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Identifying inquiry and conceptualizing students' abilities

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Introduction

Duschl and Grandy (in preparation) set the goal of determining areas of consensus and lack of consensus in understanding goals of promoting inquiry in K-12 science education. There are probably a number of points on which we can all agree.

First and foremost is that promoting inquiry is not simply a method for teaching but part of the substance itself our instruction should address. That is, we want students to develop abilities and inclinations for science as inquiry, and we see engagement in inquiry as essential for genuine understanding of the body of knowledge professional science has produced. Of course, "we" here means the science education research communities represented by the invited attendees, and if we are in consensus on this point we will do well to make it clear, since that view does not generally shape existing instructional practices and curricula. These typically distinguish "inquiry" from "content," the latter being the traditional canon. Sometimes that distinction has inquiry as a pedagogical choice, its effectiveness judged against other approaches through assessments of students' understanding of the canon; sometimes the distinction has inquiry as an add-on set of objectives, to pursue in various side activities—science fairs, egg drops, and so on—separate from the actual syllabus.

We may also have a consensus, as Duschl and Grandy (in preparation) suggest, that scientific inquiry involves some form of dialogue among evidence, theory, and models:

> [W]e recognize that the dialogic processes by which theory evaluation and data construction occur in the community are an indispensable part of the rational structure by which science unfolds.

That view does not shape existing practices either; most science curricula remain heavily empiricist in their tacit and explicit epistemologies. It conflicts as well with some views of science evident in the NSES Standards, especially in chapter 6, which generally receives the most attention (Labov, 2004): Describing "science as inquiry" objectives at different grades, the content standards clearly focus on empirical investigations rather than on theoretical inquiry or modeling. This emphasis may be as much or more for developmental reasons as for philosophical ones, and if so it bears on Grandy's and Duschl's important question:

> One central question is where in the trajectory of science education we should introduce these complications of simultaneous revision of theory and data. We know that six year olds come to the classroom with concepts, theories and belief in data. Can we already introduce some elements of the dialogic processes at that level?

This is where we would like to focus our paper, on six-year olds. What do they bring to the classroom, and can we "introduce some elements of the dialogic processes?"

We organize this chapter around a first-grade class discussion about falling objects, hoping to accomplish three things. The first is to use the case to ground discussion and possible consensus with respect to what we consider inquiry. Duschl and Grandy (in preparation) discuss the myriad of ways educators characterize inquiry, from asking questions to engaging in "hands-on" activities to conducting experiments. A compact definition is hard to find at all, let alone one for which there is a substantial consensus. Perhaps, however, we can identify examples and build consensus in that way, agreeing on instances a definition should include. In this we use the class conversation as a case-in-point, not as data but as reference; we could generate hypothetical examples to the same purpose.

The second thing we hope to accomplish is to use the conversation as data to support claims about these children's abilities, as a modest contribution to the extensive body of evidence that children have abilities for dialogic processes of inquiry (Chinn & Malhotra, 2002; Duschl, 2004; Gopnik & Sobel, 2000; Karmiloff-Smith, 1992; Metz, 2004; O'Neill & Polman, 2004; Samarapungavan, 1992; Sodian, Zaitchik, & Carey, 1991; Tytler & Peterson, 2004).

The third is to use the case to support claims that these abilities are not stable features of the children's reasoning (Siegler, 1996) but variable with context, even within a single conversation (Hammer, 2004). Over the course of the conversation we see the students shifting from one sort of activity to another, each with its own local coherence. Some of what they do looks like the beginnings of scientific inquiry; some of what they do does not, and they make the transitions from one to the other with apparent ease.

These claims about the first-graders' abilities bear on the question of what children bring to the classroom. It is an ontological question, asking what we as researchers or teachers should attribute as existing in children's minds. In the closing section of this paper we discuss the implications for curriculum and instruction of attributing *manifold resources* that may or may not be active in any moment, in contrast to attributing stable features of mind in the form of concepts, theories, and beliefs. On this view, stabilities and coherences may be local, and we understand them in terms of the students' being able to *frame* an activity in different ways.

First graders discuss falling objects

This account is based on videotapes and transcripts of the discussion, the teacher's case study (Mikeska, in preparation), and an analysis of the students' reasoning (Russ, Mikeska, Scherr, & Hammer, 2005).

Mikeska prepared her case study of this class as part of a project, *Case Studies of K-8 Student Inquiry in Physical Science* (SIPS), a collaboration among K-8 teachers and university faculty, post-doctoral research assistants, and graduate students. The project was funded by the National Science Foundation[1] to produce case studies of children's inquiry for use in pre-service and in-service teacher education. Over three school years, the teachers and staff met every other week in two-hour sessions, working in groups to discuss "snippets" of data from the teachers' classes, typically videotapes of classroom conversations. The teachers then chose their favorite snippets to revise and expand into case studies. Our purpose with these cases is to provide materials to help prospective and current teachers gain experience interpreting student reasoning and thinking about possible ways to respond.

[1] Grant #ESI-9986846, D. Hammer and E. H. van Zee.

