but no other force that's slowing it down.

Sean gave the example of something moving in "outer space ... it's not going to stop unless you stop it." Penny objected that the situation of the rolling ball is "nothing like space." Amelia objected for another reason, saying that something moving in space will still stop, because "even in space ... there are ... gases."

I intervened at this point to steer the discussion away from the question of whether there are gases in space and toward an apparent inconsistency.

58 Teacher: Bruce, you were saying there is the force on it that is moving it. So how can one side say there are no forces on it, and the other side say there is a force that's moving it.

59 Bruce: Well there was an initial force.

60 Susan: There's an initial force that makes it start, giving it the energy to move.

61 Teacher: There was an initial force.

62 Nancy: That initial force is gravity, because [if] there's no gravity it's not going to roll down.

Jack talked about a puck on an air hockey table, arguing that it will stop; he and Bruce debated whether it would stop because of friction or because of gravity.

Steve explained that "gravity slows it down because of friction ... the reason it slows down is because gravity is putting friction on the ball ... by rubbing it against the ground." This escalated the intensity of the debate. Penny's reaction was that Steve's explanation supported her position.

63 Penny: If you're saying that there's friction because of gravity, how can you take away friction and leave gravity there? If gravity's there, there's going to be friction.

I highlighted as a key issue the question of whether it is possible to think of taking away friction without taking away gravity. Ning argued that "you can" because "friction and gravity are different forces. Even their direction is different." She explained that "gravity is pointed directly down," but "friction depends" on the motion. If a book is sliding to the left on a table, "the friction direction is to the right and the gravity direction is [down]," and "we don't have to talk about gravity" because the force of the table on the book cancels it. This brought a fresh burst of discussion around the room, but there were only a few minutes left in the period. I stopped the discussion and assigned as homework for students to support or refute, in writing, any of the arguments that had been presented.

The Discussion As Seen From Misconceptions and P-Prims Perspectives

There were a number of ideas students expressed in this discussion that were at least technically inconsistent with a Newtonian account of forces and motion. I consider five: (a) gravity makes the ball slow down; (b) no friction means no gravity; (c) gravity is stronger farther from the ground; (d) gravity holds objects onto the ground; and (e) the ball's motion is caused by a force. This section discusses these ideas, describing how each may be seen either as indicating stable misconceptions or as situated acts of conceiving involving the activation of p-prims. Again, the purpose is not to argue which is the better account, and I do not consider the classroom excerpts as data that could validate or invalidate either perspective.

Gravity Makes the Ball Slow Down

Misconceptions. During the class discussion, several students articulated the idea that gravity makes the ball slow down (Penny, line 1; Nancy, lines 10, 12, 29; Jack, line 16; Susan, line 30; Amelia, line 36). Teachers familiar with the literature would anticipate the misconception that the downward force of gravity slows horizontal motion. McCloskey (1983), in particular, described this notion as part of an impetus theory of motion: Gravity and friction drain impetus from a moving object.

The misconceptions perspective provides, for example, an understanding of Penny's reasoning in line 1. Jack had compared the ball's rolling up and down the ramps in Galileo's first argument to the motion of a pendulum, noting that the pendulum did not return to its original height and asking why we should expect the ball to return to its original height. Penny went beyond Jeff's phenomenological point to suggest the cause: Gravity prevents the pendulum from rising back to its original height, so, she claimed, it is reasonable to expect that gravity would stop a ball's motion on a horizontal plane.

Without an awareness of the misconception, Penny's reasoning may seem strange: Why should what happens to the pendulum, in which gravity can be seen as acting downward against the pendulum's rise, have any implication for what happens to the ball rolling on a horizontal surface? The misconception that gravity drains impetus makes these two situations examples of the same phenomenon.

P-prims. Alternatively, one may understand the idea that gravity makes the ball slow down as constructed by students in the context of the discussion. In diSessa's account (1993), the motion of a ball on a horizontal plane is likely to activate *dying away:* The ball's motion naturally decays. In many situations, *dying away* would have been sufficient. In this situation, however, the ball's slowing needed further explanation, and the students needed to identify a cause for the *dying away.* The implicit question asking for a mechanism to explain *dying away* cued the p-prim *interference,* so that students generated the idea that gravity causes the ball to slow down. For Penny and others, the pendulum cued the same p-prims as the ball, so they generated the same explanation.

No Friction Requires No Gravity

Misconceptions. Nancy (line 10) and, moments later, Jean (line 19) stated this misconception, which ran through the discussion: "Gravity is a kind of friction; Gravity is the same as friction." Other students, including Amelia (line 5), Bruce (line 44), and Ning, confused whether Galileo was neglecting gravity; Penny (line 63) said concisely what seemed to be a widely subscribed view: "If gravity's there, there's going to be friction."

It is difficult to attribute this reasoning to any of the misconceptions that have been described in the literature. Gravity and friction play a similar role in the impetus theory (McCloskey, 1983), but that does not entail the view that friction must be present if gravity is present. In this discussion, for example, Jack showed very clearly the misconception that gravity makes the ball (and the pendulum) slow down, but he did not have a misconception that no friction means no gravity.

