

ABSTRACT

Title of Dissertation: EPISTEMOLOGICAL AUTHENTICITY IN
SCIENCE CLASSROOMS

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A scientifically literate individual understands important characteristics of both the nature of scientific knowledge and the activity that produces it, scientific inquiry. (NRC, 1996; AAAS, 1993) In support of these goals the *National Science Education Standards* (NRC, 1996) envisions science classrooms where students engage productively in activity that is similar to scientific inquiry. It is presumed that by engaging in this kind of activity students will come to deeper understandings of scientific inquiry and scientific knowledge. For this instructional approach to be successful it is necessary students not only engaging in activity that “looks” like science in important ways, but also view their own activity as *authentically* using knowledge for the purpose of making sense of natural phenomena. Notably the determination of what is authentic is problematic in a science classroom. There are two different possible arbiters “present” in a classroom, the students themselves and the discipline of science. And what is authentic to one might not be to the other.

This work provides perspectives on classroom and teacher professional development implications of this view of science instruction. Chapter two articulates a conceptualization, *epistemological authenticity*, of the nature of student activity necessary to achieve these instructional goals. Such activity involves students engaging in scientific practices with the same purposes as scientists. Chapter three uses a case study of a science classroom to illustrate some of the features of student activity that provide evidence of more and less productive student expectations about the purposes of their own participation in a science class. It also discusses the role teacher instructional choices play in influencing how students perceive the purposes of classroom activity. Chapter four considers teacher professional development, specifically images of exemplary science classrooms in the *Standards* and a supplement to it (NRC, 2000). The depictions in those documents provide little insight into student activity, instead focusing on the pre-planned instructional sequence. This is poor preparation for teachers who must pay close attention to students. An alternative depiction is presented and contrasted with the images in the supplement to the *Standards*.

EPISTEMOLOGICAL AUTHENTICITY IN SCIENCE CLASSROOMS

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Table of Contents

Table of Contents	ii
List of Figures	iv
Chapter 1: Introduction	1
My science learning and teaching experiences	5
What my experiences imply for this work	11
A description of what follows	13
Chapter 2: Epistemological Authenticity	15
Abstract	15
Introduction – Authenticity in science classrooms	15
The ‘authenticity’ literature – A critical literature review	18
Focusing the critical literature review	20
Disciplinary authenticity	22
Concerns with disciplinary authenticity conceptualizations	26
Personal authenticity	29
Concerns with personal authenticity conceptualizations	34
An alternate conceptualization – Epistemological authenticity	37
A classroom episode – Epistemologically authentic Thomas	43
Analysis of ‘Epistemologically authentic Thomas’	46
Implications and questions	48
Chapter 3: Attending to student ‘framing’ in a science classroom	51
Abstract	51
Introduction	51
Research that provides insight into how students understand school	53
Epistemological Framing	56
Productive framing as an instructional goal	58
A case study of attention to student framing	60
The setting and data sources	61
The first twenty minutes: Good wrong thinking	63
Evidence of productive student framing	67

The weight-mass moment: Productive framing vs. correctness	69
A digression into teacher thinking	70
How students responded	71
The teacher's response and student framing	74
Tension between objectives	79
One more episode	81
Conclusion	84
 Chapter 4: Supporting student inquiry through illustrations of exemplary science classrooms	86
Abstract	86
Introduction	87
Inquiry	88
Illustrating exemplary science classrooms for those new to reform goals	91
Characterizing the illustrations and their pitfalls	92
An "image of inquiry" from the <i>Inquiry</i> supplement	93
Two common features of the vignettes	94
The vignettes do little to prepare teachers to support student inquiry	97
Why a dominant focus on instructional model is both reasonable and <u>un</u> productive	101
Why a dominant focus on instructional model is <u>counter</u> -productive	105
Counter-productive conceptions of pedagogy	106
Counter-productive conceptions of what constitutes good student inquiry	109
Counter-productive conceptions of learning	110
An alternative image of student inquiry	111
Comparative analysis of this image of inquiry and those in the <i>Inquiry</i> supplement	128
 Chapter 5: Conclusion	131
Looking across the chapters	131
Issues for further investigation	136
 References	142

List of Figures

Figure 2-1	Diagram depicting the two scotch tape observations	44
Figure 4-1	Henry's diagram	115
Figure 4-2	Calvin's diagram	115
Figure 4-3	Kyle's diagram	123

Chapter 1: Introduction

Educational reformers have long been dissatisfied with their perception that school experiences fail to help students connect disciplinary knowledge they encounter in school with anything relevant to their lives outside the school walls. Dewey (1936) went so far as to argue that school experiences actually hinder students making these kinds of connections.

How many students, for example, were rendered callous to ideas, and how many lost the impetus to learn because of the way in which learning was experienced by them? How many acquired special skills by means of automatic drill so that their power of judgment and capacity to act intelligently in new situations was limited? How many came to associate the learning process with ennui and boredom? How many found what they did learn so foreign to the situations of life outside the school as to give them no power of control over the latter? (p. 26-7)

Dewey's characterized typical school experiences as 'mis-educative'. Mis-educative experiences are ones that have "...the effect of arresting or distorting the growth of further experience." (p. 25) Dewey claimed traditional schooling in the early 20th century was full of such experiences.

70-odd years later Dewey's frustration with the impact of formal schooling on students doesn't appear outdated. There is a significant amount of more recent research, using a variety of methodologies and analytic frameworks, that confirms Dewey's criticism is still consistent with much of what goes on in schools today. This work finds the activity of school has only tenuous connections to the disciplinary knowledge that serves as its formal basis and many students do not make meaningful connections between the formal knowledge they encounter in school and its intended relevance to their lives outside of school. (Pope, 2001; Lemke, 1990; Chinn & Malhotra, 2002;

Bloome, Puro, & Theodorou, 1989; Brown, Collins, & Duguid, 1989; VanSledright, 2002)

There are two criticisms of schooling identified in this work, and it is important to comment on their relation to one another. The first criticism is many school experiences don't connect to students' lives outside of school, the second is many school experiences are not appropriately representative of the discipline they purport to represent. From the perspective of my work, these criticisms are related to the instructional goal of students coming to understand the nature of scientific activity (NRC, 1996), something present school science instruction routinely fails to accomplish. Research shows that students at a variety of grade levels commonly express a view of scientific knowledge as an unproblematic collection of facts and have little understanding of the methods by which scientific knowledge is produced, or of the related roles of observation, explanation, and theory in science. (Carey et al., 1989; Kuhn, 1989; Elder, 2002; Sandavol and Morrison, 2003; Windschitl, 2004)

The work presented in this dissertation is aimed at exploring the circumstances under which science students in school settings will develop more sophisticated views of scientific knowledge and the activity that produces it. Like some others in the science education community (Rosebery, Warren, & Conant, 1992; Calabrese Barton, 1998; Hammer & van Zee, 2006) I take the view that the activity of professional scientists grows out of common, everyday experiences with the natural world. This implies that students come to science classes with experiences that can serve as productive resources for understanding the activity of professional science and the nature of scientific knowledge. However, for those experiences to be useful for that goal students must see

their relevant experiences as connected to activity in their science classes, and the activity in their science classes must appropriately represent the activity of professional science. But the criticisms of typical schooling suggest that neither of these happen frequently in science classrooms.

At least in part in response to the research findings that indicate naïve understandings of science, there is an ongoing effort among scientists, science educators, and science education researchers to implement a significant reform of science learning and teaching in schools. Documents like the *National Science Education Standards* (NRC, 1996) and *Science for All Americans* (AAAS, 1989) articulate a view of science classrooms in which the activity of students looks more like the activity of professional scientists than what is presently going on. The intention of the reform view of learning and teaching is to make science classes more like professional science, and hence make the disciplinary meanings of the concepts more evident to students as well as to provide them with opportunities to gain more sophisticated understandings of the activity of professional science and the knowledge it produces. For some this expectation is based in a ‘situated cognition’ view of learning (ie. Brown et al., 1989; Lave & Wenger, 1991), a view grounded in phenomena that demonstrate individual’s use of knowledge and their understanding of its meaning is based upon the context or situation. In this view, teaching science concepts in typical school contexts unavoidably alters how learners understand their meanings and purposes. Making school science similar to professional science in significant ways has the potential to solve this problem.

There are many difficulties a teacher might encounter when attempting to implement this vision of science learning and teaching. Among the prominent ones is

that when making school science more like professional science a teacher is most often still in a school classroom. Students familiar with following the rules of school for the sake of doing well by the typical standards of schooling are inclined to continue to do so. A teacher who aspires to create the kind of classroom envisioned by this reform must struggle against student expectations of typical schooling. From the perspective of such a teacher those expectations that Bloome et al. (1989) characterize as ‘cultural’, are evident and become salient in the students. That is, as a consequence of students being in this culture, they walk into classrooms with expectations about schooling that influence how they understand what goes on and can constrain what they see as reasonable things to do in classrooms.

Broadly, the chapters of this dissertation deal with making school science generative and meaningful for students in ways that reflect the discipline. This work is informed by both the literature of the present science reform and a strong sense of the perspective of a teacher who is sympathetic to those goals and has struggled to create classroom environments that support them. It is this latter part, the teacher’s perspective, that is the particular value of this work to the research community. I began graduate work in science education with a strong identity of being a science teacher, and I read the science education research literature through that lens. Viewed this way much of the literature is frustrating. There is an important lack of a teacher’s perspective in the literature of the reform. Viewed through my sense of the difficulty a teacher can encounter in trying to create such classroom environments, the literature too often presents a view of changing classroom practice as an uncomplicated, straightforward affair. There is little work that identifies the struggles a teacher might go through or

provides much insight into what the beginning stages of a good classroom looks like.

Among the things I hope to accomplish with this research is to characterize some of the features of science classrooms that can provide science teachers and science education researchers some insight into what productive science learning and teaching looks like in a classroom.

My science learning and teaching experiences

Because this work is grounded in my learning and teaching past, it is useful to provide the reader some insight into my sense of it. My commitment to the view of science learning envisioned in this reform is grounded not only in the research base that supports it, but also in my own experiences as both a student and teacher of science. Many of the foundational ideas of the reform resonate with me because of these experiences.

As a high school student and then an undergraduate college student my experiences in science classes were pretty typical in the ‘mis-educative experiences’ way. As an undergraduate I majored in physics, but my present sense of it is that I succeeded in my science classes more as a consequence of being an adept solver of end-of-the-chapter problems than because of arriving at deep understandings of the concepts or nature of the knowledge. In high school and college I found that I was capable of doing the things that one needed to do to be successful in physics classes, but those things did not require me to genuinely make sense of the conceptual content of the course. For example one did not need to really understand the meanings and implications of Newton’s Laws of Motion to be able to adequately solve the homework problems related to them that were assigned.

When I began a graduate program in physics six years after completing my undergraduate degree things began to change, though in truth I cannot pin down what the precise cause of the change was. Perhaps it was good teaching, a few of my teachers from that graduate program stand out in my memory in this respect. Probably there was an element of my own readiness, six years away from schooling changes one's perspective about what school should provide. And likely the fact that I was put in a position of having to help teach others played an important role as well. In addition to taking courses I was a graduate teaching assistant, leading recitation sections for students in introductory physics courses. Whatever the cause, I began to see the concepts in physics classes as related to my own intuitive senses of what was physically plausible. The concepts were things I could figure out in a way that made sense to me, and this helped guide my use of the concepts in unfamiliar situations.

It is my sense that I did quite well in the graduate program, and there is evidence that the faculty in that department thought so as well. This was a little unexpected. I began the program with a relatively weak undergraduate degree, not having taken several courses expected of beginning physics graduate students, and after six years away from any formal school experiences. The faculty member assigned as my first-year advisor gently made it clear I had been accepted into the program largely because there was an available assistantship rather than on the strength of my application. And yet during the first two years of taking the required courses for the doctoral qualifying exam my grades were quite good, among the best in my cohort, and I often found myself helping my peers with our class assignments. My sense of the success I was experiencing was (and is) that it was due to the new way I was going about learning the content, looking for physically

sensible ways of understanding the conceptual content and then looking for connections between those physically sensible meanings and the mathematical formalisms my teachers and textbooks introduced. And I was having fun. Of course it was gratifying to have the sense that I was succeeding at something, but more than that this new way of understanding how to go about learning physics concepts felt much more enjoyable than the old way.

This way of understanding both influenced and was influenced by the teaching I was beginning to do as well. As a teacher I very earnestly wanted to help the students really figure out the content rather than just learn a set of algorithms. However, I suspect that during those first years of teaching I did a poor job of it. My own understandings of the concepts were just beginning to develop, and as a teacher I lacked an understanding of both the challenges of this instructional goal and the ways I could help students accomplish it.

As an example, I recall leading a review session for the comprehensive final exam at the end of my first semester in this graduate program. I was going through the chapters in order, summarizing the main ideas covered in each. While doing this I had sudden epiphany about the concept of energy, which kept coming in chapter after chapter; motion, heat, electrical circuits, and waves. As I stood at the board it suddenly occurred to me that energy was a tremendously powerful concept that both explains and connects lots of seemingly dissimilar phenomena. Standing up there I was suddenly amazed at the power of this concept to simplify what I needed to understand. I got quite excited in the moment, urgently trying to explain my sudden insight to those poor students who I am sure were a little puzzled by what I was so worked up about. Now of course any

physicist will tell you that energy is a powerful concept that connects lots of physical phenomena. To a physicist this may seem almost self-evident, perhaps mundane. But to me in that moment it was exciting and new, a very powerful way of making sense of physical phenomena suddenly apparent to me, and I wanted to help those students see the power I saw. Though I doubt that became evident to any of them as a consequence of what I said that day.

As I progressed in my graduate program and then left it to teach full time, I had opportunities to take on more responsibility for the teaching of introductory physics courses. The summer after my second year the department was unable to find a faculty member to teach one of the courses and offered to let me teach it. That was followed by a part time job teaching calculus at a private high school, then another summer course at the University, an adjunct position at a nearby small college teaching more introductory physics courses, and then after choosing to leave my graduate program with a masters degree to teach full time, a position with a substantial teaching load in the Mississippi State University physics department.

My teaching began to change through these various positions. I wanted the students in those classes to understand the ideas I presented in the way I was discovering they could be understood. My early efforts to that end were only slightly more sophisticated than the enthusiastic description of the centrality of the concept of energy I offered to the students after my epiphany. What I knew how to do was lecture, so I stood in the front of the room and earnestly told the students how *I* understood the concepts of physics to be meaningful. In what became sort of a running joke in some of the courses I taught I would say to the students over and over “See the physics in the math!” Then I’d

patiently explain how the mathematical formalisms in our textbooks contained statements about relationships between concepts and why and how those relationships made physical sense to me. While well intentioned, my sense is these efforts had little impact. The class must have looked pretty familiar to the students; I was lecturing, there were a slew of end of the chapter homework problems assigned each week, and the tests were comprised largely by quantitative problems which asked students to utilize mathematical formulas to produce answers. While I wanted students to come to see the concepts as physically sensible, the class structure did not require them to do that. The class looked familiar to them and they did what they had done in other such classes, what I had done as a physics student in high school and college.