Mikeska had several objectives for the particular class we use to organize our comments about scientific inquiry. She describes those goals in her case study:

> *Making observations* and *drawing conclusions* are two essential components of the county's science curriculum, but my students were already doing both. I also knew they would not be challenged by the county objectives that they be able to "give examples to demonstrate that things fall to the ground unless something holds them up" and to "describe the different ways that objects move (e.g. straight, round and round, fast and slow)" (Curriculum Framework, MCPS, 2001).
>
> I wanted them to go further than these basic objectives, to use their abilities to make observations and draw conclusions to delve deeper by asking "why" questions. I consulted the science specialist for ideas, and he suggested a classic experiment: Drop a flat piece of paper and a book at the same time from the same height, and then drop a crumpled piece of paper and a book at the same time from the same height, and compare the difference in results. That seemed perfect. (Mikeska, in preparation)

In this section we present the case study in three segments: (1) Predictions for the book and the flat paper, (2) Discussing the experimental results of the book and the flat paper, and (3) Discussing the book and the crumpled paper. Following each segment we make comments regarding our first two purposes in this paper, using the segment to illustrate possible points of consensus with respect to what we consider inquiry, and using it to make claims with respect to these children's abilities.

Predictions for the book and the flat paper

On the first day, Mikeska posed the question to the students, "What will happen if we drop a book and a [flat] piece of paper at the same time?" She did not have them try it, just talk about it, and the students excitedly predicted the book would fall first. Autumn said "The paper will go down after the book," and Allison agreed, saying it was because the book "had more force." Ebony explained that the book would fall first because "the book is going to fall down first because the book is more stronger than the paper." Other students agreed; with many children speaking at once: "Yeah!" "The paper is so light." "The book is more heavier than the paper."

Mikeska settled them down to have an orderly conversation, and asked Ebony to begin:

> Ebony: Um. The book is going to fall down first because, um, they have more strength, um, than the paper because the paper, it has no strength. Because if you put it on, um, the things that you weigh yourself on, the paper is going to weigh nothing but the book is gonna weigh like one or three pounds.

Mikeska decided to have the students focus for a moment on understanding Ebony's idea, asked them to paraphrase what he'd said, and then asked whether they agreed that "the book would hit the ground first because the book has more strength than the paper." Autumn agreed because she'd seen this happen at her house, and Allison offered that they "could test it at our house this afternoon and then tomorrow morning we could tell you what happened."

Mikeska kept them on the topic of explaining their reasoning, instead of shifting to the topic of collecting empirical evidence. Ebony elaborated that "the paper will fly down like this," gesturing back and forth with his hand to show how the paper will move. Several other students mimicked his gesture and agreed with him. When Mikeska asked, "What's making the paper go like that?" several students answered immediately, "The air!" Mikeska asked what the air was doing, and Allison answered, "It's blowing it." For a few minutes the students reiterated and reaffirmed this prediction, Allison emphasizing that the book would land first even if "you dropped the paper faster," or released the book from higher than the paper.

Toward the end of this prediction discussion, Ebony added another idea.

> Ebony: The paper won't, when it hits the ground, the paper, it won't make a noise, but the book will.

Several students agreed and took the opportunity to demonstrate, with their hands, the sound the book would make hitting the floor. When Mikeska turned them back again to talk about what the air does to the paper, several students said that it "blows it." Some began talking about differences between the paper and the book, in particular saying that "the paper is thicker than the book."

Examples of inquiry?

There are two aspects of the students' thinking in this first segment of activity that, we expect, would be consensus examples of inquiry.

The first is the students' generating causal explanations. When Mikeska first posed the question, several students quickly responded not only by predicting the book will hit the floor first but also with causal explanations for why: The book has more "strength" or "force" or "weight" than the paper. The students were not using these words in the same ways a physicist would, but they were expressing a sense their peers (and we) could understand. When they explained further that the paper moves back and forth while the book falls straight down, and the teacher asked what makes the paper move that way, the children identified "air" as the causal agent. Asked what the air does, they added that the air or "wind" is "blowing" the paper.

The second respect in which this might be a consensus example is the children's explicit reference to evidence to support their answer. When they demonstrated how piece of paper moves, they were clearly making use of what they had seen. Autumn reported having seen this happen at home, and Allison followed this with a suggestion that they all try it at home and report what happened. Ebony made a rhetorical suggestion for empirical evidence in saying what a scale would read measuring the weight of a book or a piece of paper, to support his contention that a book weighs more. Later, he cited a different kind of evidence based on things he already knew to support his prediction, that when a book hits the ground it makes a sound, but paper does not.[2]

[2] Ebony may have been making an argument for consistency among observations: that the book makes a noise but the paper does not agrees with the idea that the book moves more quickly. He may also have simply been listing something else he knew would happen.

Children's abilities

Note that Allison and Ebony, with others following, responded to Mikeska's first question ("What will happen if we drop a book and a piece of paper at the same time?") not only with phenomenological predictions but with causal explanations for why: The book has more "force" or "strength" or "weight," which moves it more quickly to the ground. That is, the children were spontaneously and explicitly mechanistic. Later in the conversation, describing how paper moves as it falls, they did not move immediately to explain the cause, but they understood the question when Mikeska asked, "What makes the paper move that way?" They responded immediately, "The air!" Clearly the children were capable of mechanistic reasoning, entering into it on their own, and of understanding a request for mechanistic explanation.