There is, however, no reason to expect that all misconceptions have been catalogued, and it may be useful to think of this as a new one. It would be a way to make sense of several students' persistence in claiming that Galileo was thinking of no gravity, despite compelling reasons to the contrary (Galileo had a ball rolling down a ramp) and despite the teacher's attempt to stop this line of reasoning (line 13).

P-prims. From diSessa's (1993) perspective, the students' view that no friction requires no gravity would be an example of the incoherence and sensitivity to the immediate situation of the students' reasoning. When they were focused on the ball rolling down the ramp, the students thought of gravity as causing the ball's motion, their reasoning probably mediated by one or both of the p-prims *actuating agency* and *maintaining agency*. When they were focused on the ball rolling on a level plane, they thought of gravity as interfering with the ball's motion and associated it with friction, their reasoning mediated by *interference* and *dying away*. It was possible for students to recognize gravity as necessary for the ball's motion down the ramp and then to insist that Galileo was neglecting gravity because these were separate acts of conceiving that took place in different situations.

The students' failure to comply with the teacher's suggestion to neglect friction but not gravity may be understood not as evidence of a misconception resistant to change but as an example of regeneration. The teacher's suggestion may have convinced students for a moment, but it did not prevent them from reconstructing the idea shortly later in the conversation.

It is important to note another plausible account not directly connected with misconceptions or p-prims. Some of the students may have intuited a causal relation between gravity and friction as Steve articulated late in the discussion: "Gravity puts friction on the ball ... by rubbing it against the ground." In fact, physicists would agree in principle that it is not possible to eliminate friction between two objects that are in contact and in relative motion. It is correct that no friction between the ball and the ground would require no gravity (or no motion). Nevertheless, physicists also consider it valid and productive in such cases to suppose no friction. This is what some of the students may not have understood: the physicists' practice of supposing ideal, unattainable conditions. Ning may have been expressing this epistemological point when she noted that Galileo was thinking of an idealized situation.

Gravity Is Stronger Farther From the Ground

Misconceptions. Susan and Nancy's idea (lines 20–26) that "if you're farther away from the ground, the stronger the pull" is also difficult to attribute to any misconception described in the literature. There have been accounts of a misconception that gravity is stronger closer to the ground (Champagne et al., 1980; Hestenes et al., 1992), but not farther. Again, however, one may think of this as a new misconception.

One may also think of this as an idea Susan and Nancy constructed at the moment from other misconceptions. In fact, Champagne et al. (1980) presented the idea that gravity gets stronger the closer an object is to the earth, not really as a misconception in itself, but as a hypothesis students generate in order to remain consistent with a misconception that motion is caused by an external force, the increase in speed as an object falls indicating to the students an increasing force of gravity.

Susan and Nancy may have been doing something similar here, generating the idea that gravity is stronger farther from the ground as an attempt to remain consistent with a misconception that gravity drains impetus: Because impetus appears to drain more slowly for a ball rolling on the ground than for a ball tossed in the air, gravity must be weaker on the ground. Moreover, Susan's explanation (lines 25, 27) that, on the ground, gravity is "not going to pull you down ... because there's nowhere to go" implicates a misconception that obstacles do not exert forces (Minstrell, 1982).[8] That misconception may also have supported the construction of the idea: Not recognizing an upward force, but recognizing a change in effect, the students generated the idea that the downward force was weaker.

[8] The physicist's explaination would be that the ground exerts an upward force equal and opposite to the downward force of gravity, resulting in no net vertical force.

P-prims. Similarly, the idea could be understood as an act of conceiving from the activation of *Ohm's p-prim:* A stronger cause produces a greater effect. Gravity has a pronounced effect on objects in the air, but its effect on objects on the ground seems very small. That the students did not consider the influence of the ground is an indication that, in this situation, the p-prims *supporting* and *interference* took a low priority in their reasoning.

Gravity Holds the Ball Onto the Ground

Misconceptions. Sean's idea (lines 37, 39) that "gravity holds [the ball] right onto the surface" may indicate a misconception of gravity as a constraint, "holding [the ball] at a certain distance." Like Nancy and Susan, Sean was expressing a view of the gravitational pull on the ball as somehow related to the surface on which it rests, and his reasoning may have involved the misconception that obstacles do not exert forces.

P-prims. If we think of Sean's idea, that "gravity holds [objects] right onto the surface" as a stored piece of knowledge he may apply generally, then we should be concerned about it as a misconception. Alternatively, Sean's idea may be seen as involving the activation of one or more p-prims from what diSessa (1993) called the "constraint cluster," including *supporting, guiding,* and *clamping.* If we think of Sean's idea as an act of conceiving specific to the situation, then we may consider it an imaginative and productive line of reasoning, because, in the situation, Sean's idea was not inconsistent with Newtonian reasoning. By a Newtonian account, a force directed perpendicular to an objects' motion, such as the force of the string on the pendulum bob or the gravitational force on the ball, cannot affect the object's speed.