While I enjoyed teaching it must have become apparent to me along the way that despite my efforts and the considerable efforts of some of the students not much progress was being made. In some sense this was no different from what most physics teachers experience. I recall frequent conversations with teaching colleagues about how our students struggled. My response to this was to try out different instructional practices in the classroom, and the things I tried and liked involved students thinking and talking about their personal ideas, usually in relation to the formal ideas. I was pleased with classroom activities that got students making predictions about what would happen in certain situations, and talking with one another and with me about the reasoning that made those predictions sensible to them. These were moments that felt like the students were doing what I wanted them to do, genuinely trying to make physical sense of the formal ideas, typically in relation to actual phenomena.

The important difference between this kind of classroom activity and my early teaching efforts to change student expectations about their physics learning was that instead of me telling students how the ideas of physics were sensible to me, the students now had opportunities to tell me how the ideas of physics were meaningful to them. Notably that last sentence includes the phrase ‘change student expectations’. This is notable because as a teacher I began to believe that students came to my classes not expecting that what they were supposed to do was make sense of the concepts. So among my tasks as a teacher was to help change the students’ expectations about what they should be doing. Engaging them in extended discussions about how the concepts we were learning about did or did not make sense to them was a step toward changing their expectations about what the class was about.

After a few years of the full time position at Mississippi State I left to begin another graduate program, this one in science education at the University of Maryland. At Maryland I was provided the opportunity to teach a physics content course for pre-service intending elementary education majors. It provided me with a laboratory of sorts in which to continue thinking about and refining my teaching. As I worked to help students understand concepts by engaging with phenomena and then through discussions about those phenomena I began to see that developing deep understandings of the concepts included an understanding of the nature and purpose of the knowledge. That is, one doesn’t genuinely understand Ohm’s Law (for instance) until its purpose as a tool for making sense of physical phenomena is a part of that understanding. A part of conceptual understanding is an understanding of what kind of activity science is. This view is in contrast to many school science frameworks [ie. the *Standards* (NRC, 1996)]

that conceptualize content understandings and understandings about the doing of science (often referred to as process skills) as separate things. Or views of school science that assume a student can't *do* science until they have first *learned* some content. In the way I began to view science learning in my classroom, learning involved doing. And students who come to understand the nature of the activity of science were better learners of science conceptual content for having that understanding.

What my experiences imply for this work

Based on these experiences as a learner and teacher I was concerned by some of the things I saw in the science education reform literature when I began to read it closely in my graduate work. First, as I mentioned, the content of science classes is frequently conceptualized in a way that characterizes understanding of the concepts as a separate thing from understanding of the nature of the activity. And second, little attention was paid to changing student expectations about what is appropriate activity. My teaching sensibility suggested that this is a significant step toward good stuff happening in science classrooms. The research literature often took a curriculum developers perspective and implied that changes in the activities science students were asked to engage in would result in their understanding the activities in a fundamentally different way than typical schooling. This felt at odds with my teaching experiences. Asking students to do different kinds of things *could* have that result in some students, but it could also fail to effect any appreciable change in others. Science teachers are in a position to be attentive to how students are 'studenting' and develop the ability to respond in ways that support more students adopting more productive expectations.

For example inviting students to talk about their personal ideas in a science class works in a number of ways to support the development of different expectations about studenting. Driver, Newton, & Osbourne (2000) argue creating science classrooms where students have opportunities to talk about the merits of different ideas mirrors the ways in which knowledge is produced in science, and makes a science classroom function more like the discipline of science. Another way it can support the development of different expectations is by providing the teacher a means of assessing how students are going about studenting. A teacher can then use that assessment information to respond instructionally in ways that support productive student expectations.

The three chapters that follow¹ comprise the substantial part of this dissertation. All of them grow out of my sense that close attention to the way students are studenting is both an important element of what a science teacher should do and is under-represented in the science education research literature. The work is also influenced by a strong sense I have of being *of* science. Because of my training in physics graduate school and my long association with several different academic physics departments I have a sense of being a member of the scientific community. Consequently, I want the work students do in science classes to be accountable to the standards of the scientific community. Of course that is a sentiment few would disagree with. However, things become a little more interesting, with more room for disagreement, when the question turns to what good studenting in a science classroom looks like. What exactly is it we should hope that teachers see students doing? What kind of studenting should they aim for when they make instructional choices? The first two chapters are arguments that characterize some

¹ This dissertation is largely comprised of three chapters intended as stand-alone articles to be submitted independently for publication, they make up chapters two through four. I thank my dissertation committee for suggesting this format.

features of what we ought to think of as good science studenting. Both are grounded in the view that attending to how students understand the broader purposes of their actions in a science classroom has an impact on what they learn, so consequently teachers and researchers need to attend to those things as they make sense, in their own ways, of what's going on in classrooms.

A description of what follows

The first of the chapters that follows, chapter two, offers a conceptualization of authenticity that captures aspects of student activity that are necessary for students to arrive at deep, disciplinary understandings of science activity and science concepts. The chapter grew out of my dissatisfaction with the ways in which the concept of authenticity is used by some researchers in science education, in particular some of this literature does not look at students when deciding what is authentic in science classrooms, other work in the authenticity literature lacks sufficient accountability to the discipline. I review that literature, comment upon its weaknesses, and offer a conceptualization of authenticity that addresses them.

Chapter three focuses on the importance of teachers being attentive to how students understand the purpose of what they're doing in a science class. The first chapter articulates a view of desirable student activity and thinking, this one focuses on how teachers can recognize and support that kind of authenticity in classrooms. I ground this work in the literature on *framing* from sociology, linguistics, and cognitive psychology. The framing literature identifies that how people understand meaning is influenced by their interpretation of the nature of the activity they are engaged in. There are many ways of framing activity, this chapter investigates trying to get students to

frame what's going on in way that is authentic in the sense described in the first chapter. How students frame classroom activity is important thing to consider in classrooms where teachers are trying to implement reform pedagogy, but it is not presently addressed in the science education research literature. The substantial portion of the chapter is a case study from my own classroom to demonstrate some of the ways framing can become consequential.

Chapter four switches the focus a bit, though it follows quite sensibly from the ideas introduced in the previous two. While still ultimately interested in how teachers attend to student activity in science classrooms, this chapter shifts to addressing the question of how we can help teachers prepare to do that well. In this chapter I provide a critique of the representations of classroom inquiry published by the National Research Council's (NRC) book *Science Inquiry and the National Science Education Standards* (2000). The representations of exemplary science classrooms in this book are intended to provide teachers and others associated in reform at the school and district level (administrators, professional developers) a glimpse of what exemplary classrooms look like and the role that teachers play in them. However, they poorly characterize or fail to characterize the things that teachers need to do to support students participating productively in these types of learning environments. At moments they are at odds with the view of teaching in these kinds of environments articulated in this and other NRC publications, as well as views of teaching articulated in the research literature. The chapter articulates these criticisms and then offers a possible alternative, a case study from a combined 5th/6th grade classroom engaged in considering what causes a full moon.

Chapter 2: Epistemological Authenticity

Abstract

The term ‘authenticity’ is used in science education research in two distinct ways. For some it refers to actual or desired similarity between the activity of students and the activity of professional scientists, what I call ‘disciplinary authenticity’. For others it refers to a sense on the part of the learner that the activity is relevant to them. I call this ‘personal authenticity’. As they relate to typically desired outcomes of science instruction, both conceptualizations are inadequate on their own. Disciplinary authenticity fails to attend to how students who engage in the common practices of science understand their engagement and hence the practices themselves. Personal authenticity fails to attend to the relationship between the committed participation of the student and the desired practices that are instructional outcomes. An adequate conceptualization of authenticity in support of these outcomes involves combining aspects of the two versions common in the literature. In this chapter, I offer a conceptualization of “epistemological authenticity” that connects the personal and disciplinary senses in the literature, affords students epistemic agency, and can serve as a focus for research and instruction.

Introduction – Authenticity in science classrooms

A scientifically literate individual understands important characteristics of both the nature of scientific knowledge and the activity that produces it, scientific inquiry. (NRC, 1996; AAAS, 1993) In support of these goals the *National Science Education*

Standards (NRC, 1996) envisions science classrooms where students develop their abilities to engage productively in activity that is similar to scientific inquiry. By engaging in this kind of activity students will better understand scientific inquiry and scientific knowledge, a view referred to as achieving scientific literacy through “practice-based” classroom settings (O’Neill & Polman, 2004).

Much work in science education research has been conducted in an effort to understand the circumstances under which such abilities and understandings develop. A great deal of this work uses the term ‘authentic’ (or ‘authenticity’) to denote the actual or desired relationship between the activities of science learners and the activities of professional scientists.

There are essentially two conceptualizations of authenticity in the literature. The first focuses on the activities planned within a curriculum, which are authentic insofar as they resemble the activities of professional scientists; I will call this ‘disciplinary authenticity’. The second focuses on the students’ sense of what they are doing, and activities are authentic to the extent that students find them personally meaningful. I will call that ‘personal authenticity.’ Neither disciplinary nor personal authenticity on its own is adequate to support science education research in its effort to understand how the activities and understandings of science learners become more sophisticated.

Consider a fictional group of students studying weather, working on an assignment to predict the weather in Dallas three days from now using actual current and recent maps showing weather patterns across North America. One group examines a few successive days of maps, and a student observes, “That little line with the triangles on it is getting closer to Dallas.” Looking at her notes another student says, “That’s a cold

front, it means cold and rainy.” “Is it gonna’ get to Dallas in three days?” asks the third. The students measure the distances the front moves each day, following the procedure they were taught, and decide that the cold front will indeed arrive in Dallas in about three days. Their teacher appears and asks them to explain how they decided the front would arrive in three days. “Well, there’s always some front coming in these kinds of problems. You just have to figure out when the front gets to the city. Then we have this chart that tells us the weather one day before, the day the front gets there, and one day after. So you just figure out which one it is and that’s the answer.”

We can certainly see disciplinary authenticity: The students were doing things meteorologists do. It is more difficult, however, to see evidence of personal authenticity. It may be they were simply following the steps of a procedure they were provided (Bloome, Puro, & Theodorou, 1989), from their perspective “doing school” (Pope, 2001). If they think they are expected to follow an algorithm they have learned in order to produce a correct answer and consequently be judged successful, then in an important sense they were thinking quite differently from meteorologists, despite the similarity of their actions.

My purpose in this chapter is to propose a definition of authenticity that is accountable to both of these senses of the word. In the following section, I review the literature on authenticity to argue that most research has attended to the discipline or to the personal but not both. In the subsequent section, I propose a definition of ‘epistemological authenticity’ as a conceptualization to help educators attend to the meaning of students’ work both from their perspective and from scientists’, a definition I illustrate with an example from my own classroom.

The ‘authenticity’ literature – A critical literature review

A seminal work in the authenticity literature is Brown, Collins, and Duguid’s (1989) article “Situated cognition and the culture of learning”. While it offers inspiring examples of what classrooms can look like, sorting through the details of the article leaves one wanting more. It fails to adequately address how its vision of school is possible, and/or how we would know if that vision is happening in a classroom.

The central notion in Brown et al. (1989) is that conceptual knowledge from various academic disciplines are essentially *tools* students should come to understand how to use as a consequence of their schooling, rather than bits of arcane knowledge we require students ‘learn’ to be allowed to progress through school. A tool’s meaning is *situated*, inextricably connected to contexts associated with its use, so the ability to use these tools requires that students begin to understand the belief system of the disciplinary domain that created the tool.

Brown et al. (1989) introduce the term *authentic* to describe the normal activities of a culture, where culture means the purposes and beliefs of some group of people connected in a social network. Established social networks are *domains*. For example mathematicians form a domain. In introducing their use of the term authentic, the authors write:

The activities of a domain are framed by its culture. Their meaning and purposes are socially constructed through negotiations among present and past members. Activities thus cohere in a way that is, in theory, if not always in practice, accessible to members who move within the social framework. These coherent, meaningful, and purposeful activities are *authentic*, according to the definition of the term we use here. Authentic activities then, are most simply defined as the ordinary practices of the culture. (p. 34)

This idea is problematic when it is applied to students in school engaging with the knowledge of academic disciplines. Brown et al. (1989) note school aims to

communicate disciplinary knowledge, but importing disciplinary knowledge into a school setting can change the meaning, rendering it “inert” because meaning is *situated*. The knowledge is no longer situated in the proper disciplinary context so students do not acquire the ability to use it as it is intended.

Brown et al.’s (1989) solution to this problem is to reformulate schooling as enculturation into the relevant disciplinary culture. School becomes a place where students begin to enter into the culture of mathematicians, scientists, historians, etc. This way students are exposed to the domain’s belief system and this allows them to use disciplinary concepts in appropriate situations.

After offering this solution the authors do not address how thinking of math in school as enculturation fits into the way typical school culture frames activity. They simply argue school should be enculturation and offer a couple of examples of what this looks like. The ability of school to impact how the meaning of classroom activity is understood by students transcends a simple, well-meaning decision to think of school activity in a different way. There are established social arrangements and meanings inherent in schooling, a *culture of school* to use the language of Brown et al. (1989). They should address how this notion of authentic activity can *ever* happen in school. Is it really happening in Schoenfeld’s and Lampert’s classes? How would we know if it was or wasn’t?

Regarding authenticity we must ask coherent, meaningful, and purposeful to whom and in what way? Brown et al. (1989) are ambiguous on this, though they are sometimes read as viewing the discipline as the arbiter of authenticity; coherent, meaningful, and purposeful to the discipline. This is problematic because the notion of

situated-ness suggests activity is meaningful in different ways in different contexts. The 6th-graders studying weather were “predicting”, but they may have been predicting with different purposes from the ways predicting is done by scientists. An activity that is authentic to science when done by a scientist can have a different meaning, a different authenticity, to a student engaging in it in school.

Students who utilize disciplinary procedures to produce answers for typical school purposes *are also being authentic*. Engaging in such activity is coherent, purposeful, and meaningful for a student within the culture of typical schooling. However, it is authentic in a different way than it would be to a scientist. What role does the question of how activity is coherent, meaningful, and purposeful to the student play in determinations of what counts as authentic? Brown et al. (1989) identify this question as relevant, but fail to address how the issue of multiple meanings plays out in relation to their goal of schooling as enculturation.

Focusing the critical literature review

Authenticity has a variety of meanings in educational research. Shaffer and Resnick (1999) review educational literature that uses the term “authentic” and identify four meanings of the term; (a) real-world authenticity - materials and activities aligned with the world outside the classroom, (b) authentic assessment - assessment aligned with (what students really should learn from) instruction, (c) personal authenticity - topics of study aligned with what learners really want to know, and (d) disciplinary authenticity - methods of inquiry aligned with the essential practices of a discipline. (from Shaffer and Resnick, 1999; p. 197) Buxton (2006) reviews authenticity studies specific to science education. His review focuses on articles that articulate a pedagogical strategy associated

with the term authenticity. Buxton characterizes three meanings of the term; (a) canonical authenticity, (b) youth-centered authenticity, and (c) contextual authenticity. Canonical authenticity refers to pedagogy or curriculum that begins from canonical practices and strives to produce students who can competently engage in those practices. Youth-centered authenticity is pedagogy that begins from what is meaningful and important to the students and aims to take advantage of opportunities to make connections to canonical practices in opportune moments. Contextual authenticity tries to marry the canonical and youth-centered aims, to produce students who competently engage in scientific practices by leveraging what is personally meaningful to them.