Discussing experimental results

The next day, Mikeska reminded the children of their conversation from the previous day. In fact, as she had it recorded on video, she showed them the tape and asked them, as they watched, to keep track of the ideas they had raised. With her help they produced a list on chart paper, as shown in Figure 1.

Later in the day, she had the children break up into small groups to try the experiment, having demonstrated what they should do: Hold the book and the sheet of paper at the same height, and let them go at the same time.

After several minutes of this activity, she called them back into one group to discuss what they had found. Starting the discussion, she called first on Ebony.

What will happen when you drop a book and a flat piece of paper at the same time?
The book will fall first.

Why?
1. The book has more force.
2. The book is stronger than the paper.
3. That's what happened when she did it at her Dad's house.
4. The paper will float.

Fig 1: Ideas on chart paper (from Mikeska, in preparation).

Teacher: What happened when you dropped the book and piece of paper at the same time, at the same height? What happened? OK, Ebony why don't you go ahead and begin.
Ebony: To me, first, the paper fell first.
Several students: No way, No! Whoa!! The book fell first.
Ebony: No, to me the paper fell first.
Student: It fell at the same time.
Ebony: No, the book, um… the paper fell… the paper fell first to me!
Student: Yeah, but not to me!
Jorge: Yeah, but did the book fall first, just like the paper?
Ebony: No, the papers fell first. No, the paper – to *me*.
Alison: To Ebony – to Ebony the paper fell first.
Jorge: And to all of us the book might of fell first to us.
Students: Yeah.
Jorge: Our paper - our paper goes slowly. It's, it's a little bit, ah, ["out of practice"?].
Rachel: With me and Julio twice the book and the paper tied - twice.
Diamond: Went at the same time.

Rachel: They both tied twice.
Allison: What do you mean 'tied'?
Student: They went both at the same time.

At the time, Mikeska naturally expected that the students would come back from trying their experiment having confirmed their unanimous prediction. To be sure, that was what she had seen happening, as she circulated in the room watching the students conduct their experiments. Of course, she could not be everywhere at once, and the first students to speak were several she had not seen during the activity. To have Ebony saying that *to him* the paper fell first, and then Rachel reporting that *with her and Julio* the book and paper tied, *twice*, was surprising.

After the fact, we have the advantage that we can go find the video of Ebony dropping the paper and the book. He held the paper under the book and dropped them so that the book pushed the paper down ahead of it as they fell. (Rachel and Julio were not on camera.)

Mikeska asked others to say what happened when they did it, and several students reported that the book hit first. Diamond remarked that Henry was "putting the paper so that it could fall first." When Mikeska asked her to explain, she said he was dropping the paper first, but Henry denied it. With this as a possible direction for the discussion—here was a plausible answer for different outcomes—Mikeska pressed for an explanation for how it could be that "we got all these different results." Allison reviewed how her group had gone around two times, with different outcomes, and Mikeska asked, "Why did that happen?" Ebony answered, "Cause we did it twice," and then Rachel had a new idea.

Rachel: Forces of gravity?
Teacher: Rachel has an idea.
Rachel: Forces of gravity?
Alison: Yeah!
Diamond: What are forces of gravity?
Rachel: Gravity —
Alison: Gravity – you know how when we jump we always land back on the ground.
Rachel: Exactly. It's what keeps us down on the ground.
Student: And like ground magnets.
Ebony: No gravity. No gravity is when you're like in space and you can never fall down.
Student: You know, you just float in the air. [Ebony nods]
Alison: Gravity – see how when I jump [jumps] I'm just landing at the same place on the ground that… because gravity, gravity is just pulling me down.

Other children began to jump up and down, giving gravity a try, and Mikeska asked them to stop.

Teacher: Oh, we're not all going to — They already, they already showed us. (Students jumping.) You can sit down. (7 second pause)
Students: [Laughter.]
Teacher: [to Rachel] Okay, so, so what you're saying is that a for - what is a - you're saying the force of gravity -

Rachel: Is pulling it down at different times.
Teacher: So, you're saying the force of gravity is pulling the book down at a different time than the paper.
Student: Yeah.
Rachel: Yeah, probably. And, sometimes it's pulling it down at the same time, or pulling the paper down
Student: Before the book.

Mikeska asked why gravity would pull down differently at different times, but no one had an answer.

Examples of inquiry?

It may be more difficult to find consensus examples of children's scientific inquiry in this segment than it was in the first. One could be Rachel's emphasizing "twice" as an early version of valuing replication. Another might be the way Allison and Diamond asked other children for clarification: "What do you mean, 'tied'?" and "What are 'forces of gravity'?"