In fact, Sean's account of the role of the string or of gravity in these situations may be seen as an intuitive version of the physicist's notion of an *holonomic constraint,* which has the property that its influence can be taken into account implicitly through an appropriate selection of coordinates. Sean's reasoning about the string and gravity as imposing a constraint on the motion on the bob or ball, but as otherwise unimportant, is rigorously defensible. Thus, instead of being concerned about a misconception, we may see in Sean's reasoning the seeds of a Newtonian understanding.[9]

[9]Note further that Sean compared gravity, in the situation of the ball, to the string, in the situation of the pendulum; he could well have chosen to compare the string to the table surface and gravity to gravity. The latter comparison seems more direct: There is gravity in both situations; the string and the table both prevent the object from falling. However, the string is always lateral to the pendulum bob's motion and can therefore be seen as a constraint; gravity is not always lateral to the bob's motion, and in the case of the pendulum, it cannot be seen as a constraint.

The Ball's Motion Is Caused by a Force

Misconceptions. Bruce's question (line 48), "What's making the ball move?" was the first explicit mention of the need for something to cause the ball to move. Comments by Amelia (line 49), Harry (line 52), Jack (line 53), and Steve (lines 54, 57) all similarly indicated a misconception that motion is caused by force, although it would be difficult from these comments alone to distinguish whether students thought of the force as stored within the ball or as externally applied.

Responding to my question (line 58) of how to reconcile the view that there are no forces on the ball with the view that a force causes its motion, Bruce (line 59), Susan (line 60), and Nancy (line 62) called the cause of motion an "initial force," implying a force that initiated the ball's motion and suggesting that they were thinking of "force" as externally applied. Susan's version (line 60), that the "initial force [gives the ball] the energy to move" may be seen as indicating an impetus misconception, in that the effect of the initial force was to store impetus, "the energy to move," in the ball.[10]

P-prims. From the misconceptions perspective, the students' comments point to various misconceptions that motion is caused by force. One may alternatively understand their views as events of reasoning involving the activation—and deactivation—of various p-prims. The situation of a ball rolling on a horizontal plane has a high probability of cuing *dying away:* Moving objects slow down and stop. Asked to explain the motion of the ball, the students began to look for causes of its motion and causes of its slowing, a situation likely to activate one or both of *actuating agency* and *maintaining agency,* as well as *interference* or *resistance* as mentioned earlier.

The teacher's question (line 58), focusing attention on the conflict between the statements that there is no force on the ball and that a force causes it to move, may have favored *actuating agency* over *maintaining agency,* activating the former and deactivating the latter, so that some students began to distinguish an initial force from a continuing force. Prior to that, the students had felt no need to distinguish, either in their reasoning or in their speech, a force that acts on the ball during its motion from a force that acted in the past on the ball and set it in motion.

[10]If one were to attribute the physicist's meaning of *energy* and *force* to Susan's use of the terms, one could see her statement as correct (and thus revealing a correct conception): An initial force does work on the ball, giving it kinetic energy. It would be difficult to support such an attribution, however, given Susan's other comments as well as the fact that this discussion was the students' first look at dynamics.

On this view, much of the students' reasoning could be seen as the beginnings of a Newtonian understanding: *Actuating agency* may be a useful resource for building an understanding of the physicist's concepts of *impulse, work,* or both; *maintaining agency,* for *momentum, energy,* or both. Thus, the students were describing an initial agency imparting something to the ball, and it is not unlikely that this could develop into the idea of an impulse imparting momentum or of work imparting energy. Again, instead of being concerned about a misconception, we may see seeds of a physicist's understanding.

Tasks for Instruction

How one conceptualizes the tasks for instruction depends significantly on what one perceives in students' knowledge and reasoning. The preceding analysis considered how alternative perspectives may influence a teacher's perceptions of five ideas technically inconsistent with a Newtonian account: (a) gravity makes the ball slow down; (b) no friction requires no gravity; (c) gravity is stronger farther from the ground; (d) gravity holds objects onto the ground; and (e) motion is caused by force. This section considers how the different perceptions of these ideas may influence a teacher's sense of the consequent tasks for instruction.

In many ways, the misconceptions and p-prims perspectives lead to similar judgments about the tasks for instruction. Both suggest it would be ineffective simply to explain the standard Newtonian account; both see students' incorrect statements as reflecting cognitive structure rather than as individual, nonsensical mistakes. Both suggest it is important for an instructor to explore the students' knowledge and reasoning, to look for the sense behind their incorrect statements.

The two perspectives differ, however, with respect to what the instructor may find in that exploration. From one perspective, a teacher sees conceptions inherently inconsistent with expert knowledge; from the other, a teacher sees p-prims, knowledge elements that could contribute to expert understanding. The principal practical significance for a teacher is that the former implies the tasks of dismantling and replacing prior knowledge, whereas the latter suggests the task of modifying the organization and use of prior knowledge.