Some uses of authenticity are more relevant to this chapter than others. In light of the problematic nature of the concept identified in the previous section it is important to ask what empirical basis we can use to assess whether activity is authentic or not? This is the conundrum in the Brown et al. (1989) paper and in the weather example from the introduction. Both claim to show authenticity, but on closer examination the authenticity is ambiguous. The relevant features of the literature to consider are where authenticity is presumed to reside and what is counted as evidence of authenticity. Much existing authenticity work attends to planning for authenticity, ie. the authentic assessment literature and the focus of Buxton's (2006) review. The interest of this review is detecting authenticity.

There are two places researchers look for authenticity. They are the two different answers to the 'to whom?' question raised in the discussion of the Brown et al. (1989) paper. I will use the category "*disciplinary authenticity*" to refer to studies that conceptualize authenticity as a property of curricula and look for specific disciplinary

practices as evidence, and “*personal authenticity*” to refer to studies that locate authenticity in the learner and look at how (or if) students find activity meaningful as evidence. The sections that follow address these two uses of the term. Each describes the use of authenticity and illustrates it with examples from current research. Each section concludes with concerns about the way authenticity is conceptualized and operationalized.

Disciplinary authenticity

Disciplinary authenticity studies conceptualize authenticity as a property of curriculum and make comparisons between intended or actual student work and particular disciplinary practices as evidence in assessing quality in relation to authenticity. A curriculum is considered authentic if it asks students to engage in practices that are authentic to the discipline. In studies that assess the implementation of such curricula the quantity of a pre-specified authentic practice or some measure of the quality of practices serve as evidence.

An example of this kind of work is Chinn and Malhotra’s (2002) paper that proposes frameworks for determining the degree of authenticity of science curricula. They propose two frameworks that characterize the “cognitive processes in authentic [scientific] inquiry” and the “epistemology of authentic [scientific] inquiry”. The cognitive processes framework includes six broad categories of cognitive processes. Several categories identify specific cognitive processes that make up the category. For example, the “explaining results” category is comprised of five specific cognitive processes; transforming observations, finding flaws, indirect reasoning, generalizations, and types of reasoning. The authors support their claim that each cognitive process

identified is authentic using studies of disciplinary experts from cognitive science, literature from the philosophy of science, and anthropological studies of science. The authentic epistemology of science is covered in a similarly structured framework.

Chinn and Malhotra use these frameworks to assess the degree of authenticity of a number of ‘inquiry activities’ in science textbooks and curricula and find most of them poor. The student activities expected by most textbooks and curricula involve cognitive processes that are qualitatively different from those authentic to professional science and the epistemological assumptions of the activities are different from the epistemology of professional science.

The Chinn and Malhotra (2002) study involves no analysis of classroom activity or artifacts, though many studies do analyze such data. Assessments of variations in the design of an authentic curriculum are common. These studies report an evaluation of some aspect of the curriculum or a comparison of differences in how variations of the curriculum impact outcomes. Lee and Songer’s (2003) investigation of several weather predicting tasks in their middle school weather curriculum *Kids as Global Scientists* (Songer, 1996) is an example. They base their work on two different definitions of authenticity from the literature; Brown et al.’s (1989) activities that are “...ordinary practices of the culture...” and from the *National Science Education Standards* (NRC, 1996), “...activities similar to situations students might face in the real world.” Both situate authenticity in the curricular activities. From these definitions Lee and Songer infer curriculum design principles, features of curricula that “...add authenticity to [school] science tasks.” (p. 926) These principles guide the development of the curriculum, making it an authentic curriculum in this conceptualization.

Their investigation involves assessing the quality of student responses on several weather predicting tasks they characterize as varying in difficulty. Their data are the real time weather predictions made by students in classrooms using the curriculum. In addition to making predictions, students write justifications to support their answers. The analysis is based on three types of measures of the quality of student work. These serve as evidence of authenticity. The first is quantifying the number of “meteorological entities” students consider in their responses. This involves “Count[ing] the number of meteorological entities cited in the explanation such as temperature, pressure, wind, precipitation, cloud...” (p. 936) The second measure is the sophistication of the explanation, where sophistication is measured by disciplinary criteria. For example one of these is a score that indicates whether the student’s explanation is based on weather systems or has a less sophisticated basis. The third measure is how closely the student’s prediction matches the actual weather. These are viewed as evidence of authenticity in the classroom. Because a meteorologist’s explanation would include many meteorological entities and be based on the movement of weather systems these things are “...ordinary practices of the culture...” and they are authentic in this view.

A second example of a disciplinary authenticity study that looks for evidence in classrooms is Toth, Suthers, and Lesgold’s (2002) investigation of variations in a curriculum (Suthers, Toth, and Weiner, 1997) whose goals include teaching the coordination of scientific theory and data. This work begins by claiming that the curriculum in question is authentic, citing four features that contribute to its authenticity. The features are the curriculum (1) asks students to participate in scientific sensemaking, (2) asks them to impersonate scientists, (3) requires students to conduct an unbiased

consideration of multiple viewpoints, and (4) asks them to build evidential consistency relationships. Once again what the authors see as evidence of quality student work are particular disciplinary practices. The focus of the curriculum is coordinating theory and data so the evidence is how students connect claims and data. The study looks at student work in several ways. (1) The researchers count the number of “topic relevant information pieces” students collected during an information search, and then note if students correctly labeled the identified information pieces as data and/or hypotheses, (2) they count the number of topic relevant inferences students made and characterize their quality, and (3) each student group’s written conclusion is given a reasoning score based upon how evidence was used to support the conclusion.

Another common method used in studies assessing outcomes of authentic curricula is a comparison of a pre- and post- task. For example Cuevas, Lee, Hart, & Deaktor (2005)² study the implementation of a curriculum aimed at teaching scientific inquiry skills to elementary students. As a means of assessing the quality of the instruction the researchers administer a clinical interview style “elicitation session” to individual students and code transcripts of the sessions. The interviewer uses a protocol designed to elicit students’ ideas about how to conduct an appropriate test of a novel problem, how to determine whether the size of the opening of a container influences how fast the water in the container evaporates. Similar to the previous two studies the coding uses a locally produced rubric that scores student responses on their level of sophistication judged against a disciplinary referent.

² This study does not use the term ‘authenticity’, but it is included because the aim of the curriculum is consistent with work that uses the concept and the study refers to much of the same literature as studies that explicitly conceptualize authenticity.

Concerns with disciplinary authenticity conceptualizations

The chief concern with this conceptualization of authenticity is the failure to attend to the possibility that practices can be meaningful to students in ways other than the curriculum intends. Schooling has the ability to change the meaning of an activity or practice. Brown et al. (1989) characterize the ability of schooling to change the meaning of such practices this way:

When authentic activities are transferred to the classroom, their context is inevitably transmuted; they become classroom tasks and part of the school culture. Classroom procedures, as a result, are then applied to what have become classroom tasks. The system of learning and using (and, of course, testing) thereafter remains hermetically sealed within the self-confirming culture of school. (p. 34)

In contrast, a conceptualization of ‘authenticity’ that makes it a property of a curriculum assumes that any instance of a practice is authentic to the culture of science. The danger is that the practices are meaningful to the students as school activities rather than scientific activities and this difference is not detected.

For example Lee and Songer (2003) count the number of “meteorological entities” in students’ written justifications of their weather forecasts. The examples of meteorological entities include the terms temperature, pressure, wind, and precipitation. Students who have come to a strong conceptual understanding of these terms would undoubtedly use them to explain a weather prediction they make. But so would students who view school science as an activity where using science vocabulary words a lot gets rewarded whether or not the students understand them. This is a way many students come to understand school science (Lemke, 1990). Counting instances of a particular practice does not provide evidence that parses the difference in how students view the meaning of activity. The other measures of quality from Lee and Songer’s (2003) and Toth et al.

(2002) similarly fail to parse this difference.

Pre – post assessments of practice like the one Cuevas et al. (2005) use may appear more compelling than the analysis of classroom artifacts, but they too are unable to distinguish between these possible meanings students might have. While such evidence shows that student reasoning *has* changed, it does not provide information that helps one understand how and why it has changed. (Roseberry, Warren, & Conant, 1992) No insight is provided into how the reasoning practices are meaningful to the students.

Similar criticisms of these assumptions exist in the literature. Rham et al. (2003) fear the focus on practices has researchers trying to understand the wrong thing. By attending only to what authenticity means from a disciplinary perspective this work fails to consider what authenticity means to students and teachers in science classrooms, and consequently ignores the central roles students and teachers play in shaping the meaning of classroom activity.

To be fair, there is an obvious sensibility to looking at what a science curriculum asks students to do. For example Chinn and Malhotra's (2002) efforts to show that the 'inquiry tasks' included in many science textbooks ask students to engage in activity that bears little resemblance to the activity of actual scientists is useful. Such curricula misrepresent the nature of scientific reasoning and epistemology, something it is hard to imagine anyone viewing as desirable. However, a problem arises when the reasonable criteria for evaluating curricula are the only ones applied to the activity of students and student produced work. Whether or not students engage in a particular activity isn't the only relevant concern.

The role scaffolding plays in these curricula illustrates the danger. For curriculum

designers and researchers who assess the quality of student activity and/or classroom products solely on their similarity to disciplinary criteria it makes sense to provide students with curricular supports that provide explicit guidance. The more clearly a curriculum communicates what counts as high quality the more likely students will produce high quality work. For example Toth et al. (2002) have one experimental condition that provides students explicit guidance in the form of “reflective assessment rubrics” and another condition that does not provide the rubrics. They observe a positive effect of this guidance under certain conditions in their study. In discussing the implications of their study for classroom practice they note “This study also indicated that the explicit prompting provided by the continuous use of reflective assessment rubrics positively influenced students’ activity.” (p. 284) Based on this they advocate the explicit guidance in science classrooms employing the curriculum. An example from Lee and Songer (2003) is one of the curriculum guidelines that emerge from the analysis. “Students need specific guidance for the use of transformed products towards inquiry learning goals.” (p. 945) Their analysis shows that despite some specific guidance built into their curriculum “...in two of the three forecasting cases the transformation of content knowledge, scientific thinking and resources into a real- time forecasting task did not result in a simple authentic learning experience for all students.” (p. 945) The solution they propose is to include more specific guidance in future versions of the curriculum. Their assumption is that more guidance is unquestionably good.

If the only assessment of quality is greater sophistication judged against disciplinary standards then it is likely that providing students with more guidance will result in better classroom artifacts. However, providing more explicit guidance may

prompt students to view the activity as a typical school activity, whose purpose is to produce some correct product for the purpose of a good grade rather than an activity whose purposes are authentic to professional science. Explicit guidance is a fairly common feature of typical schooling, the kind of schooling that “transmute[s]” authentic activities of a discipline into “mere school tasks”. (Brown et al., 1989)

I am not arguing for providing no instructional scaffolds to students. Rather, the concern is *indiscriminate scaffolding*. If the guidance is not accompanied by discussion of the purposes of the practices we must worry what the students are learning.

Indiscriminate scaffolding is especially worrisome when the *only* criteria researchers use to assess quality in the classroom are based on disciplinary practices. In that situation unintended negative consequences may go unnoticed while the measures of quality indicate improvement. This illustrates one example how curricula can plausibly have a negative impact on students. There may be other ways a curriculum could do that. The broader point is how a curriculum is understood by students as meaningful in a classroom is not something that should be outside the concern of researchers.

Personal authenticity

In contrast to disciplinary authenticity, the personal authenticity researchers focus on how activity is meaningful to participants or how it is meaningful within the situation. To refer to it as a single conceptualization is misleading. These studies are unified by the assumption that one must look at the nature of the participation to determine whether an activity is authentic. For the most part they do not reject the notion that some formal characterization of disciplinary practices and concepts can be useful when constructing the goals. However, analysis focuses on how participation is meaningful to the

participants rather than how activity is meaningful in the discipline. Notably, many of these studies investigate non-school settings. The concern is that school suppresses rather than enhances authenticity.

This section describes three variations of personal authenticity. The first focuses on connections between student's lived-experiences and science. The second attends to whether students see practices as useful in professional settings. And the third articulates a conceptualization of authenticity as a property of a situation. All three views look for evidence of authenticity in participants.

Calabrese Barton (1998) studies an after-school science program for homeless children she organized. She claims that school science is not authentic to all children because it values only some lived experiences as suitable for scientific sensemaking. The lived experiences of the children at the homeless shelter are marginalized in school science, hence school science is not authentic for them. Buxton (2006) takes a similar view, though his study does occur in a school. His aim is to support situations in school where the lived experiences of students in the lowest academically achieving elementary school in Louisiana are a substantive part of the instruction.

In this work learning is authentic when learners see the content as relevant to their lives. Consequently, the researchers look for ways the children make connections between personally prominent issues and a broadly characterized view of science. As examples Calabrese Barton points to investigations the children do that grow out of their concerns about the pollution in the neighborhood and the important role food plays in their lives. Through these investigations the activities and knowledge of science come to be relevant to them in personally significant ways. Buxton focuses on short episodes

during science instruction when students mention connections they see between the content and their lives outside of school and the teachers at least briefly choose to make that a part of the lesson.

What Calabrese Barton and Buxton see as evidence of authenticity is not explicitly a topic of their reports. In Calabrese Barton's study one sees hints that she looks for students initiating activities and investigations. Buxton's criteria for selecting the authentic episodes he analyzes are moments when students exhibited obvious interest and enthusiasm. He found these easy to identify because they were rare compared to the more common lack of interest students typically exhibited during science lessons (Buxton, personal communication, Oct. 2006). In this version of personal authenticity it is the property of relevance to the learner's lived experiences that makes something authentic and enthusiasm and initiative are seen as evidence of authenticity.

The second view conceptualizes authenticity as a property of a learner's perception of the utility of practices in 'real' settings. This conceptualization grows out of the legitimate peripheral participation literature (Lave and Wenger, 1991; Brown et al., 1989). Barab, Squire, & Dueber (2000) characterize it this way:

We have argued that authenticity lies in the learner-perceived relations between the practices they are carrying out and the use value of these practices. Educators need to find means of aiding students in owning these practices and meanings, but in ecologically valid contexts. (p. 41)

The researchers' critique is that in school settings the practices of scientists (authentic practices in the disciplinary view) are seen as meaningful only for school purposes. Such practices have "exchange value" in school settings rather than "use value" in real science; therefore they are not authentic.

A mechanism for helping students see the use value of scientific practices is to put them in actual scientific settings. Studies that take this view focus on student-scientist partnership programs (Barab and Hay, 2001; Hay and Barab, 2001). The Barab and Hay (2001) study focuses on a two-week summer program for middle school students where the students worked with scientists on projects that were a part of ongoing research programs. The study documents students' engagement in a variety of the practices of science, ie. data collection practices, presentation practices, and discourse practices. But in this study authenticity is related to student "ownership" of the practices and products of their work rather than just their engagement in specific practices. So in addition to documenting specific practices the study looks for evidence of student ownership of the practices.

Barab and Hay (2001) primarily use interview data to examine how students perceived the use value of the practices, and supplements and illustrates claims with descriptions of events from the project. For example the study describes when a student-participant became upset because he incorrectly perceived the scientist he was working with already knew what the results would be from the data he was collecting. They use this as evidence that the student expected his participation was legitimate within actual science, and hence he perceived the practices he was engaging in had use value.