But the segment is more interesting for its contrast from the first. We would like to try for a consensus that the children slipped out of the sort of inquiry educators would like to promote as the beginnings of science. Ebony, to begin, seemed to have shifted in his purpose and approach from the previous conversation, when he had been so articulate in justifying his prediction that the book would hit first. Coming back to the group, he simply announced his result to the class, and did not explain the reasons for its difference from their prediction. From the first, he emphasized that the paper fell first *to him*, probably anticipating his result would differ from others', and that was how he responded to their disbelief, by reasserting his claim and emphasizing "to *me*." Allison supported his stance, affirming that "To Ebony, the paper fell first," and Jorge agreed, adding "and to all of us the book might of fell first."[3]

This is not to say the children were being irrational or unintelligent—and we need to be clear about that or we may be uncomfortable excluding anything children do from our objectives. On this interpretation, Ebony was being *creative;* he was telling the story of *his* experiment much in the same way he might tell a story about what happened to him on the playground the day before. He may have chosen to tell that story because he felt the answer to the original question was obvious and uninteresting. Allison and Jorge were providing a socially harmonious resolution to the difference of opinion, allowing Ebony to have his opinion and others to have theirs, much as they might over a matter of preference: Different people have different experiences, and they are entitled to different views.

So the children's approach here had its own rationality; we might characterize it as a version of show-and-tell, where there would be no reason to require different experiences to align. But it was a different approach from earlier when Ebony and

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[3] A number of students in the class spoke English as a second language, which added to the challenges of interpretation, both for us and for them. Jorge's question a moment earlier ("Did the book fall first, just like the paper?") was an example. He seemed to be trying to resolve the conflict as a matter of language, checking on precisely what Ebony meant, but it is difficult to know what alternative he was presenting. One guess is that he was thinking "first" might mean "right away."

other children had explained their prediction that the book would fall first in terms of causal mechanism. Here, neither Ebony nor Rachel nor Allison attempted to explain why their results (the paper falling first or the paper and the book tying) differed from the rest of the class' results, or from their predictions on the previous day. For the rest of the class, except for their initial disbelief at Ebony's result, most seemed content to accept disparate results; they accepted that everyone could have her or his own answer.

Mikeska was concerned by this resolution (or lack thereof) and tried to make the inconsistency problematic, asking how they could come up with different answers. Finally, Rachel tried "Forces of gravity?" as a possible answer, looking at Mikeska with her question. In this moment, it seems, she was trying a different kind of answer, one based in "science words," on the possibility that was what the teacher wanted. By that interpretation, this was another example of something we should not consider as scientific inquiry. Again, this is not to say it isn't rational: The students have heard this term, and it is perfectly reasonable to wonder if it is relevant here, 'Is this related to these words I've heard people use?' However, this behavior cannot be considered valuable inquiry because when students use vocabulary without being able to articulate a meaning or relevance, they will not be able to make progress in reasoning about the mechanism at work.

A more liberal interpretation would be that Rachel was thinking "forces of gravity" are variable like the wind, and their variation leads to the variation in results. By that interpretation, we might see her reasoning as more scientific. Like the students' previous use of "strength" and "weight," this would connect to some other aspect of their experience. Note, though, we need to read that in to the thinking: In the earlier discussion, children explicitly referred to measuring weight on a scale as well as to personal observations of how paper falls and the sound a book makes hitting the floor; we had a clear basis for seeing their reasoning as connected to their kinesthetic experience of weight. Here, we cannot be sure what meaning Rachel attached to the term "forces of gravity" so we cannot directly assess whether she could use it in a way that would be helpful for making sense of the situation.

For a moment, the children digressed to a discussion about gravity, and we might see some of this as explanatory: Gravity pulls objects to the ground, "like ground magnets"; without gravity things do not fall. In this conversation we find some evidence that Rachel knows the role that gravity plays in other situations, although we cannot judge how she relates that to the problem of the book and the paper. Only when Mikeska explicitly asks Rachel to apply her understanding to the problem does Rachel complete Mikeska's sentence by explaining that the force of gravity "is pulling it [the paper and the book] down at different times."

Children's abilities

If there may be consensus that, for the most part, the children were not engaging in productive science in this segment of the conversation, it would be hard to understand that in simple terms of ability. It would be difficult to make a case, in particular, that Ebony lacked the ability to explain why his results were different from other students'. He had been quite articulate the previous day, in justifying his prediction that the book would hit first, based on mechanism (the book weighs more) and on consistency with other observations (the paper moves back and forth, the book hits with a sound). And there is no reason to suppose he was not able to follow Mikeska's directions for how to drop the book. Instead, it seems more reasonable to say that although these students were capable of reasoning mechanistically (as they had done on a previous day), they did not always do so.

The book and the crumpled paper

Mystified for the moment by how the class was going, and hoping to get back to a productive discussion, Mikeska demonstrated dropping the book and paper together three times. Several children shouted "I knew it!" and "The book fell first"; someone said, "See Ebony?" Mikeska asked Ebony again — "you found out something different" —and he simply repeated "the paper fell first," shrugging his shoulders. Allison brought them back to the idea of gravity, suggesting that "gravity probably just pulled the paper a little more than it pulled the book." Ebony joked "Maybe it's tired," and others laughed and repeated the line: "Yeah, maybe the gravity's tired!"

With the discussion beginning to deteriorate, Mikeska moved the students on to the next question: What if they were to crumple the paper? Then which would win? Jorge began by saying that he knew they would tie because he had tried this at home. Diamond and several other students agreed, and Allison explained that the crumpled paper "has a little more weight," which the students had decided on the previous day was a reasonable explanation for why the book falls before the flat paper. After this brief discussion, Mikeska asked the children go back to their small groups and try the experiment.