Misconceptions

From a misconceptions perspective, one may see an impetus theory (McCloskey, 1983) underlying much of the students' reasoning. One may also see as misconceptions the ideas that no friction requires no gravity, that gravity is stronger farther from the ground, and that gravity constrains objects to move on the ground. The misconception that obstacles do not exert forces (Minstrell, 1982) also seemed to be involved. Still others, not evident in the discussion, may be expected based on prior research and experience, such as the misconception that air pressure causes gravity (Minstrell, 1989).

A primary task for instruction, based on these perceptions, would be to eliminate or at least weaken these misconceptions. This could involve, first, drawing out any misconceptions that had not been sufficiently articulated; second, confronting and confuting those misconceptions with arguments or evidence; and third, facilitating the students' construction of new, more appropriate conceptions (Strike & Posner, 1985). Within this perspective, one challenge for the teacher is to decide when the students have sufficiently articulated their various misconceptions. There is a risk in confronting a misconception too soon, that the misconception has not been sufficiently articulated and the intervention will be ineffective. On the other hand, there is a risk in waiting, that the discussion will reinforce the misconception.

A teacher who sees the students as reasoning from an impetus theory would not believe this discussion had been successful in making that theory explicit. Only Susan's comment, that an "initial force [gives the ball] the energy to move" (line 60), could be interpreted as referring to an impetus stored within the ball. Between the two versions of the impetus theory (McCloskey, 1983), by which impetus is seen either as draining on its own or because of an external influence, only the latter has been evident: In every instance, the students spoke of an external influence causing the ball to slow down, even in outer space where, Amelia argued, the ball would stop because "there are still other gases." The teacher may choose to let the discussion continue to draw out impetus theories; the teacher may intervene in some way to facilitate their appearance.

On the other hand, the view that no friction requires no gravity has, at this point, been expressed and debated at some length, and it may be ripe for confrontation. Ning already initiated a strong challenge to that misconception, in her explanation that the forces of gravity and friction act in different directions. The teacher could build on her argument or use Jack's example of air hockey to present a series of situations that lead toward an idealized limit of no friction. Recognizing this view as a deeply held misconception, the teacher could see it as necessary to discuss and confront, rather than as a passing notion that can be dismissed lightly.

Susan and Nancy clearly expressed the idea that gravity is stronger farther from the ground, and if this is a misconception, it should now be possible to confront it. For example, the teacher could ask why we do not feel heavier on the fourth floor of a building than we do on the first, ask whether airplanes get heavier as they gain altitude, or suggest that someone standing on the ground does exert a substantial force on it. The earlier analysis, however, raised the possibility that *gravity is stronger farther from the ground* may be better understood as an idea the students generated from a misconception that gravity drains impetus. If that is the case, then it may not be important or effective to confront the idea as a misconception itself.

Sean's misconception, that gravity holds objects onto the surface, may be more difficult to address, and at this point it probably has not been sufficiently articulated, but eventually the teacher could ask whether gravity's action depends on the nature of the surface, or what we should expect to happen if the surface were suddenly removed. It may be appropriate to prepare a lesson (Minstrell, 1982) specifically to elicit and confront the misconception that obstacles do not exert forces because it appeared to have been involved in several of the students' reasoning.

P-Prims

From diSessa's (1993) perspective, the discussion pointed to the involvement of a number of p-prims in students' reasoning, including *dying away, actuating agency, maintaining agency, Ohm's p-prim, interference, resistance,* and constraint primitives. A primary task for instruction would be to exploit these resources toward students' construction of a physicist's understanding.

With respect to the students' sense that the ball's motion is caused by a force, the teacher may identify *actuating agency* and *maintaining agency* as resources from which students could construct a physicist's understanding. Thus, a teacher may never challenge the view that a force is necessary to maintain motion, promoting instead its adaptation toward a view that momentum is necessary to maintain motion (diSessa, 1980). In this discussion, a teacher's question (line 58) created a situation that differentiated the activation of *actuating agency* and *maintaining agency,* as Susan and others began to describe the force as "initial." This could be seen as a step toward the expert distinction between applied impulse and stored momentum.

The p-prims account thus allows a different orientation toward student learning: The teacher may schematize instruction as promoting appropriate aspects of students' knowledge and reasoning. Rather than working to dismantle the conceptions that gravity slows horizontal motion, or that no friction requires no gravity, this perspective suggests using these acts of reasoning as steps toward a physicist's understanding. Steve's argument, late in the discussion, provided one promising option. He affirmed that gravity slows horizontal motion and that gravity causes friction, but he added a specific causal mechanism: Gravity slows the ball by pressing it against the ground, which results in friction. To give one plausible account from the p-prims perspective, this argument in effect uses the original activation of *interference,* with gravity as the interference, to activate *maintaining agency,* with gravity as the agent that causes friction, and friction becomes the interference. This would represent progress toward a physicist's understanding.

