DOCUMENT RESUME

ED 433 997 SE 062 348

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TITLE	Teacher Inquiry. Center for the Development of Teaching Paper Series.
INSTITUTION	Education Development Center, Newton, MA. Center for the Development of Teaching.
SPONS AGENCY	DeWitt Wallace/Reader's Digest Fund, Pleasantville, NY.
PUB DATE	1999-01-00
NOTE	25p.
AVAILABLE FROM	Education Development Center, 55 Chapel Street, Newton, MA 02138.
PUB TYPE	Opinion Papers (120) -- Reports - Research (143)
EDRS PRICE	MF01/PC01 Plus Postage.
DESCRIPTORS	Educational Assessment; Educational Change; Evaluation; *Inquiry; *Knowledge Base for Teaching; Physics; *Science Education; Secondary Education; Student Needs; Teacher Education; Teacher Student Relationship; *Teaching Methods; *Teaching Skills

ABSTRACT

The progressive agenda of science education reform, particularly the goal of promoting student inquiry, places substantial intellectual demands on teachers. If this reform is to succeed, the education community must do more to appreciate and address its demands. This paper presents three examples of high school physics teachers' conversations about "snippets" of each others' work with students. The purposes are: (1) to highlight the central role and intellectual demands of teacher inquiry, in particular teachers' diagnoses of students' strengths and needs; (2) to suggest that teachers often experience and express their diagnoses in terms of instructional strategies; and (3) to suggest that the value of educational research for instruction be understood primarily with respect to what it may contribute to teacher inquiry. (Contains 15 references.) (Author/ASK)

CENTER FOR THE DEVELOPMENT OF TEACHING
PAPER SERIES

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Teacher Inquiry

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The progressive agenda of science education reform, particularly the goal of promoting student inquiry, places substantial intellectual demands on teachers. If this reform is to succeed, the education community must do more to appreciate and address its demands. This paper presents three examples of high school physics teachers' conversations about "snippets" of each others' work with students. The purposes are (1) to highlight the central role and intellectual demands of teacher inquiry, in particular teachers' diagnoses of students' strengths and needs; (2) to suggest that teachers often experience and express their diagnoses in terms of instructional strategies; and (3) to suggest that the value of education research for instruction should be understood primarily with respect to what it may contribute to teacher inquiry.

"Inquiry" in the classroom generally refers to student inquiry. One does not often associate inquiry with the teacher's role, other than with respect to the questions that come up within the discipline, science questions for a science teacher, to which the teacher does not have an immediate answer. My first objective in this paper is to promote a view of inquiry as central to the teacher's role, particularly inquiry into student understanding, participation, and learning.

Although it is becoming more common to think of teaching as inquiry, the emphasis in education reform remains on methods, materials, and standards. Meanwhile, the progressive agenda of promoting student inquiry, along with the need to coordinate that agenda with the traditional goal of "covering the content," places substantial intellectual demands on teachers. If these demands are not considered and addressed, the progressive agenda is unlikely to succeed. In other words, pursuing science education reform through the development of new curricula, new materials, or new standards is not sufficient. To promote student inquiry, we must do much more to understand and support teacher inquiry.

Hammer, D. (1999). *Teacher Inquiry.* Newton, MA: Center for the Development of Teaching, Education Development Center, Inc. Also in J. Minstrell and E. van Zee (Eds.), *Teaching and Learning in an Inquiry-Based Science Classroom.* American Association for the Advancement of Science.

Teachers spend a significant portion of the day taking in and interpreting information about their students. Much of this data gathering is deliberate and explicit, as teachers take attendance, collect homework assignments and laboratory reports, and give quizzes and exams. Other information arrives on its own, in a nearly continuous stream, in the questions students ask and comments they make, as well as in their facial expressions, body language, and tone of voice.

What teachers perceive in their students and how they interpret those perceptions (whether the students are alert, confused, interested, frustrated, etc.) can dramatically influence how they choose to proceed (e.g., by posing a challenging question, providing information, continuing to new material, or digressing to pursue a student's idea). Most of this interpretation happens—*must* happen—without explicit, articulate deliberation. In this respect teachers are like other reflective practitioners, from chess players to doctors, whose reasoning is and must be largely tacit.[1]

For chess players and doctors, however, there is a general awareness that this perception and judgment is taking place, that it is intellectually demanding, and that its betterment is central to professional education. It is both possible and expected for chess players and doctors to make at least some of their reasoning explicit, as a matter of professional practice and development, and they do so in the context of specific games and cases. For teachers, in contrast, it is rare to have the opportunity, let alone the expectation, to present information from their classes to others, to make explicit their interpretations, or to consider alternatives.

Conversations Among Teachers

This paper describes work from a project designed to engage teachers in precisely this sort of conversation, centered on their ongoing experiences in the classroom. From March 1995 through June 1998 a group of physics teachers and I met roughly every other week of the school year for two hours, to talk about students and teaching. During the 1996–97 school year, this group was comprised of me and the following teachers:

Elisabeth (Lis) Angus, Winchester High School

Hilda Bachrach, Dana Hall School, Wellesley, Mass.

Edmund (Ed) Hazzard, Bromfield School, Harvard, Mass.

Bruce Novak, Watertown High School

John Samp, Cambridge Rindge and Latin High School

Robert Stern, Brookline High School[2]

Our conversations, recorded on videotape for transcription and analysis, concerned "snippets" from the teachers' classes, small samplings of the information they took in about their students in the form of transcripts, video or audiotape recordings, or samples of students' written work. Reading, watching, or listening to these snippets, we talked about what there was to see in the students' participation, exploring a range of possible interpretations. With their focus on the "data" of everyday teaching, the snippets and the conversations about them provided a window into the intellectual work of everyday teacher inquiry.

The body of this paper is organized around three of the snippets from three consecutive meetings in the fall of 1996, contributed respectively by Robert, Hilda, and Bruce. I have chosen these examples to reflect a range of physics topics and forms of snippet and, in general, because they are representative of the substance and tenor of our work. Each example will begin with the teacher's snippet, then present excerpts of our conversation, and then end with an analysis of what the snippet and conversation may reveal about teacher inquiry. I will use these analyses, in turn, to advance the following three objectives of this paper:

1. *Teacher perception and judgment.* The first objective, as I noted above, is to promote greater appreciation for the role and demands of teacher inquiry into students' understanding, participation, and learning.
2. *A language of action.* The second objective is to offer an insight that has emerged from our work regarding the language teachers use to

express what they discover through that inquiry. In our conversations we noted that teachers often experienced and communicated their interpretations in a language of action—i.e., as ideas for what to *do* in the given circumstance—rather than in an explicit language of diagnosis. For example, a teacher may express an interpretation ("The students have forgotten what they learned about inertia") by suggesting an action ("I would review the concept of inertia").

3. *A role for education research.* The third objective is to propose a view of the role of education research in instructional practice. Specifically, I will suggest that its primary role is to contribute to teacher inquiry, i.e., to teachers' perceptions of their students and judgments for how to proceed, rather than to prescribe effective methods. The conversation between teachers and researchers should therefore be understood to take place mainly at the level of their respective interpretations of students' understanding and participation. This conversation, however, may be difficult to recognize and to facilitate, owing largely to differences in the language by which researchers and teachers experience and communicate their interpretations.

Interpreting a Class Discussion About Free Fall: Teacher Inquiry into Student Understanding and Participation

The first snippet we discussed in our meeting on November 18, 1996, was a transcript Robert had prepared of a discussion in his college prep-level class about the forces on a skydiver.[3] Robert's goal for this activity was "to reinforce the idea of the net force as the driving engine for acceleration." The following is roughly half the transcript:[4]

T: What forces act on the skydiver when he first jumps out?

S1: He accelerates down; he goes faster.