When the class reassembled, the students quickly agreed that the book and crumpled paper hit at the same time, and they again focused on why, without any questioning by the teacher. Brianna opened the conversation saying, "They will fall at the same time. Cause they both got the same strength together." Rachel explained that crumpling the paper gave it more strength, and Julio said that crumpled paper is "kind of heavy." This explanation became a point of contention, and the students discussed it for several minutes without intervention from the teacher. In response to Julio's idea, Brianna said, "If it's balled up it's still not heavy, it's the same size" and reached to grab the ball of paper. She un-crumpled it, held it in her hand and bobbed it up and down, feeling its heft, and said "It's still the same size!" Allison tried to insist that the balled up paper was no longer light, arguing that her "dad could probably throw it up to the ceiling and he wouldn't, and he wouldn't say it's light." But more children, after Brianna's demonstration, agreed with her that the crumpled paper was "still light."

Having ruled out weight as a possible explanation for why the crumpled paper now falls at the same time as the book, the students continued to converse for a few more minutes. Diamond had two more ideas, one that the crumpled sheet "had more pages [?] when it's balled up… it looks like the book have a lot of pieces of paper." A bit later, she suggested that with the paper crumpled it could "roll." Diamond explained the importance of the paper's shape by saying that the crumpled paper falls more like the book, straight to the floor.

> Diamond: 'Cause the piece of paper was balled up, it don't go like this no more (Shows a rocking motion with her right arm.)
>
> Brianna: No, yeah. It don't, yeah. It just drops, kind of like the booklet.

Mikeska decided to let the exploration continue to another day, challenging the children to do the same experiment with things they find at home.

Examples of inquiry?

With the new topic of crumpled paper, the students moved back into a form of inquiry we contend science educators should support. The terms "forces" and "gravity" disappeared, and the children have returned to ideas of causal mechanism, discussing whether and how the crumpled paper has more strength or weight. Brianna's move in particular, to open the ball of paper and show that it is the same size, should be something we all recognize as productive inquiry. She drew on their experience and intuitions about an everyday activity (crumpling things up), to refute an idea that initially seemed a plausible explanation. Diamond's comment about the shape of the paper also seems like valuable scientific inquiry, identifying a specific factor other than weight that might have contributed to the change in outcome. As well, she reminded the class of their reasoning from the previous day, that the flat paper took longer because it moved back and forth on the way down.

We suggest that Ebony's joke is another example of inquiry, although here we do not expect consensus. It may seem odd to consider a joke as an "element of the dialogic processes" of science, but we believe Ebony's that "maybe [gravity]'s tired" was a productive contribution. In particular, by making fun of the idea, Ebony was not only ruling out an explanation but also calling attention to it as ridiculous. In this way, the joke helped express a sense of what could and could not constitute an acceptable explanation. Other children seemed to get it, although it is possible some of them were only picking up on the laughter rather than understanding and accepting the tacit premise.

Finally, Allison's comment that her father could throw the crumpled ball up to the ceiling but "he wouldn't say it's light" seemed an attempt to draw a distinction in meaning. There is the question of whether something is easy to lift or throw in the air, and there another question, which she does not articulate, in which something might be light or heavy. If she was trying to distinguish shades of meaning, she was doing something else educators should support as inquiry.

Children's abilities

Several children expressed some version of the idea that crumpling the paper makes it heavier (or gives it "more strength"), and from a developmental perspective the most obvious interpretation would be in terms of classic Piagetian conservation tasks. On this view, the children's reasoning is a sign they are still pre-operational.

Another interpretation would be that some of the children were thinking of "strength" and "weight" in a different sense they could not clearly articulate. That several children explained that the book and the crumpled paper have the "same strength" suggests they may have meant something different, in that moment, than what adults call "weight": It is unlikely that they suddenly came to believe the crumpled paper would have the same heft in their hands as a book. So, for example, a child picking up a small piece of lead might describe it as "heavy," although she could lift it easily or even "toss it to the ceiling."

Brianna's flattening the paper, however, is an especially clear indication that she was able to reason about reversibility and conservation. Moreover, the class's general acceptance of the idea that crumpling the paper does not change its weight suggests other children were able reason in this way as well.

A working definition of inquiry

To review, using this discussion as a case-in-point we are suggesting some examples of what science educators might agree are examples of what we mean by inquiry. Note that to this purpose it is not essential that everyone agrees that these interpretations are correct for these students at this time; everyone need only agree that if these interpretations are correct, they describe the sorts of ideas and reasoning educators should support.

The examples we suggested were of children

- arguing from a sense of mechanism to explain a prediction, that the book will fall faster than the paper because it is heavier, apparently thinking of the greater agency downwards causing the greater effect (speed) or, at another moment, thinking of the air or wind blowing on the paper as slowing its fall;
- arguing from a sense of mechanism to explain a result, that the book and crumpled paper must have the same downward agency acting since they fell at the same rate;
- drawing connections to other observations, of the paper falling in a flutter back and forth rather than in a straight line like the book, and of the book hitting the floor with a noise rather than quietly like the paper;
- asking for precision and clarity in their explanations;
- valuing replication, in emphasizing repeated results;
- drawing distinctions between two similar ideas — one (difficult to articulate) sense of how "light" the paper is versus how hard or easy it is to lift;
- checking for consistency among lines of reasoning: There is no more paper, so how could it be heavier?