The Hay and Barab (2001) study compares two out of school science programs, the first is the same one analyzed in the Barab and Hay (2001) article and the other is a week long program for high school students. Notably the second program lacks the presence of actual scientists. Instead it involves the participating high school students in a computer modeling exercise around a scientific topic, with the focus of the work being

a presentation made to participants' family members at the end of the week. The purpose of the comparison is to contrast two pedagogical models for supporting personal authenticity, *simulation* authenticity and *participation* authenticity (after Radinsky et al., 2001). They find that an advantage of the participation model over the simulation model is that use value of scientific practices is more apparent to participants when the work is part of an ongoing scientific research program. An advantage of the simulation model is it provides students a greater role in the activity. When working with scientists students are limited to routine tasks and strict adherence to established procedures. Students in this situation are not in a position to make judgments about the quality or success of the work. In contrast, in the simulation model students are more likely to take on "executive functions", making judgments about quality and success. Students in the second program organized the whole project, providing them with the potential to understanding how the routine activities they engage in support the purposes of the broader activity, and hence a better understanding of the disciplinary meanings and purposes of scientific practices.

The third version of personal authenticity comes from Rahm et al. (2003). Like the others this one begins with a criticism. The authors argue that *a priori* designations of authenticity in disciplinary authenticity views rely on static accounts of what constitutes appropriate disciplinary practices that fail to recognize how participants influence authenticity. As an alternative Rahm et al. conceptualize authenticity as an emergent property of a social interaction. In this account authenticity it is not located in any one individual. Rather, it is a property that emerges from the interaction of a group of participants. Authenticity is presumably experienced by the individuals engaged in the interaction, though Rahm et al. do not spell out the relationship between authenticity and

individuals. Strictly speaking this conceptualization is not ‘personal’ since it does not locate authenticity in the person. However, it is consistent in a number of ways with other conceptualizations in this category. Rahm et al. (2003) characterize their purpose as providing a theoretical basis for views of authenticity like the one articulated by Calabrese Barton (1998). Also, like other personal authenticity work they look to the individuals engaged in the interaction for evidence of authenticity. For example they see authenticity in a group of teachers modifying activities to focus on topics they anticipate students will find relevant to their life experiences, and also in students participating in a project with scientists who challenge one another and the scientists about the best data collection methods.

Concerns with personal authenticity conceptualizations

The quality of participation these studies use as evidence of authenticity, something like *engaged commitment*, provides insight into whether or not the activity is personally relevant. This is a desirable feature in any learning situation. We want students to find what they are learning about relevant to their lives. If nothing else it motivates their learning. However, personal authenticity studies fail to adequately articulate what evidence of the beginnings of understanding in science would look like. Beyond relevance what should we expect to see that indicates progress is being made toward the goals of understanding the nature of scientific activity and knowledge? Is the activity the students demonstrate personal commitment to meaningful to them in a way that will get them to the instructional goal?

Most personal authenticity work acknowledges the relevance of disciplinary referents but fails to attend to them in a substantial way. Both Calabrese Barton (1998)

and Buxton (2006) focus on how science instruction can be personally meaningful to students, but do not address student participation in relation to a disciplinary referent once they establish it as personally meaningful to the learners. In addition to relevance, how students go about making sense of phenomena also impacts what they ultimately understand about science. We know students often make sense of natural phenomena in ways that are not scientific. For example students sometimes generate and are satisfied with teleological or anthropomorphic explanations of natural phenomena (Southerland et al., 2001), neither of which are satisfactory explanations in science. Or how students use evidence in support of or against an explanation is often inconsistent with scientific evidence use. (Kuhn, 1989)

Work that investigates student-scientist partnerships (Barab and Hay, 2001; Rahm et al., 2003) in some sense dodges this concern. The presence of scientists presumably ensures the practices of the students are appropriate to science. Investigating such settings allows Rahm et al. (2003) to eschew static disciplinary criteria because the scientists decide whether activity is authentic to science. But what does this work say about school science settings where scientists are not present? If no scientist is present can an interaction be authentic? In school settings wouldn't some static disciplinary criteria be desirable? Because most science instruction happens in schools these are important questions to consider.

Beyond this there are two concerns with studies that situate authenticity in student-scientist partnerships, one pragmatic and one substantive with regard to the instructional goals of students developing understandings the nature of scientific knowledge and activity. First the pragmatic, the assumption that a necessary condition of

authenticity is interaction between students and members of the scientific community makes authenticity an impractical large scale goal. There aren't enough scientists to go around, never mind that working with schools isn't their primary responsibility.

The second concern is that students in these programs do not have opportunities to understand how their practices serve the broader goals of science. Hay and Barab (2001) introduce the notion of "executive control" in their comparison of two case studies of students in programs outside of school. The two case studies represent the participation and simulation pedagogical models of supporting authenticity. In the participation authenticity program students engaged in routine data collection according to established procedures and were not in a position to make decisions about the quality of their work. In contrast in the simulation authenticity program students made decisions about the practices they engaged in that impacted the quality of the final product.

The students' role in assessing quality is important to consider. Professional science is largely an assessment activity. Scientists aim to generate robust knowledge claims, and much of what they do centers on efforts to assess the quality of a knowledge claim. Many of the practices scientists engage in are in the service of this purpose. For students to understand the practices of science they need to see them serving the purpose of assessing the quality of a knowledge claim.

When working with scientists, students have opportunities to engage in the authentic practices of science in actual settings, but their lack of executive control in those situations fails to provide them with opportunities to gain insight into the purposes and meanings of those practices. One can imagine such a situation that is unproductive. A high school student working in a scientist's lab would likely be assigned simple,

routine tasks. While these are authentic tasks, carefully following a set of required procedures, may seem to the student quite school-like; following a prescribed set of rules for no apparent purpose other than being told it is important to do so, and thus make science seem consistent with the epistemological assumptions students have about school.

A study (Samarapungavan, Westby, & Bodner, 2006) of the development of understandings of the epistemology and epistemic practices of science with increasing exposure to actual scientific practice indicates that in typical settings, some desirable understandings develop only after scientists have been engaged in the activity of professional science for several years. The study compared chemistry faculty and chemistry graduate students and observed significant differences in their understandings of some practices. The graduate students expressed relatively naïve understandings of epistemic practices. In the scheme the study used for characterizing sophistication graduate students were more similar to undergraduate chemistry students than the faculty despite having more experience with the practices of science in actual scientific settings. Participation in actual scientific settings is no guarantee of the development of more sophisticated understandings of the nature of scientific knowledge and practice. As Samarapungavan et al. (2006) put it:

One implication of these findings is that apprenticeship experiences in authentic inquiry do not automatically guarantee epistemic development in students. Opportunities for epistemic development will most likely depend on the degree of research autonomy given to students, and on opportunities to engage with expert researchers in conversations and reflections on epistemic issues related to the program of research. (p. 493)

An alternate conceptualization – ‘Epistemological’ authenticity

The two views of authenticity, disciplinary and personal, are not

incommensurable. There are examples from each category where studies also attend to what is central to the other view. Among the disciplinary studies, the question of how students consider activity meaningful is occasionally present. For example, White & Frederikson (1998) assess how students' views about science changed as a result of the interacting with their curriculum. Evidence that disciplinary studies attend to how students see participation as meaningful can be seen as a part of the criteria that makes a curriculum authentic. Toth et al. (2002) claim the fact that their curriculum focuses on a question with no widely accepted answer within the scientific community is a feature that contributes to its authenticity; "...the instructional activity is authentic because students participate in *scientific sense-making* unencumbered by the belief that the correct solution was known but hidden from them." (p. 267) [italics in original]

Much of the personal authenticity literature acknowledges the importance of disciplinary criteria. Studies like Calbrese Barton's (1998) and Buxton's (2006) make clear statements that helping learners understand canonical concepts and/or the activity of science are instructional goals. Another way that the value or relevance of disciplinary criteria show up in some of the personal studies is through the presence of practicing scientists. Both Barab and Hay (2001) and Rahm et al (2003) investigate authenticity in the context of school-scientist partnership programs, where students and/or teachers have opportunities to interact with practicing scientists.

Both views of authenticity include productive elements for making sense of what goes on in science classrooms. When the instructional goal is developing understandings of the nature of scientific knowledge and activity it is important to attend to both how the scientific activity is meaningful to the students and how the students' activity is

meaningful to the scientist. As the critical literature review of disciplinary and personal authenticity shows, neither focus is sufficient in and of itself. This is not a revolutionary idea; a number of studies marry the two general emphases in some way, considering both necessary elements.

Rosebery, Warren, and Conant (1992) studied changes in students' "...use of hypotheses, experiments, and explanations to organize their reasoning." (p. 62) Though it does not use the term authenticity, the study states instructional goals that align with disciplinary authenticity research. Like some disciplinary studies, this one uses a novel task given to students before and after instruction as its primary data. However, it adopts a sociocultural perspective, adding Bakhtin's (1981) notion of *appropriation* to its instructional goals. Science instruction should result not only in students able to engage in specific scientific practices, but they should appropriate those practices. While the data analysis includes the counting of instances of particular practices (the typical disciplinary authenticity criteria of quality) it also looks for evidence of how the students understand the meaning of their activity. For example in pre-instruction interviews students responded to prompts intended to elicit hypotheses and experiments with ideas that were mostly not testable and often restatements or elaborations of the provided problem. In response to interviewer's "why" questions students invoked anonymous agents ("they", "people") and/or treated the symptoms as the cause. This behavior is consistent with the interpretation that the students see their task as finding portions of the provided text to offer as correct answers to the interviewer. Post-instruction interviews show a change in the discourse strategies used by the students. Not only do the students elaborate more testable hypotheses, but some connect them to the conceptual framework

introduced in instruction and a few use the conceptual framework to help generate hypotheses not specifically asked for in the interview. This is evidence both that the practices students engaged in are similar to disciplinary referents and that the students began to appropriate the practices.

Another study that attends to both disciplinary and personal perspectives is Anderson, Holland, & Palincsar (1997). The study reviews “canonical” and “sociocultural” approaches to science education reform. The canonical perspective aligns with disciplinary authenticity, a focus on canonical knowledge and practices. The sociocultural perspective is based on a characterization of science as a specific way of “...thinking, acting, and valuing.” (p. 364) While Anderson et al. are largely in agreement with the canonical approach and see value in the instructional implications derived from it, they argue that it serves as a poor stand-alone framework because it has little explanatory capability. While a canonical approach can be used to detect instances of desirable practices it provides no insight into possible mechanisms by which instruction fails or succeeds. Therefore it offers science education researchers no guidance when considering how to improve instruction. This criticism is related to the concern about indiscriminant scaffolding. In the absence of an explanation for poor outcomes the only instructional response is to provide more and more explicit scaffolding.

Anderson et al. (1997) propose an analytic framework they characterize as a “combined perspective”, one that combines both canonical and sociocultural criteria, and use it to analyze a lab group of five 6th-graders engaging in a unit on Matter and Molecules. The analysis focuses on one student who appears headed for success early in

the unit, but ultimately is judged not to have mastered many of the key learning goals, a disappointing result. Their analysis demonstrates that the combined perspective can provide not only a framework for assessing whether or not a student masters learning goals, but also an explanation for the student's lack of success.

A consistent assumption across these two views, and across many of the personal authenticity views in the previous section, is that disciplinary criteria are productive for evaluating students' progress toward developing understanding of the practice and products of science, but one must attend to more than just disciplinary practices to get an adequate sense of progress toward the instructional goals.

A feature that doesn't get sufficient attention in these critiques is the students' perception of the purpose of their classroom activity. Brown et al. (1989) begin their argument for authentic reform by noting that the concepts and practices of a discipline are tools that serve the purposes of a discipline. Learning about the tools involves understanding how they serve those purposes. In the absence of using the concepts and tools with an awareness of their intended purposes there is little likelihood using them will result in students understanding we want them to.

It is not enough for students to engage in activity that has the purposes of science. They have to *perceive* that those are the purposes of their activity. The learner's perception of purpose is integral to what they come to understand. This distinction between what purpose the learner perceives and what purpose someone else might perceive gets at the importance of what Hay and Barab (2001) call executive function in their characterization of a difference between participation and simulation strategies. Students collecting data in an actual scientific lab are engaged in activity whose purpose

we would perceive as related in some way to scientific knowledge production. But that does not guarantee the students perceive the purpose of their own activity that way. It is important that students perceive themselves to be engaged in a knowledge producing activity.

In science classrooms this can be challenging given students common school science experiences where they are receivers of “correct” knowledge not producers and evaluators of knowledge. So it makes sense that some of the authenticity literature, especially on the personal side, focuses on non-school settings. Despite this challenge there is reason to be optimistic about what is possible in schools. Sister Gertrude Hennessey is an elementary science teacher who aims to help students see themselves as participating in the activity of producing scientific knowledge. A study of students in her classroom shows that even very young students can develop surprisingly sophisticated understandings of scientific practice when they have significant epistemic agency. (Smith et al., 2000)

We should aim to create situations, both in and out of science classrooms, where students see themselves as producers and evaluators of knowledge claims about natural phenomena. It is also important that the practices they engage in while doing this are similar to those used in professional science. These are the criteria that must be met for science learning activity to be called authentic. To denote the importance of the knowledge production purpose in this conceptualization of authenticity I refer to it as *epistemological authenticity*. In some sense this characterization relies on disciplinary criteria, both what constitutes authentic practices and what constitutes appropriate purposes of the activity. However, because the focus on purpose is on how learners

perceive the purposes, it is similar to personal authenticity work in that it demands attention to how students understand the meaning and purposes of their participation.

A classroom episode - Epistemologically authentic Thomas³

An episode from a science classroom will illustrate this characterization of authenticity and demonstrate how the analytic tools of the different authenticity literatures can be used together to assess student activity. The episode is from a college physics course for pre-service elementary education majors I taught. The course aims to give students experiences in a science classroom where they are given as much executive control as they will take. It is intended that these experiences will inform their later discussions of science pedagogy during their science methods class and ultimately help to influence how they teach science as they become classroom teachers.

The episode comes from the day we started to investigate electrostatics. I began by directing students to make two scotch-tape observations (Arons, 1997). (See Figure 2-1) In the first students quickly peel up two pieces of scotch tape stuck to their lab tables. Before sticking the tape to the tables they fold over one end of the tape on itself, creating a handle to lift up on. Once lifted off the table the two pieces of tape repel one another when brought close together. In the other observation students put a second piece of tape right on top of the first, so instead of two side-by-side pieces of tape on the table there is one piece stuck to the table and a second piece on top of it. To keep things clear we called these two pieces the ‘bottom’ tape and the ‘top’ tape. The students first pull up the two pieces of tape together and then pull them apart. Once pulled apart the two pieces of tape attract one another when brought close together.

³ ‘Thomas’ is a pseudonym.