Similarly, to perceive the thought that gravity is stronger farther from the ground as a passing act of reasoning would relieve the teacher of the concern for eliminating it as a faulty element of the students' knowledge. Here, the teacher may focus on Susan's and Nancy's contributions as reflecting important aspects of scientific inquiry (Hammer, 1995b): They were reasoning from everyday experience, and they were trying to account for apparent differences across different situations of the effects of gravity on motion.

Finally, to understand a student's view as specific to the situation may affect the teacher's assessment of its consistency with respect to an expert account. Sean's idea that gravity "holds" the ball onto the ground is an example: Seen as a general conceptualization of gravity, this view is problematic; seen as an idea generated in the given situation, it is consistent with a physicist's understanding. Rather than challenge it as a misconception, the teacher could choose to support and build on it as a creative and productive act of conceiving.

RESEARCH PERSPECTIVES AND INSTRUCTIONAL PRACTICE

Misconceptions and P-Prims

The notion that students come to science courses with misconceptions is now routine in science education discourse. Common usage, if not all explicit conjecture, attributes to misconceptions the property of existence within students' minds. Thus, we speak of students as having, revealing, and hanging on to their misconceptions. Misconceptions (or preconceptions or alternative conceptions) connotes cognitive structures, as opposed to events or patterns of behavior, that are inconsistent with scientists' cognitive structures. They interfere with, rather than contribute to, students' development of expertise.

DiSessa and his colleagues (diSessa, 1988, 1993; Smith et al., 1993/1994) have challenged the misconceptions perspective on theoretical grounds and offered a different account of cognitive structure in terms of phenomenological primitives. These p-prims are also structures, but they are both smaller and more general than misconceptions, conceived of as involved in and contributing to both naive and expert understanding. P-prims do not interfere with students' development of expertise; they are essential to it.

It is important to acknowledge that both perspectives are less than prescriptive with respect to instructional technique. Of the two, the misconceptions perspective is more specific: It is difficult to see how instruction could succeed without confronting in some way the students' misconceptions, and most authors taking this perspective describe some form of confrontation as necessary (Smith et al., 1993/1994). However, the misconceptions perspective does not rule out the possibility of useful resources in students' knowledge. Clement, Brown, and Zeitsman (1989, see also Brown & Clement, 1989; Clement, 1991) noted that not all preconceptions are misconceptions and described the use of bridging analogies to help students gain access to their appropriate conceptions.

The p-prims perspective does not rule out confrontation. From this perspective, students need to build from their productive resources, but if they have become complacent, confrontation may be an effective device to prompt them into a process of inquiry and construction. One may also think of confronting a robust but inappropriate pattern of p-prim activation.[11]

Proponents of the two perspectives, in fact, draw many similar implications for instruction. From both perspectives, students and teachers should explore and address students' existing ideas. Proponents of both perspectives argue that it is important to address similar ideas across a wide range of situations, although for different reasons: From a misconceptions perspective, this is because the misconceptions are so deeply entrenched that they need to be confronted with multiple and varied evidence and arguments, whereas from the p-prims perspective, it is because of the sensitivity to the situation of the p-prims' activation.

Thus, in many respects, differences between the two perspectives have been of greater theoretical than instructional interest in the science education community. In at least one respect, however, the difference is instructionally significant: The misconceptions perspective implies the necessary task of eliminating unsuitable cognitive structures. It may be useful to identify and build from students' useful conceptions, but to construct from useful conceptions without eliminating misconceptions would leave in place knowledge inherently inconsistent with expert understanding.

Multiple Perspectives and Instructional Implications

The purpose of this article has been to help differentiate between two theoretical perspectives with respect to how each may influence a teacher's perceptions and intentions. The purpose has not, however, been to derive instructional implications directly in terms of methods. Although I have noted various actual and possible teacher interventions, I do not intend to be making any claims about instructional technique. In particular, I am not promoting my own methods as ideal or even as appropriate.

There are three reasons for this emphasis on perceptions and intentions rather than on methods. First, as I noted earlier, neither perspective is specifically

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[11] This may be a way to understand misconceptions from within the p-prim perspective, as robust but inappropriate patterns of p-prim activation. This would constitute a model with multiple levels of cognitive structure (Brown, 1993), and it would represent a shift from misconceptions as commonly understood. Within such a unified model, with multiple levels of cognitive structure and phenomenology, there would be alternatives for how to conceptualize any given student idea.

prescriptive with respect to method, and either could be invoked to support similar approaches.

Second, neither perspective is sufficiently reliable, nor enjoys sufficient stability and consensus in the community, to warrant commitment in educational practice. I should note that I am not embracing here a blanket "postmodern" position that we should never treat any scientific perspective as if it describes reality. There are a number of constructs in the field of physics, for example, that have remained stable for decades and are in essence unanimously accepted. Electricians, scientists, and lay people quite commonly apply *metals conduct electricity* as scientific fact; physicists and solid-state engineers treat Coulomb's law as an established truth, and in almost all situations, it has served them well to do so. In contrast, there is not sufficient basis of experience, theoretical coherence, or consensus to justify teachers' faithful adherence to either a misconceptions or a p-prims account of student knowledge.