We also suggested some examples we would all agree are not the sorts of ideas and reasoning educators should support, namely of a child or children

- altering an "experiment" to produce a desired result, and presenting the result as comparable to others;
- accepting inconsistencies in results as matters of personal choice or perception;
- using terminology ("forces of gravity") without tangible meaning.

Considering these and other examples of what we see as inquiry, we suggest that all of the positive examples fit the description of children *trying to form coherent, mechanistic accounts of natural phenomena*. "Mechanistic" here means bearing on the children's sense of causes and effects, from what they have experienced or inferred.[4] "Coherent" here means the account is internally-consistent and stable: different parts of the account do not contradict each other, and the account "holds together" over time.

In these examples, the students' reasoning about "strength" and "weight" is mechanistic: The stronger downward cause on the book produces the effect of faster motion. It is also coherent: The account fits with what they remember seeing when

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[4] Machamer, Darden, and Craver (2000) provide a more precise definition of *mechanisms* in science: "entities and activities organized such that they are productive of regular changes from start or set-up to finish or termination conditions." See Russ, *et al* (2005).

paper falls, with what they remember hearing when a book hits the floor, and with what they remember feeling, holding a book compared to holding a piece of paper. It fits as well with their more general experience of pushing and pulling on things to make them move, although no one actually makes this explicit. Other examples in the list fit the description as well: Asking for clarity, valuing replication, distinguishing shades of meaning and checking for consistency among lines of reasoning are all aspects of trying to develop a coherent account.

And, we suggest, the description excludes the examples of what is not inquiry. Making a change to an experiment to produce a different outcome—and not reporting the change!—does not contribute to forming a coherent account; neither does accepting inconsistencies without explanation. Using technical vocabulary without tangible meaning is not attending to mechanism.

These examples illustrate what we believe we could find more generally, that moments we assess as inquiry fit this general description. So perhaps we could generate a consensus for this as a working definition: *Inquiry in science is the pursuit of coherent, mechanistic accounts of natural phenomena*. It is a fairly broad definition, as it could include a wide range of epistemic activities—from consulting an authority to conducting an experiment to imagining an outcome—all of which can be part of a student's or scientist's attempts to form a coherent, mechanistic understanding. We contend that this breadth is appropriate.

The definition will clearly need refinement, at least to understand professional science. The idea of "causal" becomes problematic, for example, in describing various ideas and approaches to physics (e.g. Lagrange's formulation of classical mechanics, Heisenberg's formulation of quantum mechanics, etc.). The idea of "coherent" may be problematic for reasons Duschl and Grandy (in preparation) discuss, citing philosophers of science such as Cartwright (1983), who argues against a view of physics as the pursuit of principled coherence. We believe these refinements are possible, however, with perhaps a more generalized notion than *causal* and a more qualified version of *coherent.*

What children bring to class

Our first purpose in presenting the case study was to provide some examples to ground discussion about what science educators think of as inquiry. Our second purpose was to provide a bit of evidence regarding children's abilities. In particular, we have argued that these children showed abilities for inquiry, including reasoning from their sense of mechanism, drawing connections to aspects of their experience, and attending to consistency among ideas and observations.

In this we contribute to an extensive body of evidence that children bring abilities to begin inquiry in science, such as pre-school children's abilities for reflecting on knowledge (Gopnik & Meltzoff, 1996; Karmiloff-Smith, 1992); kindergarten-second graders' abilities to distinguish hypotheses and evidence (Sodian et al., 1991; Tytler & Peterson, 2004); second graders' abilities to analyze uncertainties in experiments they design (Metz, 2004) and for attending to empirical and logical consistencies in theories (Samarapungavan, 1992); third-sixth graders' abilities for generating, assessing, and working with analogies (Atkins, 2004; Louca, Hammer, & Bell, 2002; May, Hammer, & Roy, under review); and fourth-sixth graders' for distinguishing observation from theory and seeking consistency in reasoning (Chinn & Malhotra, 2002).

There seems to be a broad consensus that children bring a range of abilities for scientific inquiry. These include abilities educators have at times classified as "abstract" or "theoretical," such as for reasoning about the consistencies and inconsistencies among ideas, for drawing connections to different parts of their understanding, for thinking in terms of causes and effects.

Variability

There is not yet consensus with respect to how educators should conceptualize the form in which students bring those abilities. We use the term "ontology" to refer to this conceptualization: What forms of cognitive structure do educators attribute as existing in students' minds? A number of authors who ascribe more sophistication to children than depicted by traditional accounts continue to model children's reasoning abilities as stable and consistent, as stages of development and/or tacit theoretical frameworks (Burr & Hofer, 2002; Gopnik & Meltzoff, 1996; Kuhn, Black, Keselman, & Kaplan, 2000). We describe these as *unitary* ontologies in that the forms they ascribe to minds are intact units, seen as either present and functioning or not present. Other authors have argued that reasoning is more variable than unitary models depict (Feldman, 1994; Karmiloff-Smith, 1992; Metz, 1995; Siegler, 1996).