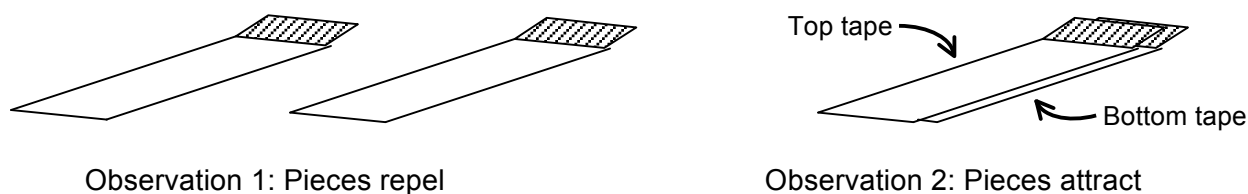


Figure 2-1: Diagram depicting the two scotch tape observations

After making the observations students had a few minutes in their lab groups to speculate about what might cause it. Then, as a class we discussed different student ideas about the phenomena. The first explanation was the two side by side pieces each get some “static” due to the “friction” associated with lifting them up off the wooden lab table.⁴ Since both pieces had static they repelled. In the second observation because the top piece of tape is lifted off of bottom piece of tape rather than the table it does not have static, perhaps because the back of the bottom tape is smoother than a table top, resulting in less or no friction when lifting. At my prompting the implied idea that static repelled static, and attracted non-static, a version of opposites attract and likes repel, was made explicit. As the discussion proceeded some students used the word ‘charge’, and when questioned the relationship between the idea of charge and idea of static a student responded they were probably the same thing.

A bit later in the discussion a student raised a question that we could not immediately answer, and began a list of open questions on the board. I told students the point of the list was to keep track of questions in hopes we might figure them out as we went along. A little later, another student wondered aloud whether the top piece of tape

⁴ Though no one articulated it in the class this would likely seem quite sensible to students because of experiences like rubbing balloons on sweaters or hair and sticking them to the wall, or with taking clothes out of the dryer and finding that they stick together.

in the second observation really had no charge. She reasoned that we did something to the top piece of tape similar to what we did to the bottom one, so it seemed likely that the top tape should have some charge as well. She suggested it might just have a different charge than the bottom piece of tape. After a short discussion of the question I added the question to our list. “Does the top piece of tape have no charge or different charge?”

After a little more discussion I directed the students to make more observations, this time focusing on the net charge created by rubbing Styrofoam with wool cloth. I left the exact observations open ended, and also prompted students to use this time to think about our list of open questions, which now numbered four. After giving the students some time to explore, and with the end of the class looming, I made a quick pass through the groups to see what types of observations they were making and to remind students to carefully record their observations so we could talk about them during the next class meeting. While doing this I noticed a student, Thomas, sitting a little apart from his lab partners and fiddling around with some scotch tape on his lab table. I asked him what he was doing. He had been thinking about the question of charge on the top piece of tape and thought he had a way of answering it. What Thomas did was set up the second observation twice, so as to get two top tapes. When he brought these two near to one another they repelled. Thomas reasoned that if the top tapes had no charge they shouldn't repel, they should not affect one another, as any two normal uncharged objects would do. Because the tape pieces repelled that must be evidence that they have some charge. Of course I insisted he explain his observation to the class. Thomas did, and there was immediate consensus that this observation was evidence that the top tape had some

charge. The explanation for the top and bottom attracting had to lie in some difference between the charges.

Analysis of 'Epistemologically authentic Thomas'

I expect readers will recognize what Thomas did was wonderful before any analysis that characterizes its wonderful-ness. But it is important to be clear about what comprises its desirable quality. Thomas' participation is epistemologically authentic. Claims of epistemological authenticity must satisfy two criteria. First, the activity must be recognizable as reflecting the characteristic activity of the discipline in some way. Second, there must be some evidence that the student views her or his own participation as meaningfully related to knowledge production.

First to the question of how Thomas' activities are meaningful within the discipline of science. Chinn and Malhotra's (2002) disciplinary authenticity study provides qualitative characterizations of the "cognitive processes in authentic inquiry" and the "epistemology of authentic inquiry". While they go on to use their framework to assess the authenticity of curricula based upon what the curricula intend students will do in class, the framework can easily be applied to what actually happens in a classroom. Two categories in these frameworks are "making observations" and "explaining results through indirect reasoning". Thomas was doing both of these things. Part of what was impressive about Thomas' activity was that he invented the observation as a means of addressing an open question. In some ways this is covered by the second activity from the lists, explaining results through indirect reasoning in authentic inquiry. This is described in the framework as "Observations are related to research questions by complex chains of inference." and "Observed variables are not identical to the theoretical

variables of interest.” In the example Thomas observed whether two pieces of tape exhibited any attraction or repulsion. As he observed attraction he related it to our question about the theoretical variable ‘charge’. He reasoned that if there were no charge on top tape then two top tapes should neither repel nor attract one another, and that if they did attract that was evidence for some charge being present on the top tape. Thomas related an observation to a research question by inference.

Next the question of whether Thomas’ participation was meaningful to him. To do this studies in the personal authenticity literature look at the nature of the individual’s participation for evidence of some particular commitment. This implies the individual is invested in the outcome of the activity. This is an easy story to tell in this case. Thomas persisted for some time in considering this question, and ultimately took it upon himself, or perhaps collaborated with his lab partners in devising a test that was able to compare the two ideas. Both are evidence that he was personally invested in finding a way to answer this question.

Another important feature of Thomas’ participation was that it was a part of an activity whose purpose was determining the merit of knowledge claims. The data suggests that Thomas operated with the sense that he was the one who was responsible for devising a way to answer the question, for constructing the class’ knowledge of the nature of the static or charge on the tape. So not only was Thomas engaging in particular practices that scientists commonly engage in, he was using those practices with the same purposes a scientist would have.

Implications and questions

Valuing activity that is epistemologically authentic has implications for how science educators think about assessment in science classrooms. The term ‘assessment’ commonly refers to the tests students take that allow us to determine whether or not they have acquired the knowledge we want them to acquire. Even ‘informal’ or ‘ongoing’ assessments typically fit this purpose. Assessment is something done *to* students. However, when the goal is epistemological authenticity we need to broaden our conceptualization to include students being assessors. When students engage in the practices of science for the production of answers whose merit is assessed by the teacher they don’t have opportunities to come to know the scientist’s purposes of the practices. Instead they learn school purposes of the practices. This is a plausible mechanism for what Brown et al. (1989) notice; authentic activities “...becom[ing] classroom tasks and a part of the school culture.” (p. 34) Because the practices of science primarily serve to assess the quality of knowledge claims and the meaning of activity is situated in its immediate context, students must engage in activity that has the purposes of science. Students must have opportunities to assesses the quality of knowledge claims. A necessary component of the authenticity Thomas exhibited was that he was genuinely assessing the merits of two competing ideas.

Giving students a significant amount of epistemic agency presents a question. If we give students the role of assessing knowledge claims what role does the body of accepted scientific knowledge play? The instructional goals of typical school science are based on the assumption that the most beneficial outcome of school science is students acquiring a breadth of understanding of current scientific knowledge. Thus, selected

aspects of canonical knowledge are at the center of most instruction and teacher assessments aim to determine whether or not students understand the targeted concepts. However, the goal of broad understanding of canonical concepts is likely at odds with epistemological authenticity, at least in certain moments. This relationship needs to be better understood. In typical school science instruction the goal of conceptual understanding plays out in ways that locates the epistemic authority in the teacher rather than in the students. While one can perhaps imagine instruction with the goal of broad conceptual understanding in which this is not the case, it is at least common. Because it is a common experience of students in science classes, the introduction of canonical knowledge may interfere with the goal of epistemological authenticity in a local sense if students interpret it indicating typical school science and adopt classroom roles that involve them being assessed rather than being assessors.

How students understand what is valued in a classroom is another important question that needs investigation. A student teacher recently told me about a conversation she had with a student in a high school biology class she was observing. The classroom teacher dedicated a significant portion of class time to a project in which groups of students select their own question to investigate and then work to answer it, an activity that seems ripe for epistemological authenticity. However, a student in the classroom commented to the student teacher that the part of the class dedicated to this project was the “fun” part, and the “real” part of the class was the time the teacher spent lecturing. If this is how students understand instruction, whether intended or not, the outcomes associated with epistemological authenticity are likely to be compromised.

Finally, a brief mention of two further two questions. First, what does it look like when students make productive first steps toward using scientific practices with scientific purposes? There are few accounts that help us see what productive first steps might look like. In the absence of such accounts we will struggle to know what to look for as evidence of epistemological authenticity. And second, what are the teacher's roles in such classrooms? The questions so far suggest what it isn't, typical assessment, and perhaps hint at some of what it is, attention to how students understand what is valuable. The next chapter begins to investigate some of these questions through a case study of my own teaching practice.

Chapter 3: Attending to student framing in a science classroom

Abstract

Studies of learning in school settings indicate that many students frame activities in science classes as the production of answers for the teacher or test, rather than as making new sense of the natural world. A case study of an episode from a class taught by the first author demonstrates what productive and unproductive student framing can look like in a science classroom. The case study demonstrates how some student activity commonly seen as undesirable may be evidence of productive framing, and activity commonly viewed as desirable may be seen as evidence of unproductive framing.

Introduction

A group of four college students in a homework help center work together on a physics problem. (Tuminaro, 2004.) The problem asks them to estimate the difference in the air pressure between the floor and the ceiling of a dorm room. One student (S1) proposes using the ideal gas law, $PV = nRT$, to solve the problem. She divides both sides of the equation by V to solve it for pressure, and the group has the following exchange:

S1: So, basically we just found the formula that P is equal to the radius times the moles times the temperature over the volume. So if we have the density we can find the volume.

S2: Is R the radius?

S3: I don't think R is the radius.

S1: It's not? The radius of the...

S2: R isn't radius, R is...

S1: Or whatever R is.

S3: Some number.

S2: It's not radius.

S1: Is it a constant?

S4: Yeah, it's a constant, it's a constant.

S2: It's a constant, it's...

S1: Awesome! One less thing for us to find.

The students proceed to focus on finding values for the other symbols in the formula, trying to solve for P.

The episode raises questions about the quality of the students' conceptual understanding, both of the ideal gas law and of the subject matter at hand; the ideal gas law is not going to help them solve the problem. Our principal interest, however, is in what the data suggests with respect to how the students understand what they are doing. What kind of activity do they think this is?

S1's reaction to learning that R is a constant and not the radius ("One less thing for us to find.") suggests she is involved in the activity of finding numeric values to plug into the symbols on the right hand side of the equation, as opposed, say, to understanding the meaning of the expression. Other students' participation similarly suggests that, for them, doing this homework problem is an activity in which they choose an equation and then plug in values to produce a numeric answer.

When we present this data to science educators there is invariably some good-natured laughter, at the suggestion that R might mean "radius" and at S1's enthusiastic response to finding out it does not. Many find this kind of activity all too familiar; everyone sees it as problematic.

Now imagine these same students acting exactly the same way, but that they happen to choose the equation $P = \rho gh$. If they proceeded in the same way, plugging in

values to the right hand side, they would probably have gotten the correct numerical answer. The density of air (ρ) is given in the problem and the acceleration of gravity (g) is a well known value among students in introductory physics courses. The only value they would have had to produce was a height (h). Would there be a similar consensus among science educators over the quality of their approach?

Few educators would want students plugging into equations they do not understand, whether or not the equations are correct. But, we expect, how students understand the nature of the activity is not generally an obvious matter for ongoing attention. If these students had applied the correct equation, for many instructors nothing about the episode would raise cause for concern.

We begin this article with arguments from the literature for the importance of instructional attention to students' *epistemological framing*, that is how students understand their own activity with respect to knowledge and learning. We then turn to consider the implications of that attention for instruction. In that section we focus on an episode from the first author's teaching that illustrates what productive student framing can look like and shows how attending to framing calls into question some common science teaching assumptions.

Research that provides insight into how students understand school

The method to produce answers in the example may be unique to some science courses, but student activity in school whose purpose is to produce correct or acceptable answers is observed in a variety of subject areas. How answers get produced varies somewhat in different subjects, but producing answers without a substantial sense of how or why knowledge functions in a discipline is common across school subjects. Evidence

suggests many students are successful in school by producing answers in particular ways without coming to what one might colloquially call an understanding of the knowledge.

Analysis of discourse in high school science classrooms identifies a common pattern of teacher-student interaction Lemke (1990) labels “triadic dialogue” (others. ie. Cazden (2001), call this pattern “IRE” for initiation - response - evaluation). A teacher asks a question, a student or students respond to it, typically with a single word or a short phrase, and the teacher evaluates whether the response is correct. In Lemke’s view what counts as learning science is mastering the discourse of science, so this common pattern makes it difficult for students to “...find the science in the dialogue.” Instead, successful science students learn how to play what Lemke refers to as *the classroom game*.

While in-class discourse is a different from what we see in the example from the introduction, completing homework problems, there is an important similarity between them. In both cases students run the risk of becoming skilled at the classroom game rather than some activity that provides them insight into science. The students in the introduction use a scientific formalism, but for them it functions as a template for an algorithmic process by which they attempt to produce an answer. That the ideal gas law is an expression of a relationship among several concepts is not relevant to the activity they engage in, and it appears they are not likely to learn much about science by doing what they do.

While educators are justifiably dismayed that this is how the students do homework, it is important to recognize that it is reasonable behavior from a student perspective. These particular students are at a somewhat selective university in a physics class taken by life science majors, many of whom are medical profession intending.

They are academically successful and what we see them do is simply what has served them well in school science in the past.

There is more research that supports this claim. The activity in high school math classrooms has been characterized as operating like a tacit contract between students and teachers (Brousseau, 1997; Herbst & Kilpatrick, 1999) where the answers students produce must be produced in a specific way, and they serve as a sort of currency to be exchanged for a grade. This work uses the phrase *didactical contract* to label this characterization of the common activity in math classrooms. Other work characterizes the nature of classroom activity as getting its meaning from the societal culture (Bloome, Puro, & Theodorou, 1989). In this view "...the enactment of lesson is not necessarily related to the acquisition of intended academic or non-academic content or skills but is related to the set of cultural meanings and values held by the local education community for classroom education." (p. 272) This characterization of classroom activity is labeled *procedural display*.

These studies into how disciplinary knowledge is used and understood as meaningful in classrooms are statements about how researchers interpret school activity. High achieving high school students in Pope's (2001) ethnographic work showed similar understanding of their school activity. The students in Pope's study saw academic success as a means to socially desirable ends, and worked very hard at activity aimed to achieve that success. But from the students perspective being successful in school was not about substantial interactions with the disciplinary content of school courses. Pope characterizes the relationship between the activity of school and disciplinary content this way:

For the most part [students] were asked to accumulate facts that seemed to have little relevance to their lives and to complete tasks accurately and efficiently without delving deeply into subject. An A grade, therefore, did not necessarily mean that the students learned and retained content area knowledge and skills or that they understood important concepts or theories; rather, the grades proved that the students were adept at providing the teachers with the information required on tests and quizzes, and that they memorized these facts and figures just long enough to “ace” the exams and move on to the next set of tasks. (p. 156)

Epistemological Framing

That students approach school in these ways is problematic both for their learning at the time and because the actions of students in a science class today are influenced by their past experiences in similar situations. The students in the opening episode tacitly chose to proceed as they did based on how they perceived the situation similar to past experiences. Because they arrive with expectations for how to succeed (Redish, Steinberg & Saul, 1998; Elby, 1999), it can be difficult to engage students in more productive activity.