S2: But the air slows him down so he can't fall faster.

S3: But he doesn't slow down, so something must be getting bigger.

T: Someone come up to the board and draw the forces acting on him.

S4: There's the gravity that pulls him down. (Student draws a vertical arrow down.)

T: What's the common English word for force of gravity?

Students *(collectively):* Weight.

T *(to S4):* Add the letter W to your diagram. Now what?

S4 : Then there's the air resistance. (He draws a vertical arrow up, but not connected to the weight arrow. Long silence.)

S5: You have to put the arrows together.

T: Why?

S5: Because they're both pulling on the person.

S4: Yeah, that's right. (He draws both arrows connected to the same point.)

T: How are the two arrows related? Are they the same? Is one bigger?

S4: Well, the weight is bigger because it's pulling down.

T: Does everyone agree? (Calls on a student.)

S6: No, it can't be right because the speed is increasing. The force of gravity is getting bigger.

T: What's the common word for force of [due to] gravity?

S6: Weight.

T: So what are you saying? The person gets heavier as he falls?

S6: *(smiling)* No, but something is wrong. He keeps going faster as he falls, doesn't he?

S4: Sure he does, but it's the gravity that pulls him down.

S7: But doesn't the air resistance get bigger?

T: You have some good ideas, but there is confusion here. The difficulty, as I see it, is that you're confusing the *motion* with the *forces*. Remember that you started the year with learning how to describe motion [kinematics]. All the graphs and equations you did. Now you're looking at *forces* [dynamics]. It's the forces which make things move, and we've got to separate these two effects. Let's concentrate on just the forces; then we'll connect them to the motion.

Excerpts from our conversation

Bruce started our conversation with the suggestion that S6's comments revealed a common misconception. Robert's response showed that he too considered S6's contribution significant, but for different reasons:[5]

Bruce: [S6 showed] a misconception, that we've talked about before. That the speed is proportional to the force *(reading S6's comment from the snippet):* "That can't be right because the speed is increasing. The force of gravity is getting bigger."

Robert: [S6] is usually very, very slow in reaching any sort of [original idea], so for her to say what she did... She said it so immediately, she knew the speed was changing, but in all of the year it's the first time I've ever seen her, you know, come up with something herself. [There] must something else, another force, another factor. It was nice to see her do that. She couldn't quite get it, and I'm not sure whether that's [important]. I thought it was a turning point in the whole discussion.

After a brief exchange to help others locate S6's comments in the transcript, I turned the conversation back to what Robert had been saying:

David: And that was a turning point, and the student who said that was somebody who—

Robert: Who normally doesn't see things very intuitively. She's very methodical, she's very good at memorizing stuff . . . but, for original ideas, no. This is the first time that I saw that with her. Which was that you can see that somewhere what we had is not enough. There needs to be something else. But you didn't know what it was.

Shortly afterward, Robert elaborated on what he had intended in this conversation and what he saw happening at this juncture:

Robert: I've never done this one before . . . I'm using a new textbook this year and I looked around, I thought that might be a good way to tie up some of the ideas, let the students talk. Instead of doing [lots of] problems today, we'll spend a while, whatever we need, just talking about [one] problem. And it just was so enlightening to me to see that, just what you're saying, [they came up with the] idea, there needs to be another "force." That's the key item: There needs to be something else to make it accelerate. It doesn't have to be an increase in the force, but it needs to be something.

Turning back to the misconception he saw in S6's comment, Bruce commented on Robert's response at the end of the excerpt above:

Bruce: You may reinforce [the misconception] with what you say: "It's the forces which make things move." Which makes it sound like you need the force to have the motion. Which is something a lot of us say, [although] we don't mean it that way.

This reminded Robert of a related difficulty: students' reluctance to accept a velocity as an initial condition of an object, a problem he agreed his language may aggravate:

Robert: Typically the thing that comes up, now that you mention it is, even when you have problems with things moving at a constant velocity, there are always a handful of kids, you know, they want to get that acceleration in the beginning, [thinking] "You gotta get it going," and I say, "OK, now it's going" . . . Well, maybe I contribute to that.

Bruce recalled a suggestion John had made the previous year of a strategy for responding to this difficulty: Start with the room lights off and then turn them on after setting a ball in motion. The idea is to help students distinguish between the concepts of *velocity* and *force* by focusing their attention on the ball's initial *motion*—i.e., when the lights come on, the ball is moving—and away from any prior, initiating *force*.

Hilda reminded us that the students were talking about a skydiver who had no initial downward velocity. In this case, she noted, the students' reasoning may have been appropriate because "there had to be a force, otherwise [the skydiver] wouldn't come down." Robert maintained, nevertheless, that the students were not distinguishing force as causing *velocity* from force as causing *acceleration.*

After a brief digression on the sensitivity of students' understanding to particular wording, I asked Robert to say more about the snippet. He reflected on his impressions of the discussion, reiterating his pleasure and surprise at how it went, and recounted more of what happened after the segment he had transcribed:

> Robert: I thought it was a great class. The class ended, the kids didn't want to go! . . . I had no idea it would turn out this way. I started out with, here's this problem, let's look at the different forces, maybe get to the idea of seeing that the net force would keep changing.
>
> Lis: Were you drawing on the board at all?
>
> Robert. Very little, I did very little.
>
> Hilda: The kids did [draw on the board].
>
> Robert: The kids did most of it. At the very end, when this one student wanted to know how—we finally got the idea that the net force is changing—he wanted to know, how does the net force change? I asked, "What do you think would happen?" and [he drew] a set of axes with force and time. And he stood there a while, and eventually he drew a straight line decreasing to zero. Which was, I thought, a very good first step, because the kids have never done this before.

The student was correct that the net force on the skydiver would decrease to zero. As the skydiver's velocity increases the force of the air resistance increases as well, until the force of air resistance (upward) equals that of the earth's gravity (downward). The straight line was not correct. The net force would approach zero asymptotically, not as a linear function. Robert was impressed by the student's having made the first realization; he was not worried that the explanation wasn't fully correct at this point, when the students were first considering the question.

Teacher perceptions of students' understanding and participation

The snippet continued further, as did our conversation; we spent roughly half an hour talking about it, the amount of time we typically allocate. Our conversation was also typical in the range of perceptions it reflected, by the snippet's author and by the rest of the group. Among their interpretations of the students' understanding and participation, Robert and the other teachers noted the following:

A misconception, on the part of S6, that the speed is proportional to the force. Bruce mentioned this in our conversation, but Robert had evidently seen something similar in S6's contribution, since, a moment later in the snippet, Robert told the students, "The difficulty, as I see it, is that you're confusing the motion with the forces."

An original contribution by a student, S6, who was more inclined to memorization. Robert recognized the same misconception Bruce did, but he perceived S6's idea in several other ways as well. He saw S6 as participating in a way that was new for her, a perception not available to the rest of us from the snippet itself, since it depended on Robert's experience from the start of the year.

A valid insight in S6's idea that, as Robert put it, "there needs to be something else," and a productive turning point in the class discussion. In addition to seeing S6's reasoning as reflecting a misconception, that is, a conception inconsistent with the Newtonian understanding Robert wanted students to develop, Robert saw it as containing an insight that could help her and the class progress toward that understanding.

Possible (and inadvertent) reinforcement of a misconception by the teacher's comment, "It's the forces which make things move." This was not directly a perception of the students' understanding, although indirectly it attends to how they might reasonably interpret a statement by the teacher.

Students' difficulty with the idea of an initial velocity. Bruce and Robert talked about the students' confusion over the concepts of motion and force, both with respect to this particular situation and as a more general misconception. Here, Robert connected their reasoning to a related pattern he had seen in students' reasoning, i.e., their difficulty thinking of an object as having an initial velocity.