Unitary accounts compete in the literature with *manifold* ontologies that also ascribe cognitive units but at scales that need not correspond with ideas or behavior. Minsky (1986) coined the phrase "society of mind" to capture this view of cognitive phenomena arising from the activation of many "agents," seen as existing in the mind but not necessarily functioning in any given moment. DiSessa's (1993) "phenomenological primitives" ("p-prims") is a manifold model of intuitive physics, specifically intuitive sense of mechanism. We have suggested a similar approach to modeling student epistemologies (Hammer & Elby, 2002). In that work and here we use the term "resources" to refer, generically, to the elements in these models of mind, including agents, p-prims, and schemata (Rumelhart, 1980) as particular models for these elements.

Our analysis of this case study argues for views of children's reasoning as variable, in several respects. First with respect to the substance of the children's thinking, there was certainly evidence of children believing that heavier things fall faster than light things. But the children's first prediction for the crumpled paper had it hit the floor at the same time as a heavier book. No doubt they were influenced in that prediction by contextual cues—the crumpled paper question followed the flat-paper question, and the children likely expected contrast. Still, the instance puts pressure on the attribution of a robust misconception that heavy things fall faster than light things: Why would the hint of contrast with an earlier question be sufficient to suppress it?

There was also evidence of variability in the children's use of their abilities for inquiry. During the first segment, the children quickly agreed that the book would fall first and began to give various reasons to support this answer, including mechanistic arguments for why the book falls first and connections to their experience: the book is heavier; the air blows on the paper; the paper moves back and forth; the book makes a loud noise when it hits. During the second segment, after they had tried dropping the book and paper, the conversation shifted dramatically, to an unproblematic acceptance of different people having different answers and then to the obscure and unclear notion of "forces of gravity." During the third segment, discussing the book and crumpled paper, the students returned to a scientifically more productive mode of sense-making, discussing reasons the paper might have fallen more quickly this time, debating whether or not the crumpled paper could be heavier and considering how shape affects an object's descent.[5]

From our perspective, this should not be surprising: Children are able to understand and engage in many different kinds of epistemic activities, from fact-finding ("go see if it's raining") to tangible explanation ("if clouds are all full of water how do they stay up?") to playful explanation ("the clouds are crying because the wind punched them") to story-telling ("once upon a time…"). Different activities call on different abilities; why would we expect children to stick to one kind of activity? In this example they seemed to move from an activity of tangible explanation, for why they expected a book to fall faster than paper, to an activity of show-and-tell, of what happened when they tried dropping books and paper. In the first segment, their explanations needed to make sense, in some common way, with respect to what they knew about causes and effects. In the second segment, after a moment of puzzlement—some children possibly still thinking about what makes physical sense—most seemed to shift into a tolerant stance. Soon the conversation would revolve around "forces of gravity," and one child's jumping prompted others to try that activity, too.

Newton and Newton (1999) found similar phenomena in 10 year-olds sometimes being unable to recognize the "kind of understanding" that was appropriate to a particular context. Diakidoy and Ionnides (2004) found that second graders in their study confused hypotheses with statements of preference. Rather than understand these confusions in terms of levels of development in the children's abilities, however, we understand them as arising from shifts in the students' understanding of what they are doing, from the first activity of tangible explanation to the next activity of show-and-tell. Metz (to appear) discussed the social context of elementary school, valuing harmony over argumentation. She gave examples of teachers having children vote to resolve disagreements and of children using "rock, paper, scissors." In the case above, the children resolved the conflict with a shift in the activity, one that allowed each student her or his own perspective.

On this account, the children have resources for understanding different kinds of knowledge, including intuitive versions of hypotheses and statements of preference, as well as many others—questions, observations, fictional stories and "real" stories, and so on (Hammer & Elby, 2002). Different contexts, including fine-grained differences within a given conversation, activate different epistemological resources: Children are capable of understanding knowledge in a variety of ways and of engaging in a variety of epistemic activities.

Coherence

It may be important to emphasize that we are not describing children as randomly incoherent in their epistemic activities. In this case, the first graders moved from one relatively coherent activity to another. Within the first segment, when they seemed to frame the conversation as one of tangible explanation, most student comments make

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[5] Of course, not all the students were participating all the time, but the shift in the conversations cannot be attributed simply to different students speaking. Ebony, Allison, and Rachel all spoke in more than one segment of the conversation, and in varying ways.

sense within that framing. During the second segment, a series of student comments make sense within a framing of show-and-tell, and so on. That is, we are not describing the children as varying randomly in the ways they thing about the question; we are describing them as varying among different local coherences (Russ et al., 2005).