We have adopted the term “framing” based on previous work in sociology (Goffman, 1974), sociolinguistics (Tannen, 1993), and cognitive science (Minsky, 1985; Schank, 1990). Tannen (1993) describes framing as a kind of *schema* (Bartlett, 1932):

...all these complex terms and approaches amount to the simple concept of what R.N. Ross (1975) calls “structures of expectations,” that is, that, on the basis of one’s experience of the world in a given culture (or combination of cultures), one organizes knowledge about the world and uses this knowledge to predict interpretations and relationships regarding new information, events, and experiences. Bartlett (1932)...in effect said it all: “The past operates as an organized mass rather than as a group of elements each of which retains its specific character.” (p. 16)

The central idea of framing is that people generalize knowledge from past experiences for use in making sense of what is going on in future situations perceived to be similar. For example, when entering an unfamiliar restaurant we immediately interpret what kind of restaurant it is (Schank, 1990). Is there a little podium with

someone standing behind it? Are there people standing at a counter ordering food?

Based on our past experiences with a variety of different kinds of restaurants we know what features of the restaurant will help us figure out what type it is. Once we interpret the type of restaurant we know what to expect, such as whether someone will bring a menu or customers order at a counter.

While there are variations in the framing literature, there is broad consensus on a few key points. The first is that there is an interpretive aspect associated with framing, a tacit answer to the question “What is it that’s going on here?” (Goffman, 1974). Another important feature is that framing influences expectations and interpretations. Framing a restaurant in one way, people have expectations for how they and others should behave, for example to approach the person at the podium and request a table, and that when someone arrives with a large piece of heavy paper, it is the menu. Framing the establishment as a fast food restaurant, people would expect to choose their own table and be puzzled by someone arriving with a large piece of heavy paper.

In the same way a restaurant patron frames the activity of ordering a meal students frame their activity in science classes. They tacitly answer the question “What is it that’s going on here?” Answering this question invokes expectations largely based on their past experiences of what is appropriate. There are many aspects to that framing, including when and where to sit, what to bring, how to dress. We are especially interested in students’ framing of what is taking place with respect to knowledge and learning, that is their *epistemological framing* (Redish, 2004; Hammer, Elby, Scherr & Redish, 2005). Different ways students might frame how knowledge functions and their relationship to it are more productive or less productive for the instructional goals.

Productive framing as an instructional goal

Learning science means, in part, making progress toward understanding concepts and phenomena as scientists understand them. It should also mean making progress toward understanding intellectual activities as scientists do.

We take it as an essential instructional goal that students come to understand inquiry in science as making sense of natural phenomena, and the knowledge they encounter in science class as helpful to that end. The students doing the homework problem in the introduction were using scientific knowledge (the ideal gas law) for a different purpose. Helping them make progress in science entails, in part, guiding them to frame what they are doing as making sense of natural phenomena, rather than one of formal answer production, the “classroom game” (Lemke, 1990). There are, undoubtedly, finer distinctions we could draw in each of these framings, but for the remainder of this paper we refer to “making sense of phenomena” and “the classroom game” as two general ways students can frame what they are doing.

When framing school activity as a classroom game knowledge serves as a sort of currency to collect and turn in for credit towards academic success. Consider the role knowledge plays and students’ roles in relationship to it in this kind of framing. What is important is that the knowledge is used in a way that will allow it to count. The value of a student response is assessed in relation to how closely it corresponds to what the teacher or textbook sanctions as correct. From the perspective of the student, the authority determines what knowledge is relevant and correct.

However, if students frame school science as an activity whose purpose is making sense of some natural phenomenon they select and assess knowledge differently.

Existing knowledge is relevant if it is useful for sense-making. Constructed knowledge has merit if it does, indeed, make sense to them. This, of course, is more in line with how knowledge functions in science. In this we are not suggesting that students have scientific expertise in assessing knowledge. Scientists, for example, place substantial emphasis that knowledge is systematic and consistent in deciding what makes sense, which students may not do. We are claiming only that scientists frame what they are doing as making sense of phenomena rather than as applying authority-sanctioned knowledge.

Lets return to the physics students working on the homework problem to illustrate what a productive framing might look like in that situation. Those students framed the activity as a kind of classroom game, this resulted in them choosing an equation to use as a template for plugging in numbers and producing a numeric answer. $PV=nRT$ was a piece of knowledge provided by authority, and that is an essential feature in the their decision that it is relevant to the activity.

However, it was the hope of the instructor that his homework question would prompt a different framing. He intended the question to contain a surprising assertion, that there is a difference in air pressure between the floor and ceiling of a dorm room. He hoped this would prompt students to ask themselves or their homework partners something like “How can there be a difference in air pressure in someplace as small as a dorm room?” Raising and then considering this question is a version of framing activity as figuring out some natural phenomenon. If the students discussed that question a bit they would have had reason to doubt that the ideal gas law was relevant to the situation.

It could have also provided them a natural phenomenon to connect meaningfully to the relationship between fluid pressure and depth expressed in the relationship $P = \rho gh$.

The difference between what the instructor hoped would happen and what actually happened illustrates a challenge associated with student framing in science classrooms. Because of their past experiences in science classes many students come to science classrooms inclined to frame the activity in an unproductive way, even in situations where instructors take steps specifically aimed at supporting more productive framings. This implies we need to be attentive to student framing and to consider what features of the situations students see that support unproductive framing.

A case study of attention to student framing

Little up to this point is likely to provoke controversy. Educators and educational researchers are generally dismayed by students engaging in some sort of classroom game without understanding the content in a substantive way. No one who sees the data presented at the beginning of the chapter argues that the students doing the physics homework problem are doing something of value. However, when one considers classroom practice, moments arise when attention to students' framing as an objective may be at odds with common teaching practices.

What follows is a study of an episode from the first author's science classroom. Our intent in analyzing it is twofold. First, because attention to student framing is important, we use it to illustrate what productive framing can look like in an actual classroom. Second, we use it to demonstrate that the agreeable-in-theory argument up to this point has significant and sometimes counter-intuitive implications for teaching practice. In a moment during this episode Paul ("T" in what follows) responded to

students in a way many science teachers would find inappropriate. This classroom moment provides an interesting example to consider from the perspective of framing.

The setting and data sources

The data comes from a university physics course for pre-service elementary education majors.⁵ This class involved lots of student discussion, both in small lab groups and as a whole class, and also included data collection and infrequent lecturing. The students in it were not provided formal curricular materials, no textbooks or lab manuals. Instead they maintained a personal lab notebook that serves some of the functions of a lab manual or text, and they prepared what I call “daily sheets,” short reflective writing assignments students complete at the end of each class meeting and I review prior to the next class. I provided most of the activities students engaged in, but also willingly followed student-suggested activity when appropriate. The ideas that form the conceptual substance of the course are almost wholly student-generated, although this is not to say they are not formal science ideas. Most of the students (19 of the 23) took some level of formal physics course in high school, and certainly all of them encountered formal school science instruction beginning in elementary school. So in many cases the ideas and terms students introduced were formal scientific ones.

The purpose of this class is for students to understand both the formal knowledge of physics and how that knowledge functions within the discipline. These two goals overlap significantly. It is the view of many who teach the course that to genuinely understand formal scientific knowledge one must have a sense of how it is used purposefully within the discipline that generated it. Understanding how knowledge

⁵ In general respects, the class is similar to the course “How to Learn Physics” described in Hammer & Elby (2003).

functions in science is considered a particularly important goal for this student population because they will provide children with some of their earliest school science experiences, and those experiences will begin to form the young students' expectations about school science. However, this instructional focus is relevant in any science course, as the example in the introduction shows.

Because there is a focus on understanding the nature and purposes of scientific knowledge, students' epistemological framing is at the forefront of my attention when I teach it. Helping students frame the class productively is a necessary part of my objective given this instructional goal. This means I need to be able to tell if I'm meeting it, so I look for evidence of productive and unproductive framing. And that's challenging.

In an effort to better understand the evidence available to detect student framing I began collecting data to analyze. During the semester the following data comes from each class meeting was videotaped using two stationary digital video cameras, one at the back of the room facing forward and one at the front of the room aimed at the students. There were two teaching assistants, a regular visitor who attended about two-thirds of class meetings, and occasional other visitors to the class. We held a debriefing at the end of each class meeting with the teaching assistants and any visitors to the class that day. These meetings were audio recorded.

The course is arranged into three conceptual units, each lasting about five weeks. The class meeting described here is from the first week of a unit studying buoyancy, which was the second unit of the semester. (In the other units during the semester the class studied electric circuits and electrostatics.) This class meeting was the second one

that focused on the study of buoyancy phenomena. In the first buoyancy activity students worked in their groups to predict whether several different objects would float or sink and then made observations to see if their predictions were correct. The class discussion that followed focused on students' ideas, informed by the observations and other things they knew about sinking and floating, about the features of an object that determine whether it floats or sinks.

The first twenty minutes: Good wrong thinking

I began the second class meeting by announcing there were two questions I wanted to write on the board. Articulating questions we hoped eventually to answer was a common practice. Occasionally I would specify the questions, as I did in this class, but more often students would generate them, either at my prompting or on their own initiative. It was my intent to get the questions up quickly and then invite students to add any questions they had. Both of questions arose in the previous class meeting, and I simply wanted to provide a clear statement of them. The first was why some materials floated in water no matter what their shape while other materials floated when shaped one way but sank if shaped another way. The second was why and how shape mattered for the latter group of materials.

Before I got to the second question a student, Rachel, proposed an explanation for floating to answer the first question. In explaining the question I picked up an apple and a solid copper cylinder as examples of the kinds of things that “naturally” float and sink.

Rachel's idea was one her lab partner, Katie, suggested the previous class meeting, that air is an active lifting agent that causes things to float.⁶

Teacher: ...So here's an object (*holds up copper cylinder*) that's made of some material that just naturally sinks, doesn't float, okay, so my question, one of the questions I want to get up there is what's different about materials that naturally sink and materials that naturally float? Is that, that's a very long winded, (*calling on Rachel who has raised her hand*) Uh, yes.

Rachel: I have a question about that. (*points to the apple*)

Teacher: The apple.

Rachel: Okay, on Wednesday we were talking about just what kind of things would float and what kind of things would sink, Katie mentioned something that, something about air, there was certain amounts of air (*trails off*)

Teacher: A lot of people in their daily sheets talked about air having the property of making things float.

Rachel: Making things float. So isn't there some kind of possibility that somewhere in that apple there is some place where there is air? Cause like they have seeds in the apple, and I don't, I've never really looked at apple seeds before, but maybe they could be hollow, or maybe the space where the seeds are in the apple, there's some air in there.

Katie: I mean there are hollow parts in an apple.

Rachel: Right. So maybe that may explain why it floats, maybe not necessarily cause...

Teacher: Yeah, okay. I mean it's different from like cutting a pumpkin in half.

Rachel: Well that's obvious cause (*inaudible*)

Teacher: That's obvious, you're right, right.

Katie speculated that all floating objects have some air in them even if they appear solid. For example, she thought, styrofoam must have some air in it even though

⁶ Katie's idea was the air in an object lifts it up when the object is in water. We observed a pumpkin float and this idea made a lot of sense in that situation. Katie noted that an air bubble in water rises to the surface as evidence in support of her claim.

we do not see any air pockets. Several other students doubted this explanation. One of them, Bekah, predicted a piece of aluminum foil would float, and that would be evidence against the air lifting idea since aluminum does not have air in it. She offered an alternative explanation: The density of an object determines whether or not it floats. This prompted Rachel and Katie to speculate about the relationship between density and air.

Bekah: I kind of have an idea. This thing is aluminum, right? (*holds up a solid aluminum block*)

Teacher: Yep.

Bekah: So what if we took a piece of aluminum foil and put it in there. (*points to a large beaker with water in it*) That, does aluminum foil have air in it? Like I would think it would float. So then I think that depending on whether or not she thinks it'll float, I remember back in class when we talked about this, like mass over volume, and if it's less than the density of water it's going to float, so no matter what the object is, it depends how big it is, and (*inaudible*), so I don't think air is really a big factor.

Teacher: So Bekah, you're, and you wrote this in your daily sheet, you're arguing for air is not a factor, the density is the important thing.

Bekah: Yeah.

Teacher: Okay

Bekah: I just think air, I'm sure it has, like it doesn't hurt it, but it had to (*inaudible*)

Katie: Maybe air affects the density then.

Rachel: I was just going to say that it seems like it's really the same thing. We're just calling it air and she's calling it density. Just like, if you (*inaudible*)

Katie: I mean maybe the atoms, if you take the styrofoam, it's (*she picks up a piece of Styrofoam and looks closely at it*)

Rachel: I don't really know so much about density, but it's not that, I don't think [styrofoam is] that dense.

Teacher: So if, if there's a lot of air pockets kind of mixed in with the material then it would be less dense.

Katie: Yeah.

Rachel: Right.

Katie: Because air is the, okay, density is the absence of air. Like the more dense an object is the less air it has.

Teacher: The less air there is, okay.

Katie: So maybe they work together in that way.

Teacher: You all getting this in your notes?

Students: No.

Teacher: Just a thought, I don't know, I...

Student: Something about air and density.

Teacher: Well I think that, so I just, as kind of a little aside

Tessa: Can that be a question? Can that be a question? What's the relationship between air and density?

Teacher: That's beautiful. What is the relationship between density and air? (*TA writes the question on the board*)

The students had pieces of aluminum foil in their lab notebooks from a previous homework assignment, so we were able to quickly test Bekah's prediction and found that if set on the surface the foil floated, but when pushed under the water it sank to the bottom. This was not what Bekah and a few others expected. A group of students showed that if you crumpled the foil into a ball and pushed it under water it floated back up. A student suggested that the floating aluminum ball had air trapped in it, implying that the air was the cause of the floating.

Evidence of productive student framing

The class discussion up to this point shows evidence many students were framing the activity in a productive way, as making sense of natural phenomena. There is evidence they were trying to make sense of the phenomena of floating. The students proposed different explanations and engaged in discourse aimed at comparing their relative merits. Students took the lead in introducing ideas that served the purpose of making sense of the phenomena; Rachel re-introduced Katie's idea of air as a lifting agent and Bekah introduced density as an alternative. The students judged the merit of these ideas by how consistent they were with the phenomena.

A particularly nice moment occurred when Bekah proposed the observation she expected would support her density explanation. In arguing for density rather than air Bekah was probably recalling something she learned in a previous science class; objects less dense than water float. But rather than appeal to authority, she proposed an observation to show that density, not air, was the important thing to consider. Similarly Rachel and Katie trying to connect Bekah's density idea and their air idea is evidence that they were engaged in trying to figure out the formal scientific ideas; they were framing the activity of this class in a way in which that is a reasonable or an expected thing to do. Making those kinds of connections, between formal ideas and intuitively plausible ones, is precisely what students should do to develop conceptual understanding (diSessa, 1994).

Shortly after the discussion described above I invited students to add other questions to the class list. The first student I called on asked to add the question "Why do cans of Coke sink and cans of Diet Coke float?" This was a phenomenon we observed

during the previous class that many students were very interested to discuss and did. Many of the features I identify in the air/density discussion were present in this discussion as well. The students introduced ideas and argued for or against them based upon the evidence available.