Students' interest and engagement. Robert was enthusiastic about the outcome of the discussion, both for the students' engagement ("The class ended; the kids didn't want to go!") and for the substantive progress they initiated ("The kids did most of it").

To be clear, the point here is not these particular perceptions, and I am not claiming they are "correct." I expect other teachers would offer different interpretations, as happens routinely in our conversations. My point is that these perceptions represent multiple dimensions of teacher awareness concerning the students' conceptions of forces and motion, their modes of reasoning and participation, and the level of their interest and engagement. This awareness encompasses both individual students and the class as a whole, in general, over the school year, and in particular moments.

In fact, this list of teacher perceptions is incomplete, as it reflects only those that Robert and the rest of the group made explicit. It is clear that much goes unsaid in our conversations about the snippets. For instance, Robert saw something in the students' reasoning that led him to press them with respect to vocabulary: "What's the common English word for 'force of gravity'?" It is a reasonable guess that he saw the students' distinguishing as two ideas (the *weight* of an object and the *force of gravity* on that object by the earth) what a physicist considers one idea. By insisting on their use of the "common English word," he was insisting that they apply their everyday understanding of weight—in particular, that the weight of an object is independent of its motion—to their reasoning about "force of gravity." From Robert's comments on other occasions, it is also likely that he perceived and hoped to address a general pattern of students' treating physics as disconnected from their everyday experience.

Moreover, it is sobering to consider, this is only an excerpt of Robert's snippet, which itself represents only a fraction of what transpired in a single period of a single school day. Here, then, is an illustration of this paper's opening premise: Teachers take in and process an enormous amount of information about their students' understanding and participation. Most of this inquiry is and must be tacit, because there is more information than explicit thought could accommodate. It would be impossible for any teacher to articulate all of his or her perceptions and intentions.

Although it seems to be both possible and productive for teachers to articulate *some* of their perceptions and intentions, nevertheless, at least in the United States, it is rare for this to occur. Teachers seldom have the opportunity or occasion to show others their "data," to present their interpretations, and to have those interpretations challenged with alternatives. Because of this, teachers are mostly left to themselves, individually, to develop the intellectual resources they need to meet the intellectual demands of interpreting their students' understanding and participation, diagnosing their students' strengths and needs, and making judgments for how to proceed.

We do not pretend that our conversations capture more than a fraction of teacher thinking. But by capturing that fraction, these conversations allowed the teachers to exchange and compare not only methods and materials, but perceptions of students in particular moments of instruction. Our conversations, grounded in specific instances from the teachers' classes, provided not only ideas for instructional strategies but also new diagnostic possibilities, an exchange of resources to support the intellectual work of teaching.

In this respect, in their ongoing inquiry into students' understanding and participation teachers have much in common with education researchers, specifically those who conduct research on learning. They study essentially the same phenomena, i.e., student learning, although in different ways, and it is reasonable to expect that teachers and researchers could support one another in their efforts. The central purpose of this project was to explore how this collaboration might occur, particularly how perspectives from education research might contribute to teacher inquiry. I will discuss this further in a later section, "A role for education research."

Interpreting Lab Reports on Simple Circuits: Describing Perceptions in a Language of Action

This next snippet, from Hilda, serves to further substantiate the view I am promoting of teaching as inquiry, and of teacher expertise as involving intellectual resources for engaging in that inquiry. The main purpose of this section, however, is to reflect on the language by which the teachers articulate their interpretations: The teachers often experience and express what they perceive about their students as ideas for how to proceed in instruction.

Our meeting on December 12, 1996, opened with a snippet from Lis, a videotape produced by two of her "college prep" students as part of an optional project. They had performed two experiments in projectile motion. First, they fired a "BB gun" across a field at a target, measuring the distance the BB fell in its trajectory below the horizontal, and showing that this distance, 10 inches, was consistent with a calculation from kinematics equations they had learned in class. Their second experiment was to throw two pumpkins from a cliff, launching them horizontally at qualitatively different speeds. They measured how long the pumpkins took to fall and the distances they fell outward from the cliff, again to compare with the theoretical predictions.

There was much to discuss about this tape, including the students' investment in their work, the validity of their reasoning and measurements, and the value of their "seeing" the BB fall 10 inches in its trajectory, not to mention their campy humor. Their conversation often digressed from the details of the videotape to general comments about the motivational and conceptual value of "real-world" and "open-ended" projects, and strategies for assigning and assessing them. I mention Lis's snippet first because it came up in our conversation about Hilda's snippet, which is the main focus of this section.

Hilda assembled her snippet from student reports and her observation of much more traditional laboratory work on Ohm's Law.[6] In one lab the students systematically varied the voltage and resistance in a simple series circuit by changing the number of batteries or the resistor. They measured the voltage and current using three different resistors for each of at least five values of voltage, and they plotted their results on graphs.

Most of the students' lab reports were in line with what Hilda intended, but not all of them. For her snippet Hilda collected some of the divergent responses to questions in the "results" section, including, "What happens to the current when the voltage is increased (R constant)?" and "What happens to current when the resistance is increased (V constant)?" The following is quoted from Hilda's snippet:

> Despite a discussion of cause/effect, there were still those who answered:
>
> > "The current would decrease, as would the voltage; as the resistance gets greater, it allows less electrons to pass through the circuit at a given time."
>
> Then, in her [this student's] conclusion, she said, "We could also see that when the resistance stays the same and the current increases, the voltage would increase in proportion to it. This could be proven by R=V/I."
>
> Even though they answered the questions correctly, in the conclusion, where they are required to sum up, there were those who said:
>
> > "We discovered that as current decreases, the voltage decreases and the resistance increases."
> >
> > "Because the R must remain constant with each circuit set-up, if the current is decreased, then the volts must be increased to compensate. This satisfies the equation and makes sense because in order to compensate for a lower current due to a higher resistance, the volts must be higher in order to push the electrons through."
> >
> > "When the current flowing increases, the circuit voltage increased."
> >
> > "As the current increases, the potential difference increases."
>
> Included in "sources of error" were:
>
> > "The batteries: As we used them, they lost energy."

At the end of the "snippet" Hilda added a comment about one group's work on a previous experiment that had favorably impressed her:

> I'd like to mention a really interesting way that one student saved her group's experiment, [which] was measuring with a tangent galvanometer the dependence of its magnetic field on the strength of the current. In this PSSC experiment, a light bulb is used in the circuit to limit the current and to show that there is current. About halfway through the process of winding on coils one at a time, the light bulb blew! After changing the bulb they saw that the compass needle deflection increased by a much larger amount than expected for a single coil increment. One of the girls recognized that it must be a different bulb, letting more current flow in the circuit—this was before doing the Ohm's Law experiment! She was able to select a bulb like the one that burned out, and they were back to similar increments.

Excerpts from our conversation

John opened our conversation about Hilda's snippet with an interpretation of the difficulty some of the students had on the Ohm's Law lab and his suggestion of a way to address it:

> John: I look at this and my thought is, one of the toughest concepts that over the years I have had to try to teach is what electric potential or voltage is in the first place. Students come into class and they've talked about volts . . . all their lives, [but] essentially, nobody knows what it is. And about five years ago, somewhere I got my hands on a piece of shareware called "Circuit Vision." I can bring in copies. It runs on a MacIntosh.

This software, John described, allows one to build a virtual circuit made up of batteries, resistors, and wires. The program then enacts a mechanical analogy of that circuit, showing current as the motion of little balls. Small escalators carry the balls from lower to higher levels, analogous to batteries lifting charge to greater voltage, and the balls push paddle wheels as they fall back down, analogous to charge expending energy as it moves through a resistor to a lower voltage. In this way the program visually presents an analogy between *electric potential* (or voltage), meaning the electric potential energy per unit of charge, and *height*, which can be understood as the gravitational potential energy per unit of mass.