Work in two research projects at the University of Maryland has described similar phenomena of students shifting among different epistemic activities from young grades elementary school (Louca, 2004; Louca, Elby, Hammer, & Kagey, 2004; May et al., under review) to introductory college physics (Lippmann, 2003; Lising & Elby, forthcoming; Tuminaro, 2004). Redish (2004) has suggested these phenomena connect to accounts in linguistics and anthropology of *framing* (MacLachlan & Reid, 1994), meaning an individual's forming a sense of the activity. In this description, for example, the first graders were at first framing the activity of discussing the book and paper as one of tangible explanation; later they framed the activity of reporting their results as one of show-and-tell.

These local coherences are consistent with a resource-based ontology of mind. In fact, Minsky's (1986) model included "frames" as cognitive structures comprised of agents in a particular organization. We take "framing" to refer to the activation of a set of resources that is self-consistent and locally stable (Hammer, Elby, Scherr, & Redish, in press; Redish, 2004).

For example, Rosenberg, Hammer, and Phelan (forthcoming) analyzed an eighth-grade conversation of the rock-cycle (Phelan, in preparation) to show different stabilities in terms of mutual activations among epistemological resources. At the outset of their work, the students were in a "cut and paste" mode of reasoning, gathering information from their worksheets and placing it in an ordered list. Rosenberg, *et al* (forthcoming) offer a simplified model of local coherence to this activity in terms of a set of resources for understanding epistemic forms and activities: *knowledge as propagated stuff* (transmitted from a source to a recipient), *information, accumulation*, *ordering,* and *ordered lists*. These resources formed a closed system in which one activity (e.g., retrieving information from the worksheets) led to the next (placing it in the list), which called the next (retrieving more information), and so on.

The teacher, Jessica Phelan, admonished the students to "start with what you know, not with what the paper says," and the students shifted into a different mode of thinking. A simplified model of the new mode includes *knowledge as fabricated stuff* (made from other knowledge), *imagining, causes* and *causal story* (in which the chain of events depends on causation). Again, these resources call and re-call each other, forming another locally stable system. This system allows a natural explanation for how the students' difficulty identifying a causal link for their story (how does sedimentary rock get exposed to heat?) triggers a different mode focused on problem-solving and argumentation: *Causal story* requires *causes*, and if there is not one available for the next event, the story-telling must pause, to locate or construct a cause.

In the case of the eighth-graders, it was evident they were deliberate and aware of their shift in mode of reasoning. In the case of the first-graders here, we do not have this evidence, and we suspect that for some of the transitions they were neither deliberate nor aware. When Mikeska first posed the question of the book and the paper, the students entered into a mode of mechanistic sense-making about why the book would fall faster. The next day they fell out of that mode and then back into it, over the course of the conversation; there is little reason to suspect they were aware of these transitions. One aspect of progress, for these students, would be their coming to recognize mechanistic sense-making as an epistemic activity of science.

Implications

We have noted two points we believe deserve and are likely to achieve consensus in the communities represented in this volume.

The first is over examples of what educators would and would not consider examples of inquiry, drawing from this first-grade discussion. Citing Abd-El-Khalick (2004), Duschl and Grandy (in preparation) listed (some of) the range of ways researchers have characterized inquiry. By giving examples and, in our attempt, defining inquiry as a pursuit, we hope to clarify that inquiry is something to promote and assess in students' actions and reasoning. It is part of the substance that should pervade science instruction, rather than a pedagogical approach or an ancillary objective pursued through added, side activities.

The second point of likely consensus is a broad-brush estimation of children's abilities, of what children bring to class. Children are capable of much more than traditional accounts credit them. Certainly this has implications for early objectives in science education, including increased emphases, even for six year olds, on the dialogic processes Duschl and Grandy (in preparation) describe. Young children can and do enter into mechanistic sense making as well as comparing and assessing ideas and evidence; they can be both theoretical and empirical in pursuit of coherent accounts of natural phenomena, connecting to and expanding on their sense of mechanism.

Perhaps there is a third point of consensus in the phenomenology of variability: What we see children doing at any one moment is of only limited value in determining what we will see at another moment. We advocate a resources-based account of children's abilities, but the phenomenology may be enough for useful implications for instruction. It would mean that to the extent children are not behaving as we might like, in any moment—using anthropomorphic reasoning, e.g., or ignoring inconsistencies, or conflating hypotheses and evidence—it does not necessarily reflect a developmental or structural limitation. It also means that to the extent we discover children behaving in ways we see as valuable—mechanistic reasoning, reconciling inconsistencies, coordinating theory and evidence—it does not mean they have "arrived" and the objective is covered.

In sum, we hope to help motivate explicit instructional emphasis on scientific inquiry, as its own agenda. Educators need to learn to assess student reasoning by means focused directly on inquiry and not simply on progress toward canonical ideas. A rich collection of case studies, with examples of what inquiry looks like, should be the starting point. Especially in early grades, if children are capable of a variety of kinds of activities, which they move into and out of with ease, educators should help guide them to those that represent nascent scientific inquiry.

Still, we find it easiest to speak of and think about this variability in terms of a resources-based ontology: What might help activate the children's sense of tangible, causal explanations? In this sense we might see progress in education in terms of helping children learn to activate productive aspects of their abilities with respect to inquiry in science, to move into these productive modes of thinking not only by accident or for context sensitive reasons but because these are forms of reasoning they understand as intrinsic to science.

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