Another feature that provides insight into framing present in this discussion was language use. The framing literature in sociolinguistics (ie. Tannen, 1993) argues word choice provides an indication of framing. In the class discussion a student, Nikki, suggested that the difference between sugar and artificial sweetener could explain why Coke sinks and Diet Coke floats. Nikki explained to the class why it seemed plausible to her that this could explain sinking and floating in this case. Rather than using formal scientific terminology she used everyday, common words like “thicker”, “sugar-y”, “heavier”, and “light”. In moments when students frame activity productively we should expect them to use language that is sensible to them and likely to the people they are talking to. This is especially true in introductory courses like this one. The language Nikki chose indicates she was framing the activity as simply trying to make sense of the phenomenon.

In contrast, many students’ framing of school science as a “classroom game” (Lemke, 1990) includes the expectation that they use formal scientific words in their talk, though without the attendant expectation that the words be used sensibly. A clear example of such behavior comes from Lising and Elby (2005). A group of students in a college physics course were trying to understand light and shadows in an observation they made. One student, Veronica, used everyday language to explain the phenomenon; another, Jan, wanted to use the technical science terms “vector” and “polarized.”

Veronica objected, saying "...you're trying to make it more difficult...". Jan responded that she was "...just trying to make it, like, physics-physics-oriented."

Students understanding and appropriate use of the formal terminology of science is certainly a desirable goal, insofar as it serves making sense of phenomena. When it does not serve that purpose, when the terms are used because they are sanctioned by the teacher or textbook, they can reflect an unproductive classroom game. In contrast, the use of everyday, less technical language may reflect productive framing, in particular when that language is evidently serving to help students make sense of phenomena.

The weight-mass moment: Productive framing vs. correctness

Following Nikki's comment about the difference between sugar and artificial sweetener I introduced an analogy: adding different amounts of pennies to two small, empty floating cups. I wondered to Nikki if this might be a way of thinking about her idea, that adding sugar or artificial sweetener is like adding different amounts of pennies, and if enough pennies were added one of the cups would sink. This prompted another student, Kim, to ask Nikki if she was arguing that "weight matters". This was an idea from the previous class that some students argued against, noting that lots of very heavy things float (we observed a pumpkin) and lots of light things sink (we observed a paper clip). Once again a student argued density was the thing we needed to be paying attention to. Katie, looking to reconcile ideas, pointed out that there must be some relationship between weight and density, because as one added weight, in the form of pennies to the cup, it would eventually sink. So the density must increase as weight is added.

A digression into teacher thinking

Immediately after Katie's comment I abruptly shifted the activity of the class, going from an open conversation where students jumped in when they had something to say to a teacher-directed kind of activity. It is important for what follows to understand my decision to change the activity the students were engaged in. So, I digress here for a few paragraphs into a description of why, in that moment, the shift seemed potentially very productive.

It seemed like an instructionally ripe moment for a couple of reasons. First, it was conceptually ripe. Implicit in the students' comments was the idea that things more dense than water sink and things less dense than water float. While we had talked quite a bit about density, no equation for it had been put up on the board and thus formally entered into our list of class ideas. It felt like an appropriate moment to introduce a density equation and ask students to use it to empirically verify the more dense/less dense idea. Another reason this moment seemed ripe was because of my sense that many of the students were framing the class activity in a productive way. I thought they could continue this productive framing despite the shift. I decided to introduce an equation for density; my hope was that given the concepts in play as well as the productive framing, students would make conceptual connections to the mathematical formalism of the equation rather than treat it like a prescription for a set of steps to carry out.

The equation I wrote on the board was "density = weight/volume". Readers of this journal may recognize this is not the density equation commonly presented in science classes, "density = mass/volume".

My choice of ‘weight’ rather than ‘mass’ was not pre-meditated; that is, I didn’t walk into the class that day thinking I would define density in this way. However, it was intentional, a choice I made in the moment. In the discussion among students that immediately preceded this many students were using words ‘weight’ and ‘heavy’ when talking about the relevant features of objects with respect to floating and sinking. Just before I wrote down the equation Katie argued that when “weight” is added to a floating cup its “density” must somehow increase. I meant to build from the students’ reasoning, and so I chose to use the word they had been using. I also think of ‘weight’ as a more everyday, common sense word than ‘mass’, and I thought using weight would help maintain the common sense feel of the class discussion up to that point. Just as I take word choice as evidence of framing, I expected the students will do the same.

How students responded

As the following transcript recounts, several students immediately spoke up to correct what they probably perceived to be a simple error, something like incorrectly spelling a word. In retrospect, that is not surprising, although it took me by surprise at the time. With little explicit consideration it simply made sense to me to define density the way I did and I assumed the students would see it as a sensible thing as well. The transcript also recounts how I responded to their corrections, and that will be the subject of consideration in the next subsection.

Teacher: And so, what I wanted to do was (*pause while writing “density = weight/volume” on the board*) ... was put a mathematical equation on the board in honor of the fact that we have a mathematician visiting us today.⁷

⁷ A colleague who is a mathematician was a visitor to the class that day.

Student: Isn't it mass though?

Murmurs of consent from other students

Teacher: Pardon?

Student: It's mass right?

Teacher: It's mass?

Student: Yeah.

Teacher: (*writes "mass" on the board next to his density equation*) Okay. I'll tell you guys what I think weight is, you tell me what you think mass is. Weight is how heavy something is.

Student: Mass is a measure of amount of matter.

Tessa: You could say something's heavier, you could say it's a very heavier, it's like...but mass is like a number.

Katie: No...

Teacher: Well when I step on a scale I weigh, well I won't say how much I weigh, but I weigh a certain number of pounds.

Rachel: Mass is the amount of matter...

Tessa: That's pounds, that's not weight.

Mike: Mass is (*inaudible*)

Katie: Yes it is.

Cianti: Yeah it is.

Tessa: Pounds is a measure.

Teacher: But don't I "weigh" myself?

Cassie: They're both measurements.

Several students talking over one another

Teacher: Liz!

Liz: Mass is the amount of matter an object has because mass is going to be the same if you're on the moon or if you're here, it doesn't depend on gravity, weight does.

Elizabeth: I like that definition.

Cassie: That works.

Elizabeth: It makes sense.

Teacher: Okay. Two objects on the surface of the earth with the same mass, do they have different weights?

Student: No.

Student: I don't think so.

Student: On the moon?

Student: No.

Teacher: On the surface of the earth.

Student: Say that again.

Student: No.

Student: No.

Elizabeth: Say that again.

Teacher: I mean is anybody going to the moon soon?

Katie: Can you repeat it?

Teacher: Two objects with the same mass, both here in this room, do they have different weights?

Rachel: They can.

Teacher: How can they?

Rachel: If they have different amounts of matter making...

Teacher: But wait, mass is how much matter there is.

Katie: No, cause it's, it's matter on earth... you're trying to make the point that it really makes no difference between the two.

Teacher: That's the point I'm trying to make.

Katie: So, ok. Just never mind.

Nikki: I think we're just used to saying density equals mass over volume. Like "d" equals "m" over "v".

Teacher: Okay. Well I want everybody to feel good in this class. (*he erases the word 'weight' and writes 'mass' in its place*) But when you weigh something on those little scales you're measuring the weight. So, whatever works for you. My point is that as long as nobody's planning on going into outer space we can just sort of lump them all together.

Nikki: Okay.

Teacher: Okay? I mean I agree there is a distinction to be made, but, ah, I'm not sweating it, so... (*he writes the word 'weight' in parentheses next to the word 'mass'*) Whatever. Okay.

The teacher's response and student framing

Consider my response with an eye to framing considerations. Up to the point where the students asked if I made a mistake many of their actions indicated they were framing the class activity productively. When several of them asked if I had used the wrong term I interpreted it as their recall of the mass density formula they learned in previous science classes, and worried this might reflect a shift in their framing. They might have been shifting to a classroom game, focusing on sanctioned correctness rather than sense-making. Now, I suspect their correction was almost reflexive, but a density definition, whether mass density or weight density, represents a concept and I want students to recognize that when we use a definition in science we need to consider whether the concept it represents is appropriate for the context.

My concern was that switching the definition to mass density in a moment when weight density which was more continuous with their discussion, would send the message that textbook correctness was more important thing, ironically in a moment

when conceptual correctness was not really at stake.⁸ I feared that changing the equation at that moment would be consistent with students' typical framing of school science as a classroom game. I work hard to combat that framing in this class and am often on the lookout for evidence of it popping up as I teach.

Indeed, the literature on framing identifies it as an ongoing process (Maclachlan and Reid, 1994). Individuals are accomplished at attending to what's going on around them for signals that indicate the type of activity and altering the framing when it appears appropriate. This characteristic of framing is quite useful to a science teacher who wants students to engage in a different kind of activity from what they have done in their previous science classes. Students are capable of framing the activity of a science class in other, more productive ways. There are pieces in the math (Chazan and Schnepp, 2002) and science (Louca et al, 2004; Rosenberg, Hammer, and Phelan, 2006) education research literatures that don't use the concept of framing but describe shifts from less productive to more productive student participation that appear to be framing phenomena. Hammer et al. (2005) includes examples from classrooms that illustrate productive framing shifts.

But a framing shift can also be unproductive. As a teacher I attend to what the students are doing, with a particular eye toward how they appear to be interpreting the nature of the activity. With that in mind when the students asked if I didn't mean to use

⁸ Strictly speaking, my use of weight-density (which is what I defined) rather than the more common mass-density was perfectly valid; one can work out all of the physics of buoyancy using weight-density and be rigorously correct. The ancient Greeks did not have a distinction between an object's weight and its mass and yet Archimedes did such a fine job working out the physics of buoyancy we continue to teach 'Archimedes principle' in science classes today. Scientists do, by convention, typically mean mass density when they use the unmodified word 'density,' and I was violating that convention, but it is only in that sense that I was "incorrect."

‘mass’ I was worried it might be an indication of a shift, and my response to them, to raise the issue of whether or not using mass was more sensible than using weight, was aimed at keeping students framing the activity productively. It may be my response did not have this effect. But this episode is not my focus because I claim it is exemplary teaching, rather it is an episode rich for considering the implications of student framing.

What else is there to see that gives us some insight into student framing? Liz, when given the floor, offered the example of the moon for making the distinction between weight and mass. While she’s right, an object’s mass doesn’t change with location while its weight can, her response may be evidence of her framing the activity in an unproductive way. Her example, the moon, is the canonical school example for illustrating this distinction.⁹ She surely heard this example before in a previous science class. Her response to my query is essentially the right answer to the question “How does mass differ from weight?” in a classroom game framing of school science and might be an indication that she was framing our class in that way.

This is a subtle but important point, and perhaps a comparison will help to clarify it. As a contrast to Liz consider Bekah’s earlier introduction of density as an explanation for why things float or sink. Both Bekah’s and Liz’s ideas almost certainly originate in their past school science experiences, so in that sense they are similar. However how the two students used the ideas within the discourse is dissimilar and may indicate a difference in how they were framing the class activity. In Bekah’s case the idea of density is offered as an alternative to another explanation, namely Rachel and Katie’s air

⁹ I happened to have four different introductory physics textbooks lying about in my office one day and each of them uses the moon example as a context where the conceptual distinction between weight and mass is consequential. (Tipler, 1982; Hewitt, 1997; Reese, 2000; Giancoli, 2005)

as lifting agent idea. Bekah's idea is intimately connected to observations of phenomena the class is making, and she goes on to reason that her idea implies a piece of aluminum foil will float. While she's wrong about that implication, and the subsequent observation was not what she predicted, the activity of reasoning about the implications of an idea as a means of demonstrating its merit is quite different from the way Liz introduces the moon example.

In Liz's case the idea appears to have merit simply because it is the right answer. She does not connect it to phenomena we are investigating nor does she offer any particular reason why it is a good example. It is simply *the* example one uses in these moments if one frames the activity as the typical science classroom game. This difference is epistemological; the way knowledge functions in these two situations is different.

I do not intend this as a criticism of Liz per se. While there is evidence she is framing the activity unproductively for science, it is a familiar school framing and may have been supported by my actions. In fact, I likely contributed to the shift in how Liz and others framed the activity. My intention in raising the question of how weight and mass differed was to press students toward sense-making. Since they were arguing for "mass" rather than "weight," I was asking them to give a tangible meaning of "mass." In hindsight, it was reasonable for Liz to interpret the meaning of my query as the kind of activity she was familiar with in school science. And she knew the 'correct' answer to this question, it was the moon example. So my posing the question to the class may have unintentionally prompted a shift in Liz's framing.

The same can probably be said regarding the students who initially asked if it shouldn't be "mass" rather than "weight". The introduction of the density relationship is preceded by a marked shift in my demeanor. My tone of voice changed, from a soft, facilitating tone to a sharp, directing one, the familiar "teacher voice". Furthermore, in the first twenty minutes of class discussion I didn't write on the board, letting a teaching assistant write student ideas and questions on the board as they come up while I stood among the students. Most of the time I stood in the back of the classroom. Shortly before writing the density equation I walked up to the front of the classroom and took the chalk from the TA who then sat down at her table, leaving me standing alone at the board. These actions look very much like the actions students might have seen in their previous school science experiences, and could plausibly prompt some students to re-frame the activity as a classroom game.

My point in attending to teaching actions that might prompt students in this episode to shift into an unproductive framing is not to compile a list of things a science teacher should avoid. There are times in a science class when a teacher should deliver information to students. In those situations the goal is for students to continue to frame the class productively while the teacher delivers information to them. Rather, I include the teacher's actions to point out that what a teacher does impacts how students frame the class, for better or worse. The framing literature (Goffman, 1986; Tannen, 1994) argues that we communicate our framings to one another very effectively. In that moment I shifted my framing of the activity and that the students also shifted is, in retrospect, not surprising. So teachers need to attend to student framing frequently, looking for evidence that gives insight into how they are framing the activity.

Tension between objectives

Some readers may argue we present a false dichotomy here, essentially pitting productive student framing against correctness. You might respond the goal is both, not one or the other. And that *is* the goal. However, based on their past science class experiences many students will arrive in a science class inclined to frame it unproductively. A feature of science classrooms that promotes unproductive framing is correctness being valued above all else. It is possible then that a science teacher's insistence on canonical correctness could prompt students to frame science class activity unproductively. This kind of teacher behavior is a familiar feature of typical school science, and consequently may prompt unproductive, typical school science framing. So in this classroom moment productive framing and correctness may be at odds for some of the students. While the goal is ultimately both, teachers should expect to encounter moments in science classrooms when the two are at odds. In a class that genuinely emphasizes student inquiry, such moments will not be rare (Hammer, 1997). If a science teacher's choice is *always* correctness in such situations then students will view it as simply confirming their unproductive framing. While no one such incident is the cause of that framing, the pattern students become familiar with is incrementally mis-educative.

In this particular case there is little reason to think that systematic insistence on correctness can be compatible with productive framing. The distinction between the scientific concepts of weight and mass is a challenging one for students to grasp (Ruggerio et al, 1985; Smith, Snir, and Grosslight, 1992), probably because there are very few experiences most people have where the distinction is an important one to make. As the terms are commonly used outside of science classrooms the words 'weight' and

‘mass’ are often synonymous, meaning something like the amount of stuff, or matter. For example when someone talks about “losing weight” it refers reducing the amount of their body, not reducing the force with which the earth pulls down on them, although of course on the surface of the earth the magnitudes of the two are directly proportional. And within the context of studying buoyancy there is no need for the distinction, weight is as good a concept as mass (and perhaps better since weight is the relevant downward force) for explaining the phenomena. So to insist on using mass in this case is not driven by a conceptual need to make the distinction related to the phenomena under investigation.