> John: And I think, as a result of that, students get a better concept sooner of just what voltage is. And some of the questions, I mean, this one question that somebody made in the middle *(reading from Hilda's snippet)*: Because R must be constant with each circuit set-up, "if the current is decreased, then the volts must be increased to compensate," as if somehow voltage and power are different measures of the same thing—one goes up, the other one's gotta go down.
>
> *(Hilda nods in agreement.)*
>
> John: Others are just kind of looking at it as a mathematical equation. In some cases they're getting it right, getting the mathematical equation right, but I still get the feeling they have no idea what they're talking about.
>
> Hilda: No, that's the thing. That's right. In other words, the inverse proportion is there and the mathematical equation, but it's not there in terms of the concepts.

Hilda elaborated, in a tone of amused exasperation, her perception of how the students were using the equation:

> Hilda: [They were] using the equation as though it were pure numbers and not a measurement of anything that had significance. So when I talked about it, I talked about it as a cause and effect idea. Or sometimes I'd say to them, "You know, we put the cart before the horse. You've got things not in sequence. What's controlling what? We often talk about an independent variable [and] a dependent variable. What's the control here?"

As Hilda noted, the students had manipulated the voltage by changing the number of batteries they connected in series. Several students, nevertheless, described their observations as though the change in voltage resulted from the change in current (e.g., "as current decreases, the voltage decreases and the resistance increases"). In this way, Hilda pointed out, they were not making a meaningful connection between the equation (V = IR) and their measurements in the lab.

We also spent some time talking about the group of students who discovered they were using the wrong bulb. In our conversation Hilda recounted a similarly impressive episode in which a group of students, working on the Ohm's Law lab, found that their measurements did not correspond to the markings on a resistor, ultimately deciding it was mismarked. Hilda described what impressed her about these cases:

Hilda: I thought they did a really good thinking job there. Where they weren't going to just write down this number and say, "I've got 200 percent error" or something like that. [They] came over to say, "You know, we really think that this one's [mismarked]."

David: So that's another example sort of analogous to this one [in the snippet].

Hilda: Yeah, yeah, where they are showing greater sense . . . that something that's different isn't, "Uh-oh, we've got some errors in our experiment," but they looked for what could make this happen so that they could talk about it, that's what they actually did in their report. [In contrast to] one girl [who] just reported 200 percent error and didn't bat an eyelid . . .

David: So . . . they found some discrepancy and they were committed enough to the ideas to deal with it.

Hilda: *Right.* Exactly. I can't even, sometimes they go through a whole experiment and they don't even notice if they've got some really anomalous data that just doesn't fit.

For Hilda, the problem went beyond this particular experiment, and she proceeded to describe another example in which students somehow misread a scale to find that it took more force to pull a cart up a shallow incline than a steep one:

Hilda: But they don't notice [the mistake] until you look at their numbers and ask them, "What went wrong here?" . . . They're doing exactly what they were told to do and they don't really see, is it good data or is it not good data?

This reminded John of students' failing to catch absurd answers on their calculators, specifically in finding trigonometric functions of angles measured in radians when the calculators are set to measure angles in degrees. Robert saw this as a general liability of students' inordinate faith in calculators, which can lead them to accept such results as "a person's height [is] 43.5 meters." John noted that he "had that problem before calculators," and everyone agreed calculators were not the root cause.

Our conversation turned to the topic of students who do not notice absurdities in measurements or in calculations. Referring back to Hilda's examples of those who did notice and resolve inconsistent results, I asked why other students do not do this and whether it is something they could be taught:

Hilda: I had a discussion about that one time and [the students said] they figured I was doing something to trick them. That if I'm giving them problems on a test, the numbers don't have to be real numbers, and so I could make it come out like a person can be 43.5 meters tall. I got into this mode then of telling them . . . "This is a real problem. There's no tricks. The numbers should be the order of magnitude of what you would expect."

Ed referred back to Lis's "snippet" as an example of an instructional approach that might help:

Ed: One answer to your question, to the teachable-ness of this, is to give them a BB gun, take them out in the field and have them make a video, and see whether the 10 inches [are real]. They even did the conversion to meters—that was very impressive. I wonder, is that a way to make them [think of the results as meaningful]?

Ed's comment about the students converting their results to meters prompted an exchange about the prevalence of unfamiliar units in introductory physics. Lis remarked, "We didn't grow up with kilograms. And I think that they don't really know what [it means]." John agreed, "Except for seconds, pretty much everything we deal with in physics is not real to too many students." We continued on the general topic of the connection to "reality" for the rest of the conversation, considering the influence of students' experiences in mathematics classes and whether it is helpful or harmful for them to practice methods of calculation they do not yet understand.

Teacher perceptions of students' understanding and participation

Again, our conversation about the snippet reflected a variety of interpretations of the students' understanding and participation:

Students' difficulty with the concept of electric potential (voltage). John opened the conversation with this thought and proceeded to describe a piece of software he found helpful. Given a simple electrical circuit, this program depicts a mechanical analogy to help students visualize electric potential as analogous to height.

Treating the mathematics as disconnected from the concepts. John noted that some students were struggling with the conceptual relationship, whereas others were just "looking at it as a mathematical equation," without regard to its meaning.

Treating mathematics as disconnected from the procedure and measurements in lab. Hilda also felt that the students were "using the equation as though it were pure numbers," rather than involving quantities with physical significance. In particular, Hilda referred to the fact that the students' explanations did not correspond to the procedure they had followed in the lab.

Trying to make sense of discrepant data. Hilda wrote about one group of students who discovered that they had inadvertently used a different type of bulb, and she told us about another group who determined that a resistor was mismarked. Hilda was impressed that "they looked for what could make this happen so that they could talk about it," in contrast to others who simply attributed discrepancies to experimental error, without looking for any specific cause.

Ignoring common sense when thinking about physics. Toward the end of this conversation we digressed from Hilda's snippet to talk about a general perception of students, that many do not treat physics as connected to "reality." Hilda told of her students' saying they expected her to "trick" them and of her developing the habit of reassuring them that there are "no tricks." Ed spoke of Lis's snippet as a means of teaching students to treat physics as "real."

It may seem surprising that a group of teachers could find so much to discuss in these snippets, which to the untrained eye are fairly sparse excerpts and observations. The first point in this paper, however, is that these are not untrained eyes. Working every day with students, teachers become adept at interpreting what they see and hear. Like physicians, for whom a handful of symptoms in a patient may indicate a variety of possible conditions and courses of treatment, these teachers have developed a wealth of knowledge and experience, intellectual resources for thinking about students.

It is unusual, however, to understand teaching in this way, including among teachers. Even in these conversations, the teachers often seemed more inclined to talk about instructional materials and techniques than about interpretations of student statements and behavior. If inquiry into student knowledge and reasoning is at the core of teaching and teachers' expertise, as I am suggesting, then why would teachers be reluctant to have conversations about it? This next section concerns the second point of this paper: that teachers often talk about their interpretations by talking about instructional materials and techniques.

A language of action

At the outset of this project, I had tried to impose the following ground rule: In conversations about snippets we should restrict ourselves to comments that concerned students' statements and behavior, rather than what the teacher did or should have done. I had two reasons for imposing this rule. The first was to promote a focus on perceptions of students, rather than on the means for addressing them. The second was to encourage an atmosphere of respect for the teacher presenting the snippet. I had experienced too many conversations about teaching that had degenerated into uncomfortable and unproductive criticism of the teacher's actions.

My rule proved difficult to enforce, however, and, in the end, counter-productive. A key example from the first year was John's "turn on the room lights" strategy, which Bruce recalled during our conversation about Robert's snippet. Discussing another teacher's snippet, John had offered the following:

> John: [I say] things like, "You know, what if the room lights come on and you see the ball already going down the alley? You know somebody pushed it, but you have no idea who pushed it. All you can say is, Well, here it is right now. Now tell me what forces act on it." And sometimes they get it when I talk about room lights coming on. You know, I've had some trouble getting them to forget about earlier things.