Third, there are many, many other perspectives and considerations that contribute to instructional decisions (Ball, 1993; Clark & Peterson, 1986). Indeed, teachers would find it absurd to suppose that either or both of the misconceptions and p-prims perspectives could be sufficient to determine appropriate intervention. Research, moreover, provides strong theoretical and empirical reasons to believe that an adequate theory of knowledge, reasoning, and learning must include a range of cognitive and affective structures and processes in a complex ecology (Baron, 1985; Niedderer & Schecker, 1992; Schoenfeld, 1983). Elsewhere, I have discussed the influence on instructional perceptions and intentions of an epistemological perspective (Hammer, 1995a), that is, a view of students as having beliefs about knowledge and learning, and of an inquiry-oriented perspective (Hammer, 1995b). Examples of such considerations appear in the preceding analysis: One may understand the students' insistence that no friction requires no gravity as reflecting a difference between their practice of inquiry and the physicists' practice, in that the latter often involves supposing idealized, unattainable conditions. One may perceive, in the students' arguments that gravity is stronger farther from the ground, that they were reasoning from everyday experience.

There was much more. My objectives in assigning students to find arguments against Galileo, and in planning to debate the matter in class, were not limited to students' progress toward physicists' understanding of forces and motion. I also hoped to promote the notion that it is important to consider alternative views thoroughly before accepting one as correct, and I meant to raise students' awareness and skepticism of their hidden assumptions. Moreover, I wanted them to begin to connect reasoning in physics with reasoning in everyday life, such as in voting for president, an example I chose because it was a current event, or in being a lawyer, which I chose specifically for Joanne, who planned to become a lawyer and who, at this point in the year, remained emphatic in her view that I should be providing information rather than asking students to reason and discuss.

During the discussion, I was aware not only of the content of the students' statements but also of their engagement and interest both for the class as a whole and for individual students. For the class as a whole, this discussion marked a qualitative change in the general level of their participation from the previous days, with well over half of the students actively contributing and most of the rest quite attentive. This was progress I wanted very much to maintain and extend. Penny, who had been all but silent since the beginning of the year, was one of the main instigators of the debate. She and others around the room were frequently talking out of turn, breaking into heated side discussions, always (as far as I could tell) on topic; these side discussions included some of the students who never took the main floor. Joanne, meanwhile, sitting in the front row, was checking her watch, and Mona and Tim remained passive and uninvolved, perhaps uninterested or perhaps intimidated.

It would thus be misleading to present instructional implications of misconceptions or p-prims perspectives directly in terms of intervention. With or without these perspectives, teachers' perceptions of students remain incomplete and ambiguous, and the practice of instruction remains uncertain. Such a state of affairs is uncomfortable for researchers, as the practice of research generally involves a search for definitive, principled understanding, but it is a fact of life for teachers. I am suggesting a modest epistemological stance with respect to the instructional implications of education research: Both researchers and teachers should, at least for the present, understand research as supporting teachers' development of conceptual tools, to broaden and support teachers' awareness, judgment, and inquiry, rather than as providing reliable findings and principles or as prescribing methods and curricula (Richardson, 1994; Schön, 1987).[12]

When I reflect on the respective contributions of misconceptions and p-prims perspectives to my perceptions and intentions as the teacher of this class, I discern several roles. Both contributed to my sense of the students' conceptual understanding, in particular to my distrust of their initial acceptance of Galileo's argument and to my anticipation of various ideas. I considered the misconceptions perspective the more valuable resource with respect to my agenda of helping students become aware of their reasoning. Thus, I told the students that part of the purpose of having this discussion was to draw out conflicting knowledge I suspected they had lurking in their minds. (In subsequent discussions, I described *force causes motion* as a "mental magnet," an idea that lives in our heads and to which we are drawn.)

The p-prims perspective, on the other hand, motivated my decision to draw out and build on the students' distinction between an initial and an ongoing force, rather than to draw out and then confront the idea that motion is caused by force. Over

[12]Minstrell's (1992) account of "facets," influenced by both misconceptions and p-prims perspectives, is an example of a construct of research designed more as a tool for instructors than as a theoretically and empirically defensible model.

the next several days, the class considered various definitions and names for these two kinds of forces, eventually settling on *inner force,* defined as a force stored within a moving object, and *outer force,* defined as caused by something external to the object. These terms became part of the class vocabulary; we refined the definitions, and eventually I offered that these ideas of inner force and outer force were similar to what physicists' call momentum and, simply, force.

More generally, the differences between p-prims and misconceptions perspectives on student knowledge affected not only my sense of how to help students progress toward physicists' knowledge but also of how to coordinate this agenda with others (Ball, 1993; Hammer, 1995a, 1995b), including promoting students' participation in inquiry, appropriate beliefs about knowledge and learning, and confidence in themselves as scientists. Often, these other agendas provide reasons for caution with respect to confrontation as an instructional strategy. To contest students' reasoning, for example, may dissuade them from participating or from believing that their ideas and experience are relevant.