What we came to recognize was that, while most of John's comment was explicitly to suggest a teaching strategy, it was also implicitly to express his interpretation of what was happening in the snippet in question, namely, that the students were not distinguishing a force *acting* on an object from a force *having acted* on the object a moment ago. Moreover, John's description of his strategy was helpful in communicating his interpretation to the rest of us, including the snippet's author, who came to understand the students' thinking differently as a result: "Yeah . . . I think maybe [that was the idea] these kids really had. Not so much that they thought it was pushing now. But more that it was pushed then."

This moment led us to the realization that a comment about teaching strategy may also serve to convey an interpretation, and we were then able to recognize that this was happening fairly often. In other words, the teachers often communicated "what to see" in the students' understanding and participation by suggesting ideas of "what to do" to help them. Their suggestions for methods and materials, therefore, often had a dual purpose: to *explicitly* suggest instructional action, and to *implicitly* suggest a diagnosis of the situation.

For this reason, to rule out comments about teaching would be to rule out a principal mode by which the teachers discussed their interpretations. From the teachers' perspective, adherence to my rule made our conversations inauthentic, disconnected from their knowledge and experience, and we decided to abandon it. Perhaps it had served a purpose at the beginning, promoting a level of sensitivity and mutual respect in our conversations, but we came to see it as an impediment.

Turning back to our conversation about Hilda's snippet, there were several examples of comments that explicitly concerned ideas for instruction, serving as well the role of expressing an interpretation. The first example was again John's, who identified in Hilda's snippet a pattern he had seen before, of students' difficulty with the concept of voltage: "Essentially, nobody knows what it is." He went on to describe what he found to be an effective means of addressing this difficulty—a computer program that displays mechanical analogies of electric circuits, with voltage analogous to height. By describing the computer program John was not only suggesting it as an effective approach, he was also specifying what he saw as the problem, considerably clarifying what he meant by "nobody knows what it is." In particular, John saw the students as lacking what researchers might call a "mental model."[7]

John went on to note that some students were "getting the mathematical equation right, but . . . they have no idea what they're talking about," and Hilda agreed, saying, "That's the thing . . . the inverse proportion is there and the mathematical equation, but it's not there in terms of the concepts." As the conversation continued, however, it became apparent that Hilda and John had different interpretations of what the problem was, or, at least, they were focusing on different aspects of it.

When Hilda elaborated on her interpretation, she explained that the students were "using the equation as though it were pure numbers and not a measurement of anything that had significance." She talked about how she tried to address this in class, clarifying what she meant by "a measurement . . . that had significance":

> Hilda: I'd say to them . . . "You've got things not in sequence. What's controlling what? We often talk about an independent variable [and] a dependent variable. What's the control here?"

Hilda was primarily concerned that the students did not connect the mathematics with their experience in the lab. They had manipulated voltage by changing the number of batteries, but in their reports they described the voltage change as a result of changes in the current or resistance. This was a different perception from John's, that the students lacked a conceptual understanding of voltage. For example, with different equipment the students could have manipulated current as the independent variable. In that case a student could appropriately have written, "When the current flow increases, the circuit voltage increased," and Hilda's concern would not apply. John's could, however, because that statement, an empirical summary of the experimental findings, does not indicate what the student understands about the concepts.

Hilda agreed with John that the students did not understand the concepts, but she attributed this to a more general problem: that they did not expect ideas in physics to make sense. She was saying, in effect, that the students were all capable of keeping track of what quantity they were measuring, but the fact that their explanations did not reflect what they had seen suggested they did not expect the relationship they were studying, Ohm's Law, to have tangible meaning. John's interpretation, in contrast, was specific to the content: The students did not understand the concept of voltage. They may not have been able to keep track of what they were doing in the lab because they needed a mental model for reference. To understand that the voltage in the circuit is determined by the number of batteries, for example, requires an understanding of voltage.

It was not our purpose in discussing this snippet, nor is it my purpose here, to decide which of these interpretations is correct. Either, I expect, could apply for particular students in particular situations. As a matter of principle, it is probably best left to the teacher, in this case Hilda, to make that judgment, because in the end she has the most information about her students. My purpose here is to suggest that Hilda and John interpreted the students' understanding and participation in different ways and that we learned about this difference primarily from what they said about instructional action—John describing what he would do and Hilda recounting what she did.

Later in the conversation I asked why some students do not try to reconcile inconsistencies—unlike the students Hilda described who had worked hard to understand anomalous data—and whether this was something they could be taught to do. Ed suggested that one answer might be to give students more experiences of the sort we had seen in Lis's snippet, in which a group of students had conducted their own experiments in projectile motion, shooting a BB gun across a field and tossing pumpkins from a cliff.

Ed's suggestion is another example of a perception described in terms of instructional action. He was, in effect, offering another interpretation of why students may not expect physics to make sense. Hilda said that her students thought she could do "something to trick them," and that she had responded by saying she would not, an interpretation of the problem as arising out of a specific, articulable belief. Ed considered the possibility that, for some students, the disconnection between physics and everyday experience lay more deeply, in a more general and less articulate sense of physics as taking place in a different domain of experience from their own, an interpretation similar to perspectives of knowledge and reasoning as "situated."[8] For such students, addressing the problem would not be as simple as telling them to use their common sense; it would involve constructing with them a context for physics that directly engaged their everyday experience.

In this way, Ed was using the idea of assigning "real-world" projects to help him express and refine his ideas for why students may not expect physics to make sense. In fact, much of our conversation about Lis's snippet could be seen in this way: Lis presented us with an example of an assignment designed to address aspects of students' understanding and participation not addressed by more conventional assignments, and our conversation drew our attention to those aspects. By referring back to Lis's snippet, Ed brought those considerations to bear on the issue at hand—that students did not see physics as meaningful.

Teachers spend much of their time and thought in gathering and interpreting information, trying to gain insight into their students' understanding and participation. In this way, they have much in common with those engaged in formal research on learning. Still, there are important differences. Researchers intend their inquiry to produce explicit, articulate perspectives and claims, supported with arguments and evidence, hopefully to withstand peer review. Teachers inquire toward action, in the context of their classes, hopefully to the benefit of their students, with little time or opportunity for explicit reflection and awareness, let alone public articulation. In short, researchers *publish*, whereas teachers *act*, and this difference is reflected in the ways in which they experience and express their respective insights into learning and instruction.

Interpreting a Test on Planetary Motion: A Role for Education Research

In this section I present the third and final example from our conversations, one that illustrates a role for education research. I suggest that the interaction between teaching and education research should be understood principally on this common ground: between the practice of teaching and the practice of research, of inquiry into student understanding and participation.

We discussed the third snippet on December 16, 1996. It concerned students' responses to two questions from a test on planetary motion and gravity, which Bruce had given to his twelfth-grade college-prep students. As part of his snippet, Bruce explained that the class had seen and discussed the PSSC film *Frames of References*. Much of their discussion focused on what reasons there were for believing the earth revolved around the sun, and what reasons there had been for earlier beliefs that the sun revolved around the earth. Bruce noted that the class had explicitly addressed whether the apparent motion of the sun across the sky was a reason for believing the earth moves, i.e., airplanes and clouds also move across the sky, but that is obviously no reason to believe the earth is moving:

> Nevertheless, to the true-false question, "The rising and setting of the sun proves that the earth spins on its axis," 18 of 25 students answered "true." Since we explain this observation today by saying the earth is turning, I can understand such a response from those who forgot the film and our discussion.
>
> However, halfway down the page was this question: "State two reasons why earth-centered models of planetary motion were favored for so long over sun-centered models." Ten of the 18 who'd answered the previously discussed question "true" nevertheless used the apparent motion of celestial objects as a reason for this, too. Typical answers included:
>
> S1: " . . . when they saw the sun rising at the east + setting at the west, they concluded that the sun went around the earth."
>
> S2: "People believed that the sun traveled around the earth because the sun rose and set every day."
>
> S3: "It seemed that the sun rotated around the earth because of the change in day and night."