I am often aware of this tension between, on the one hand, as Perry (1970) described, my intentions to support students' "sustained groping, exploration and synthesis ... initiative and scope in their own thinking" (p. 211), and, on the other hand, a sense that I need to repair "errors" and "inexactnesses" (p. 211) I perceive in their reasoning. I find that it amplifies this tension to think of students' knowledge in terms of misconceptions. Discussions with students invariably present a myriad of errors and inexactnesses, and the tasks of addressing the underlying misconceptions, as well as the risks of inadvertently contributing to them, conflict in my thinking with the importance of establishing and promoting the students' participation. In contrast, I find it alleviates this tension somewhat to think of students' knowledge in terms of p-prims. The task of supporting students' construction from useful cognitive resources generally aligns in my thinking with the task of promoting their participation.

This has not, however, been a study of my thinking, and these reflections at the end of the article should be distinguished from the analyses earlier. With respect to misconceptions and p-prims perspectives, the analyses went far beyond my perceptions and intentions as the teacher during the class, and in other respects, they fell far short. As well, I do not claim to have faithful access to my thought processes during the class; I consider my reflections only a plausible account. Moreover, I was not a typical teacher: I was teaching one class, videotaping, keeping a journal, and contemplating the influence of research perspectives on my work.

This was a study of the two perspectives and what they might in principle say about students in an authentic instructional context. Such hypothetical analysis is useful, first, in promoting clarity and precision in researchers' and teachers' understanding of the perspectives and, second, as a step in understanding their instructional significance. Further study, however, must involve other teachers. Informal conversations suggest that the influence of the misconceptions perspective on teachers' thinking varies considerably. For some, it implies the importance of anticipating and confronting students' mistaken concepts; for others, it suggests what seems to be the opposite, the importance of validating student ideas as rational and legitimate.

We need to learn more about how teachers are influenced by these and other perspectives. The Cognitively Guided Instruction project (Knapp & Peterson, 1995) is one example of such research: They presented teachers with research about elementary mathematics learning (Carpenter, 1985) and studied the influences on the teachers' practices. McDonald (1986) described another, in the conversations among a group of teachers who, to their surprise, came to find useful new insights in educational theory. Further work in similar directions will inform the development of research perspectives, how and whether they should be presented to teachers, and, more generally, how we should conceive of the relation between research and instruction.

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REFERENCES

Arons, A. B. (1990). *A guide to introductory physics teaching.* New York: Wiley.

Ball, D. (1993). With an eye on the mathematical horizon: Dilemmas of teaching elementary school mathematics. *Elementary School Journal, 93,* 373–397.

Baron, J. (1985). *Rationality and intelligence.* New York: Cambridge University Press.

Brown, D. E. (1993). Re-focusing core intuitions: A concretizing role for analogy in conceptual change. *Journal of Research in Science Teaching, 30,* 1273–1290.

Brown, D. E., & Clement, J. (1989). Overcoming misconceptions via analogical reasoning: Abstract transfer versus explanatory model construction. *Instructional Science, 18,* 237–261.

Camp, C., Clement, J., Brown, D., Gonzalez, K., Kudukey, J., Minstrell, J., Schultz, K., Steinberg, M., Veneman, V., & Zietsman, A. (1994). *Preconceptions in mechanics: Lessons dealing with students' conceptual difficulties.* Dubuque, IA: Kendall/Hunt.

Carey, S. (1986). Cognitive science and science education. *American Psychologist, 41,* 1123–1130.

Carpenter, T. P. (1985). Learning to add and subtract: An exercise in problem solving. In E. A. Silver (Ed.), *Teaching and learning mathematical problem solving: Multiple research perspectives* (pp. 17–40). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Champagne, A. B., Klopfer, L. E., & Anderson, J. H. (1980). Factors influencing the learning of classical mechanics. *American Journal of Physics, 48,* 1074–1079.

Clark, C. M., & Peterson, P. L. (1986). Teachers' thought processes. In M. C. Wittrock (Ed.), *Handbook of research on teaching* (pp. 255–296). New York: Macmillan.

Clement, J. (1983). A conceptual model discussed by Galileo and used intuitively by physics students. In D. Gentner & A. Stevens (Eds.), *Mental models* (pp. 345–362). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Clement, J. (1991). Nonformal reasoning in experts and in science students: The use of analogies, extreme cases, and physical intuition. In J. Voss, D. Perkins, & J. Siegel (Eds.), *Informal reasoning and education* (pp. 345–362). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Clement, J., Brown, D., & Zeitsman, A. (1989). Not all preconceptions are misconceptions: Finding "anchoring conceptions" for grounding instruction on students' intuitions. *International Journal of Science Education, 11,* 554–565.

diSessa, A. (1980). Momentum flow as an alternative perspective in elementary mechanics. *American Journal of Physics, 48,* 365–369.

diSessa, A. (1982). Unlearning Aristotelian physics: A study of knowledge-based learning. *Cognitive Science, 6,* 37–75.

diSessa, A. (1988). Knowledge in pieces. In G. Forman & P. Putall (Eds.), *Constructivism in the computer age* (pp. 49–70). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

diSessa, A. (1993). Toward an epistemology of physics. *Cognition and Instruction, 10,* 105–225.

Haber-Schaim, U., Cross, J. B., Dodge, J. H., & Walter, J. A. (1976). *PSSC physics* (4th ed.). Lexington, MA: Heath.

Halloun, I. A., & Hestenes, D. (1985). The initial knowledge state of college physics students. *American Journal of Physics, 53,* 1043–1056.

Hammer, D. (1995a). Epistemological considerations in teaching introductory physics. *Science Education, 79,* 393–413.

Hammer, D. (1995b). Student inquiry in a physics class discussion. *Cognition and Instruction, 13,* 401–430.

Hestenes, D., Wells, M., & Swackhamer, G. (1992). Force Concept Inventory. *The Physics Teacher, 30,* 141–158.

Huffman, D., & Heller, P. (1995). What does the Force Concept Inventory actually measure? *The Physics Teacher, 33,* 138–143.

Knapp, N., & Peterson, P. L. (1995). Teachers' interpretations of "CGI" after four years: Meanings and practices. *Journal for Research in Mathematics Education, 26,* 40–65.

Maloney, D. P., & Siegler, R. S. (1993). Conceptual competition in physics learning. *International Journal of Science Education, 15,* 283–296.

McCloskey, M. (1983). Naive theories of motion. In D. Gentner & A. Stevens (Eds.), *Mental models* (pp. 299–324). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

McDermott, L. C. (1984). Research on conceptual understanding in mechanics. *Physics Today, 37,* 24–32.

McDonald, J. P. (1986). Raising the teacher's voice and the ironic role of theory. *Harvard Educational Review, 56,* 355–378.

Minstrell, J. (1982). Explaining the "at rest" condition of an object. *The Physics Teacher, 20,* 10–20.

Minstrell, J. (1989). Teaching science for understanding. In L. Resnick & L. Klopfer (Eds.), *Toward the thinking curriculum: Current cognitive research* (pp. 129–149). Alexandria, VA: Association for Supervision and Curriculum Development.

Minstrell, J. (1992). Facets of students' knowledge and relevant instruction. In R. Duit, F. Goldberg, & H. Niedderer (Eds.), *Research in physics learning: Theoretical issues and empirical studies* (pp. 110–128). Kiel, Germany: Institut für die Pädagogik der Naturwissenschaften an der Universität Kiel.

Niedderer, H., & Schecker, H. (1992). Towards an explicit description of cognitive systems for research in physics learning. In R. Duit, F. Goldberg, & H. Niedderer (Eds.), *Research in physics learning: Theoretical issues and empirical studies* (pp. 74–98). Kiel, Germany: Institut für die Pädagogik der Naturwissenschaften an der Universität Kiel.

Perry, W. B. (1970). *Forms of intellectual and ethical development in the college years: A scheme.* New York: Holt, Rinehart & Winston.

Richardson, V. (1994). Conducting research on practice. *Educational Researcher, 23*(5), 5–10.

Sadler, P. M., Schneps, M. H., & Woll, S. (1989). *A private universe.* Santa Monica, CA: Pyramid Film and Video.

Schoenfeld, A. (1983). Beyond the purely cognitive: Belief systems, social cognitions and metacognitions as driving forces in intellectual performance. *Cognitive Science, 7,* 329–363.

Schön, D. A. (1987). *Educating the reflective practitioner: Toward a new design for teaching and learning in the professions.* San Francisco: Jossey-Bass.

Schuster, D. (1993, August). *Semantics and students' conceptions in science.* Paper presented at the summer meeting of the American Association of Physics Teachers, Boise, ID.

Smith, J., diSessa, A., & Roschelle, J. (1993/1994). Misconceptions reconceived: A constructivist analysis of knowledge in transition. *The Journal of the Learning Sciences, 3,* 115–163.

Strike, K. A., & Posner, G. J. (1985). A conceptual change view of learning and understanding. In L. H. T. West & A. L. Pines (Eds.), *Cognitive structure and conceptual change* (pp. 211–231). New York: Academic.

Thornton, R. (1987). Tools for scientific thinking: Microcomputer-based laboratories for physics teaching. *Physics Education, 22,* 230–238.

Viennot, L. (1979). Spontaneous reasoning in elementary dynamics. *European Journal of Science Education, 1,* 205.

Viennot, L. (1985). Analyzing students' reasoning: Tendencies in interpretation. *American Journal of Physics, 53,* 432–436.

Whitaker, R. J. (1983). Aristotle is not dead: Student understanding of trajectory motion. *American Journal of Physics, 51,* 352.