What surprised Bruce was the number of students who could, on the same test, answer both that people once thought the sun's apparent motion was actual, and that the sun's apparent motion across the sky "proves" the earth rotates:

> And, although the top two scorers on this test answered these correctly, there was no pattern to who got these right or wrong. This seems to me a perfect (in fact, extreme) example of the "pieces" approach to learning physics—that ideas don't have to fit together or even make logical sense!

Excerpts from our conversation

In our conversation, Bruce explained that he sees this behavior often:

> Bruce: I see this kind of disconnect a lot. I'm sure we all do. But I was surprised there were so many of them, this time. Particularly when they had seen the film and we had dis-

> cussed things over. And these two questions were on the same page, about half a sheet apart.

John suggested that some students might have read the question "as 'the rising and the setting of the sun *reflects the fact* that [the earth spins on its axis],' rather than *'proves.'*" Bruce agreed that was a good possibility—in fact, one student had told him she answered "true" to the first question "because the rising and setting can be explained by the earth spinning"—but he felt this was consistent with his interpretation: Given the emphasis on this point in the class discussion, it was odd that a student would misinterpret the question in this way. If a student treats "proves" as equivalent to "can be explained by," this suggests that the student was not paying attention to the logical connections among ideas.

In a similar vein, Lis noted that both parts of the statement in the first true/false item are "true": The sun does rise and set, and the earth does spin on its axis. Seeing two true statements joined together in a sentence may have distracted students from the logic of the statements' relationship, especially under the duress of a test. Hilda and John talked about the general liabilities of true/false and multiple-choice questions: they are open to such misreadings; they invite test-taking strategies, such as trying to second-guess the test author's intentions; and it is difficult to know why students answer as they do, even when their answers are correct.

Returning to the snippet, Hilda affirmed Bruce's interpretation, in part because of her own similar experience:

> Hilda: They don't see that they're answering this one, which contradicts that one. Because I very often have that [happen]. You know, they're doing the exact opposite for those two questions, and they're not seeing the connection when we go over it in class.

Lis's first reaction to the snippet, however, was surprise at the difference from what she had seen in her students. Early in the conversation, she remarked that her students seemed to have a head start on this topic from previous classes, having considered the transition from an earth-centered to a sun-centered world view "at a philosophical level" in previous classes:

> Lis: They do a lot in humanities that follows right along with [these ideas in] mechanics . . . They all do. It's amazing. I mean, they would be using the words "geocentric" [and] "heliocentric." They would be quoting Aristotle . . .

Lis emphasized that she was not referring to a "technical" familiarity, in the sense that students would be able to solve physics problems; she was referring to a familiarity with these larger systems of thought and the general shift in popular belief.

Later in the conversation, Lis observed that the students in the snippet all approached the test question, which asked why people had favored earth-centered models of planetary motion, as a question about *physical objects,* rather than about *people* and how they form beliefs. Thus, they answered in terms of the sun's apparent motion in the sky and the earth's rotation rather than, for example, in terms of the influence of the Church and popular religious convictions.

As in the previous two examples, the snippet and our conversation about it raised a range of interpretations of the data—in this case, student responses to two questions on a test. Here, I will focus specifically on how research on learning may have contributed to that range.

A role for education research

By and large, the education community tends to think of the connection between research and teaching in terms of instructional methods and materials. In other words, research on learning should have implications for what teachers do in class, such as forming cooperative groups, adopting microcomputer-based materials, or assessing through student portfolios. Research, in short, should establish and prescribe effective methods.

In this project, we set out to develop a different understanding of the relationship between teaching and research on learning, at the level of interpretation rather than method. Instead of asking how researchers' findings should inform teachers' techniques, we asked how researchers' interpretations might inform teachers' interpretations. To that end, we read articles from the research literature, considered the perspectives they presented, and asked what insights they could provide into the snippets we were discussing. Instead of methods or general principles, we were looking for insights into particular moments of learning and instruction.

I have been especially interested in the possible contributions of my own research on student learning. During the first year of the project, I asked the group to read two of my articles on students' beliefs about knowledge and learning, or student "epistemologies." We read one of my articles in May 1995 (Hammer, 1995) and another in November 1995 (Hammer, 1994). Bruce referred to that work when he called the exam results an "example of the 'pieces' approach to learning physics." "Pieces" was the term I had used to describe the belief that physics knowledge is a collection of independent, disconnected bits of information, as opposed to a connected, coherent system of ideas.

The important point here is that Bruce's use of the perspective in discussing his snippet reflects an influence at the level of interpretation: He saw his students as not attending to the connections among ideas. In fact, Bruce described this sort of contribution to his thinking on several occasions. In one other case he discussed a snippet he had written to recount how three of his better students had solved a problem about light reflection, concluding that one's image in an ordinary mirror is upside-down, contrary to everyday experience:

> Bruce: He apparently never made the connection, even though we'd talked about it, that this is like when you look at yourself in a mirror on the wall. Or else how could he possibly put it upside down? In that sense it seemed to be an example of your [David's] kind of disconnection between reality and physics class . . . Prior to reading your article, a couple of years ago I probably wouldn't have thought of it any other way except, well, they just confused [ordinary mirrors and curved mirrors] and didn't think what they were doing. (5/2/96)

In other words, the perspective gave Bruce a new diagnostic option for understanding his students, one he has applied and found useful in certain circumstances. This is a less prescriptive and, I contend, more appropriate role for research on learning than what is generally assumed in the education community.

If this is the role I as a researcher expect my work to play, then conversations such as these are essential, both in developing the ideas themselves and in understanding how they may or may not contribute to teacher perception and judgment. To be sure, our conversations led me to reconsider both the perspective and how I have presented it. I will not pursue that topic here except as follows, specifically in regard to the language of action I discussed in the previous section.

In proposing and designing this project, I had assumed a clear distinction between diagnosis and action, which helped shape my thinking about the role of education research. Consistent with the philosophy behind "cognitively guided instruction" (Carpenter, Fennema, and Franke, 1996), I consider teachers to be in a much better position than I to derive methodological implications for their practices. For that reason I had been careful to avoid prescribing methods when writing about student epistemologies.

I was taken aback, therefore, by how Bruce described what he found useful about my articles: it was not their presentation of the theoretical framework but rather the ideas they contained for what to do in class, which he drew primarily from the classroom episode and discussion of instructional strategy (Hammer, 1995). On the other hand, it was clear from his comments that he used the perspective as a diagnostic option for understanding his students. That Bruce considered the articles most useful with respect to the ideas they provided for instruction, I contend, is another example of the melding of interpretation and method in the language of action I described in the previous section. As we discovered in the failure of the ground rule I tried to impose on our conversations, for teachers, diagnoses of student strengths and needs are tightly interwoven with strategies for addressing those strengths and needs.

Thus, I maintain that it is more appropriate for education research to offer insights into student understanding and participation than to prescribe methods, but I do not maintain that it is inappropriate for education research to *suggest* methods. From our experience in this project, suggestions of method are an important means of communicating those insights.

We would also expect a parallel influence by teacher inquiry on education research. This project was designed to study how perspectives from research may contribute to teacher perceptions, but there have been signs throughout our conversations of what teacher perceptions may offer education research. One example is Lis's observation that the students had used "technical" rather than "social" language to answer a question on a test. This could be the kernel of a doctoral dissertation: What might affect students' choice of mode of reasoning or discourse? Under what circumstances would they have approached the question in terms of, for example, how people are swayed by popular opinion? More to the point, her insights in this regard should be of interest to researchers investigating discourse in science teaching (e.g., Lemke, 1990; Roth and Lucas, 1997).

In sum, teacher inquiry overlaps substantially with research on learning. Both involve observing students and examining what they produce, so it is not surprising that they form similar ideas. But there are important differences in the practices of teaching and research: Researchers publish, whereas teachers act.[9] With an insight into student understanding and participation, a researcher asks, in essence, "What can I say about this?" whereas a teacher asks "What can I do about this?"

The differences in practice are reflected in differences of language, as we found in this project, which present a challenge to substantive exchange between teacher inquiry and research on learning. At the same time, the differences in approach represent complementary strengths. Researchers can and must focus on developing narrow, articulate views; teachers can and must be more broadly aware and responsive. We have explored the role that perspectives from research may play in supporting teacher inquiry, but the benefit should certainly be mutual.[10]

Teacher Inquiry and Student Inquiry

The effective exchange of insights among teachers and researchers with respect to student inquiry is of primary importance. State frameworks and national standards call for a greater emphasis on student inquiry in science education. As a general nicety, student inquiry seems a simple, desirable goal. In specific contexts of instruction, however, it is not a simple matter at all.

The core of the problem is that, whereas everyone recognizes the importance of student inquiry, no one understands clearly how to discern and assess it, or how to coordinate it with the more traditional but still important agenda of "covering the content" (Hammer, 1997). This, of course, is not for lack of trying, but attempts by philosophers of science to define the "scientific method" (e.g., Popper, 1992/1968) or by educators to specify "process" skills as appropriate educational objectives (starting with Gagné, 1965) are widely considered unsuccessful. If it is possible to capture the essence of scientific reasoning (and some agree with Feyerabend [1988] that it is not), it has not been done.

The "hard" sciences have achieved stable, precise, and principled systems of knowledge. Within these systems there is much that is, at least in practice, "objectively true." There are clear, reliable, and reproducible methods, for example, for determining atomic masses or for manufacturing light bulbs. Education research has not achieved this quality of understanding; for good or ill, it is not possible to provide teachers with clear, reliable, and reproducible methods for assessment and instruction. Interpreting student understanding and participation remains highly subjective, and the onus of that interpretation inevitably falls to the teacher in specific moments of instruction, such as those recounted in the snippets above.

Moreover, this discrepancy between the quality of knowledge *within* science and the quality of knowledge *about* science and science education has particular significance for teachers trying to coordinate objectives of student inquiry and traditional content. In general, it is relatively straightforward for a physics teacher to recognize when a student's answer to a question is correct or incorrect, judging it against the established body of knowledge. It was not difficult to see that the student in Robert's snippet was incorrect, from a Newtonian standpoint, when she said that, "The force of gravity is getting bigger." However, it is not at all straightforward to assess her *understanding*, to determine whether her comment reflects a misconception that will prevent her from learning Newton's Laws if it is not eliminated, or a valid insight that will help her if she is encouraged to develop it. Nor is it straightforward to assess her reasoning as inquiry—to measure the value for her of having contributed an original idea, or to weigh that value against the fact that it was incorrect.

Robert has often expressed his desire for students to learn to engage in scientific reasoning rather than simply "cover the content" with a superficial understanding of the ideas. However, to pursue his inquiry-oriented objectives and have conversations like the one in his snippet, Robert must compromise the traditional content of the course. Not only must he be able to reconcile this for himself, he must also be able to justify it to concerned administrators, parents, and students, all of whom will be well aware that his class has not "covered" as much of the textbook as other classes. What should he tell them? How can he make what they have gained as tangible as what they have lost?

Similar tensions arise in other snippets. To pursue many activities of the sort Lis assigned, which led to the students' videotaped experiments in her snippet, would similarly diminish the traditional content. How should she consider and describe the relative value of those activities, as compared to other more familiar activities, as she plans the distribution of time over her year?

Hilda saw differences between her students, not only in the *correctness* of their reasoning but also in the *quality* of their reasoning. A number of her students had followed the lab instructions and arrived at mathematically correct conclusions, but she was troubled by their thinking, nonetheless; it contrasted with the work of other students, who had identified sources of discrepancies in their measurements. Precisely how should she interpret the differences between these students—was it interest, intellectual ability, confidence, or all of the above?—and, what is largely an equivalent question in the practice of teaching, how might she design instruction to promote the more impressive reasoning? And, again, how should she weigh the value of that agenda against the value of covering more material?

In his students' responses to two test items, Bruce saw an indication that they were approaching physics as a collection of incoherent facts. How should he value that perception against his perceptions of the correctness of the individual responses? Should students who were less consistent in their responses to questions on an exam but got a greater percentage "correct" receive a higher or lower score than students whose answers were more consistent but who had a smaller percentage of correct answers? This may be seen as a conflict between valuing inquiry (the internal coherence of a student's reasoning) and valuing traditional content (the correctness of a student's individual answers with respect to the intended body of knowledge).

It is clear that there is much work to be done. If we are to achieve student inquiry-based science instruction, we must do more to appreciate and address the intellectual demands that that agenda places on teachers. I believe this will require conversations among and between teachers and researchers, much more than is currently occurring, and that these conversations should begin from specific, authentic episodes of learning and instruction.

Acknowledgements

This project was funded by a joint grant from the John D. and Catherine T. MacArthur Foundation and the Spencer Foundation under the Professional Development Research and Documentation Program, and by the Dewitt Wallace–Reader's Digest Fund under a grant to the Center for the Development of Teaching at Education Development Center, Inc., in Newton, Mass. However, this paper is solely my responsibility and does not necessarily reflect the views of any of these organizations.

I am most grateful to Lis, Hilda, Ed, Bruce, John, and Robert for participating in this project, for all their help and ideas in designing and redesigning it along the way, and for the windows they provided into their practices, as well as for their critical readings of several drafts of this paper. Thanks also to Denise Ciotti, Kass Hogan, June Mark, Jim Minstrell, Peggy Mueller, Barbara Scott Nelson, Mark Rigdon, Ann Rosebery, Annette Sassi, Deborah Schifter, and Emily van Zee for helpful comments, suggestions, and questions. Finally, I thank Jen Davis-Kay for her expert copyediting.

Notes

[1] *Exploring the Place of Exemplary Science Teaching* (Haley-Oliphant, 1994) includes several chapters that discuss teaching as inquiry into student understanding and participation. See especially the chapters "Improvisational teaching" by Julia Riley, "Improvising learning conversations" by Robert Yinger and Martha Hendricks-Lee, "How do I read my students?" by Betty Wright, and "Learning from the stories of science teachers" by Kenneth Tobin. Other writings include Duschl and Gitomer (1997), in which they describe "assessment conversations" as tools for teacher inquiry into student understanding, and Hammer (1997), in which I present an account of my inquiry as the teacher in a high school physics class.

[2] See Schön (1983) for an account of the nature of expertise in "reflective practitioners."

[3] All of the schools listed are Massachusetts public secondary schools with the exception of Dana Hall, which is a private school for girls. I recruited teachers for this project through mailings and phone calls to local high schools, and the teachers were compensated as consultants. The project began in March 1995 under the auspices of the Teachers' Resources Network of the Center for the Development of Teaching at Education Development Center, Inc., in Newton, Mass., from a grant by the Dewitt Wallace–Reader's Digest Fund. That funding ended in June 1996, but we were awarded a grant to continue for two years, beginning in August 1996, by the MacArthur/Spencer Foundation Professional Development Research and Documentation Program.

[4] All of the schools have recognizable distinctions between levels of physics classes. At the top level are the Advanced Placement classes, which almost always occur in the second year of physics instruction. Among the first-year courses there are the "honors" courses, which may be calculus-based; algebra-based "college-prep" courses, typically with two or three sections; and, at some schools, a "conceptual" level with minimal mathematics.

[5] The discussion here concerns the skydiver's fall before he opens his parachute. Readers who are not familiar with Newtonian mechanics may wish to consult the appendix for a brief explanation.

[6] Ellipses (. . .) indicate where I have omitted portions of the transcript. Square brackets ([like these]) indicate words I have substituted or added to the transcript for clarity.

[7] Ohm's Law is a relationship among the electric potential, or voltage, (V), the current (I), and a resistance (R), usually written "$V = IR$." It states, in essence, that the voltage across a resistor and the current through the resistor are proportional: The higher the resistance, the greater the ratio of voltage to current.

[8] Gentner and Gentner (1983) discussed students' different mental models of electric current and voltage.

[9] Brown, Collins, and Duguid (1989) is probably the most well-known reference.

[10] It is for this reason that I have generally referred to teachers' interpretations as "perceptions" and researchers' as "perspectives." It is not to imply that teachers do not have perspectives or that researchers are unperceptive; it is to connote different modes of inquiry—one more characteristic of teaching and one more characteristic of research. The practice of research requires that interpretations be made articulate, in presentations, publications, and proposals, whereas the practice of teaching requires action, responding to students during class, and choosing or designing materials and assignments. To act responsibly, teachers must perceive more than anyone could articulate; to be articulate, researchers must omit from their perspectives much of what they see.

[11] For extended discussions of the value of teacher inquiry for education research, see Cochran-Smith and Lytle (1993) and Schifter (submitted).

References

Brown, J. S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher, 18* (1), 32–42.

Carpenter, T. P., Fennema, E., & Franke, M. L. (1996). Cognitively guided instruction: A knowledge base for reform in primary mathematics education. *Elementary School Journal, 97* (1), 3–20.

Cochran-Smith, M., & Lytle, S. L. (1993). *Inside/Outside: Teacher Research and Knowledge.* New York: Teachers College Press.

Duschl, R. A., & Gitomer, D. H. (1997). Strategies and challenges to changing the focus of assessment and instruction in science classrooms. *Educational Assessment, 4* (1), 37–73.

Feyerabend, P. K. (1988). *Against Method.* New York: Verso.

Gagné, R. M. (1965). *The Psychological Bases of Science—A Process Approach.* Washington, DC: AAAS.

Gentner, D., & Gentner, D. R. (1983). Flowing waters or teeming crowds: Mental models of electricity. In D. Gentner & A. Stevens (Eds.), *Mental Models* (pp. 75–98). Hillsdale, NJ: Erlbaum.

Haley-Oliphant, A. E. (1994). *Exploring the Place of Exemplary Science Teaching: This Year in School Science, 1993.* Washington, DC: American Association for the Advancement of Science.

Hammer, D. (1994). Students' beliefs about conceptual knowledge in introductory physics. *International Journal of Science Education, 16* (4), 385–403.

Hammer, D. (1995). Epistemological considerations in teaching introductory physics. *Science Education, 79* (4), 393–413. Also 1995, EDC Center for the Development of Teaching Paper Series, Newton, MA.

Hammer, D. (1997). Discovery learning and discovery teaching. *Cognition and Instruction, 15* (4), 485–529.

Lemke, J. L. (1990). *Talking Science: Language, Learning & Values.* Norwood, NJ: Ablex.

Popper, K. R. (1992/1968). *Conjectures & Refutations: The Growth of Scientific Knowledge.* New York: Routledge.

Roth, W.-M., & Lucas, K. B. (1997). From "truth" to "invented reality": A discourse analysis of high school physics students' talk about scientific knowledge. *Journal of Research in Science Teaching, 34* (2), 145–179.

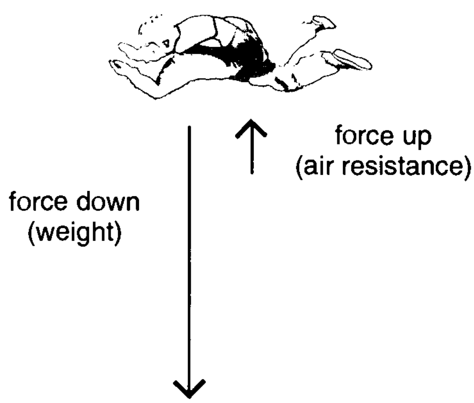
Schifter, D. (Submitted). Learning geometry in the elementary grades: Some insights drawn from teacher writing.

Schön, D. A. (1983). *The Reflective Practitioner: How Professionals Think in Action.* New York: Basic Books.

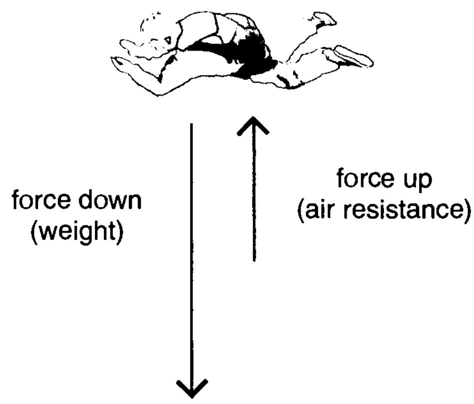
Appendix: The Forces on the Skydiver

In the standard Newtonian account, there are two forces acting on the skydiver. One is the gravitational attraction by the earth on the skydiver, i.e., the skydiver's weight acting downward on the skydiver and with a constant strength. The other is the force of air resistance, i.e., the force with which the air pushes back as the skydiver moves through it. That force is not constant; its strength depends on the velocity the skydiver is moving relative to the air.

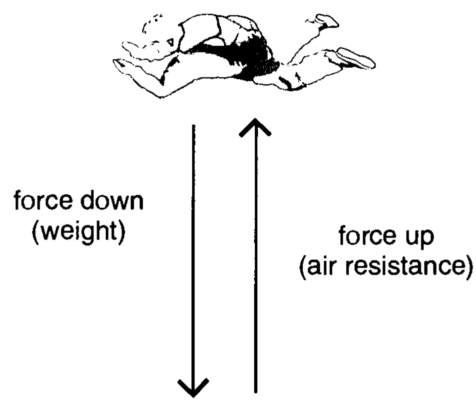
When the skydiver first starts falling the force of air resistance is small, so there is a large net force downward. That large force means that there is a large acceleration, with "acceleration" defined to mean the rate of change of velocity. In other words, the presence of the large force means that the *velocity* of the skydiver is changing quickly; it does not mean that *the skydiver* is moving quickly. (This is the idea to which Robert was referring, that the net force causes an *acceleration,* not a *velocity.)*



Eventually, the skydiver is moving so quickly that the upward force of air resistance is equal to the skydiver's weight, and the net force is zero. Since the net force is zero, the skydiver's acceleration is zero, i.e., the velocity is not changing. It does not mean the velocity is zero: The skydiver does not stop moving.



As the skydiver picks up speed downward, the strength of the upward force by the air increases. (The skydiver feels a stronger rush of air pushing upward.) The net force acting on the skydiver is still downward, because the skydiver's weight is stronger than the air resistance. But as the air resistance increases, the size of the net force decreases. That means the skydiver has a smaller acceleration: The skydiver's velocity is changing less quickly. It does not mean the skydiver has a smaller velocity.



David Hammer

After six years at Tufts University, David Hammer moved this fall to the University of Maryland at College Park, which has had the unfortunate consequence of ending his affiliation with the Center for the Development of Teaching. David is now an associate professor with a joint appointment in Physics and Curriculum & Instruction, teaching courses in both departments and continuing his research in physics education.

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