Another objection readers may raise is that arriving at this point is a consequence of poor instructional sequencing. With careful sequencing of the conceptual content these kinds of moments can be avoided. There is value in carefully sequencing content to facilitate both supporting students’ productive framing and their coming to deep understandings of canonical content. Sequencing can help to minimize moments like this one, where correctness and productive framing are potentially at odds. However, it is implausible to think that a curriculum, no matter how carefully engineered, will eliminate such moments altogether. For example it is likely that all of the students in this class received formal instruction on both weight and mass along the way in their school science past, and yet several who were willing to speak up when queried about the difference demonstrate misunderstandings of the scientific conceptualizations. The argument that sequencing is the problem presupposes that the earlier instruction will be successful in some particular learning goals, which was not the case here. The realities of

science classrooms indicate that no matter how carefully instruction is sequenced, science teachers will encounter moments like this one.

One more episode

A moment from later in the buoyancy unit provides an example of correctness and productive framing going hand in hand quite nicely and so seems relevant to include here as an example of what successful coordination of those goals can look like. As the class' investigation of buoyancy proceeded we made some observations with a spring scale supporting a hanging metal cylinder and saw the scale read less than the weight of the cylinder when the cylinder was hanging completely submerged in water. This led to a class discussion about a mechanism by which water pushes up on the submerged cylinder, and a little later I lectured about how the increase in fluid pressure with depth results in a net upward force on a submerged object. But how the upward pressure push explanation was related to density was a bit of a mystery. We used both to explain floating and sinking, but could not explain how they were related to one another, and had explicit discussions in class about our inability to make that connection. During a later class meeting, the students made a series of observations of the upward pressure push force and concluded that its magnitude depends only on the volume of the submerged object, not the object's weight.

On the day of those pressure push observations there was a class discussion aimed at sorting out how the downward pull of gravity on an object and the upward and downward fluid pressure forces combined to make an object sink or float. In the midst of that discussion Bekah excitedly offered an idea about how the pressure push and density were related. She explained to the class that the density of an object was the ratio of the

downward to upward pushes on a submerged object. She appeared to think other students didn't understand what she was saying and jumped up and wrote on the board:

$$\frac{\text{weight}}{\text{volume}} \longrightarrow \frac{\text{downward push}}{\text{upward push}}$$

She explained in more detail that the weight told you the downward push on an object and the volume told you the upward push on it. When the downward push is greater than the upward push the object sinks, and of course this would mean that the ratio of downward to upward (the density) is greater than one, which we also knew meant an object sinks. And if the downward push is less than the upward push then the ration (the density) is less than one and the object floats.

Her idea was tremendously well received by other students in the class. Most students wrote about it in their daily sheets that day and many of them used what we came to call "Bekah's Law" in their explanations on the test for the buoyancy unit.

I was also pretty excited by Bekah making this connection between the fluid pressure mechanism of the buoyant force and the density explanation of buoyancy. While I recognized Bekah's reliance on the density being more or less than one worked a consequence of our use of metric units and primarily using fresh water as our liquid, there was important correctness in her observation. The density of an object does indeed tell us about the ratio of the up and down forces, where the up force is the buoyant force and a function only of the object's volume and down force is the weight of the object and is a function of its mass.

But what was most exciting to me about Bekah pointing out this relationship was that it broadened my own understanding of the phenomena. It is a connection I did not

recognize prior to that moment, though I now use it sometimes in my teaching. That Bekah invented this way of understanding what density means in the context of buoyancy is lovely for a number of reasons beyond its contribution to my own understanding. It indicates she was working to find ways of understanding the concepts that are sensible to her. Not only that, she also felt it was important to communicate her new found understanding to her classmates. She was contributing to the class' knowledge. The idea itself is a powerful way of understanding density as it relates to buoyancy. Bekah and her classmates alike were probably excited about the idea because they understood it. Finally, she presented her idea in a kind of mathematical expression, in a way that was continuous with the students' own discourse. That is, she *composed* an equation, something students do not do very often in introductory courses, and she did so at her own initiative.

This moment relied upon Bekah seeing this as the kind of activity she should engage in, it relied upon her framing the class in such a way that making sense of the content for herself and her classmates is what she thought she should do. Had she framed the class as the typical school science classroom game where the expectation is that knowledge is received from the teacher, this may not have happened. Bekah's productive framing contributed to many students in the class coming to an understanding of the conceptual content. Seen more broadly this was a moment where productive student framing contributed to the conceptual content goals of the class. In moments like the weight-mass episode such goals can be locally at odds, but the decision I made was aimed at facilitating students participating in a way like Bekah later did, and can lead to productive framing supporting the conceptual goals.

Conclusion

While no one sets out to convince students the key to success in a science class is mastering a set of answer producing algorithms or memorizing definitions, these are common outcomes of school science. To begin to correct this we must critically examine the common practices of science teaching that unintentionally contribute to student framings that include these expectations. To some degree we are aware of framing evidence already. There are moments when unproductive framing is easy to see, as in the episode that leads off this chapter, or a student who responds to a teacher trying to get her to think through the implications of an idea “Can’t you just tell me the answer?”

Recognizing unproductive framing in a few obvious moments helps one understand that framing is important to pay attention to in classrooms. However, it is an insufficient level of recognition for changing how students typically frame school science activity. To do this, teachers need to assess how students frame activity much more frequently and be sensitive to less obvious evidence; and that is more difficult. One contribution of this article, perhaps, is to begin to compile an inventory of the things we can look for that provide us evidence of productive and unproductive framings. Student framing is evidenced in how students use knowledge, whether students see initiating explanations as one of their roles, whether they make connections between concepts and natural phenomena, whether they seek connections between different concepts in play, and what language they choose to use and how they use it. This is a partial inventory, but suggests the beginnings of where we can look to assess how students frame science classes.

Notably, the list above does not include whether conclusions students arrive at are correct. Indications of productive framing will not generally come from correctness, which will inevitably make for tension between the goals of supporting productive framing and helping students come to correct conclusions. Part of what is lovely about Bekah's connecting the density explanation to the pressure push explanation is that she's largely correct, but the correctness itself is not evidence of productive framing. In contrast recall Bekah was the student who predicted aluminum foil would float in the discussion that lead up to the weight mass controversy. In that case there was also evidence in her actions she was framing the activity productively, though her prediction was not correct. Presently, common practices in science classrooms systematically favor correctness in moments when these two objectives are at odds. It's plausible that what allowed Bekah to come to her lovely, correct conclusion was being in a classroom environment where correctness was not systematically favored, but rather the tension between productive framing and correctness was something to which the teacher paid attention.

Chapter 4: Supporting student inquiry through illustrations of exemplary science classrooms

Abstract

Among the challenges associated with implementing the reform vision of science learning and teaching characterized in the *National Science Education Standards* (NRC, 1996) is the need to communicate to teachers, administrators, and professional developers what a good student inquiry in a science classroom looks like. The *Standards* and a later supplemental document, *Inquiry and the National Science Education Standards: A Guide for Teaching and Learning* (NRC, 2000), both include illustrations of classroom inquiry at least in part for this purpose. These illustrations of exemplary science classrooms focus the reader's attention on the instructional sequence at the expense of describing student ideas, reasoning, and interactions in detail. This focus does not adequately support science teachers understanding what they need to do to facilitate quality student inquiry in the classroom. By focusing on instructional sequence the illustrations provide (1) an overly simplistic view of classrooms in which good student inquiry is happening, (2) do not support an understanding of the role formative assessment plays in supporting student inquiry, and (3) may actually hinder teacher's understanding of the need to be attentive to student ideas and reasoning. As a contrast to the nature of the chapter concludes with a description of a fifth grade classroom where students engage in a class discussion around the question "What causes a full moon?" Analysis of the description indicates how it supports teacher's understanding of quality student inquiry and how it can be facilitated.

Introduction

There are many challenges to broadly implementing the reform vision of science learning and teaching outlined in the *National Science Education Standards* (NRC, 1996), henceforth the *Standards*. Among them is the need to illustrate for teachers, professional developers, and school administrators what it looks like when student inquiry in a science classroom is going well. Many in these positions have little or no experience with engaging science content as inquiry, yet they play critical roles in implementing the reform.

The *Standards* locates teaching and teachers "...at the center of the reform in science education." (p. 15) The need to help individuals with a very direct impact on instructional practices understand what kind of classroom activity the reform is aiming for is particularly pressing. The *Standards* and related reform documents address this need in several different ways, among them by presenting images of classroom inquiry to illustrate different aspects of reform learning and teaching. The *Standards* itself has more than a dozen short examples of exemplary teaching practice interspersed throughout the text. These are intended to demonstrate the attainability of the view it offers and to illustrate some of the specific elements of the reform it articulates. A later document intended as a supplement the *Standards'* view, *Inquiry and the National Science Education Standards: A Guide for Teaching and Learning* (NRC, 2000), henceforth the *Inquiry* supplement, includes several lengthier vignettes of classroom practice as well as analysis of the vignettes to point out the features of inquiry they illustrate. The *Inquiry* supplement is intended for those with a direct impact of classroom practices; teachers, administrators, and those involved in professional development.

This chapter argues that the vignettes of exemplary science classrooms in the *Inquiry* supplement (1) fail to adequately support teachers attempting to change their teaching practices to align their classrooms with the vision spelled out in the *Standards*, and (2) run the risk of being interpreted by readers in a way that reinforces common but counter-productive expectations many teachers bring to teaching science. This argument is grounded in the conceptions of learning and teaching characterized in the *Standards*, the *Inquiry* supplement, and research literature that aligns itself with those reform documents. After making this argument the chapter presents a vignette of student inquiry in a science classroom as a contrast and a possible alternative to the vignettes in the *Inquiry* supplement.

Inquiry

The notion of “inquiry” is the central element of the reform vision in the *Standards*. Though the way that word is used can make its meaning a bit difficult to pin down. The term inquiry is used to refer to several different concepts. First there is this frequently cited passage from the chapter titled “Principles and Definitions”:

Inquiry. Scientific inquiry refers to the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work. Inquiry also refers to the activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world.

Inquiry is a multifaceted activity that involves making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is known in light of the experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations and predictions; and communicating the results. Inquiry requires identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations. Students will engage in selected aspects of inquiry as they learn the scientific way of knowing the natural world, but they also should develop the capacity to conduct complete inquiries. (p. 23)

So one of the things inquiry refers to is the activity of scientists when they do science; inquiry is what scientists do. The *Standards* generally uses the phrase “scientific inquiry” to flag when this is the intended meaning. As it pertains to a science classroom, inquiry refers to both a set of learning goals for students and some strategies teachers employ in support of those goals. The preface of the *Inquiry* supplement characterizes inquiry as it relates to science classrooms this way:

The term ‘inquiry’ is used in two different ways in the *Standards*. First, it refers to the *abilities* students should develop to be able to design and conduct scientific investigations and to the *understandings* they should gain about the nature of scientific inquiry. Second, it refers to the teaching and learning strategies that enable scientific concepts to be mastered through investigations. [italics in the original] (p. xv)

There is coherence among these various meanings. The inquiry of scientists (scientific inquiry) serves as a referent for the activity students are expected to come to master (what I will call ‘student inquiry’). It is assumed that by mastering student inquiry students will learn content more deeply and with increasing independence from instructional direction, both desirable instructional outcomes. The term inquiry is also used to refer to some instructional strategies (what I will call ‘inquiry pedagogy’) that are expected to support both the traditional conceptual understanding goals of science instruction as well as the new goals introduced by the *Standards* that students come to be able to engage independently in an activity that is similar to scientific inquiry in important ways and to develop an understanding of scientific inquiry at least in part by engaging in student inquiry.

Given the goals laid out by the *Standards*, not all of these meanings are equally important. At the center of this view is a student’s capacity to engage in student inquiry. Scientific inquiry provides the referent and a reason to believe that students who can

engage in relatively sophisticated student inquiry will benefit from the sophistication. Inquiry pedagogy supports the development of students' abilities to engage in student inquiry. At the center is the student inquiry itself. It is the thing that carries with it the presumed benefits. In addition to the benefits listed in the previous paragraph, the scientific education research community expects that students will come to explicit understandings of the nature of scientific inquiry through their more and more sophisticated student inquiry, and consequently will be more scientifically literate. So all of this rhetoric of inquiry is ultimately in support of school science instruction that enhances students' abilities to engage in increasingly sophisticated scientific-like student inquiry.

Making these distinctions among the various meanings of the term inquiry is important for the argument this paper makes, and I will be careful to be clear in my use of the various meanings. Both the *Standards* and the *Inquiry* supplement also use the phrase 'classroom inquiry' on occasion. That phrase is problematic for making clear distinctions because it is rarely evident if it refers to student inquiry in a classroom or the inquiry pedagogy strategies teachers use in a classroom. In many instances of the use the term 'classroom inquiry' refers to both simultaneously, essentially suggesting that inquiry pedagogy strategies and student inquiry necessarily go hand in hand. That is an assumption that the *Standards* and the *Inquiry* supplement appear to make tacitly, and one I will question in this chapter. I will not use the phrase 'classroom inquiry' so as to be clear in making the argument.

Illustrating exemplary science classrooms for those new to reform goals

The illustrations of exemplary science classrooms in the *Standards* and the *Inquiry* supplement focus almost exclusively on the things the teachers do. They lack significant descriptions of what students do, what the teachers pay attention to as a gauge of how well the lesson is going, and insight into the decisions the teacher makes in support of the learning goals. All of these omitted features are at least as important to include in descriptions of exemplary instruction as what the teacher does. The omission of them has the potential to present an image of science teaching that is at odds with the goals of the reform. This claim is based in conceptions of good teaching articulated in the *Standards* as well as research literature that investigates teaching aligned with the goals of the *Standards*.

This is not to say that the instruction described in the *Standards* and the *Inquiry* supplement is poor teaching. Rather, my criticism is that the features of classrooms that are emphasized in the vignettes may negatively impact the practice of actual teachers, administrators, and professional developers trying to facilitate classroom inquiry in their own classrooms, schools, and districts. Much goes on in any science classroom, and the process of describing the goings on necessarily involves focusing on selected aspects. Which aspects get attention in the description implies what is valued. What the illustrations in the *Standards* and the *Inquiry* supplement imply does not adequately help a reader understand the nature of the teacher's role in supporting student inquiry.

This seems a particularly important argument to make regarding classroom illustrations in National Research Council publications because, as the de-facto authority regarding the reform view of science learning and teaching, they hold an elevated status

in relation to other published images of exemplary classrooms, and perhaps reach a wider audience. So the potential for the illustrations in those publications to make an impact on actual classroom practice is greater than in other publications.

Characterizing the illustrations and their pitfalls

The place to begin is by characterizing the illustrations of classrooms provided in the *Standards* and the *Inquiry* supplement. This analysis focuses primarily on one of the vignettes presented in the “Images of Inquiry in K-12 Classrooms” chapter from the *Inquiry* supplement. There are four extended vignettes presented in that chapter, one from K-4, one from 5-8, and one life science and one physical science vignette from 9-12. This analysis will largely focus on the 5-8 vignette, a recounting of a several weeks long instructional unit from an 8th grade class that explores the cause of the moon’s phases. This is the longest of the vignettes in the *Inquiry* supplement, so in some ways it is the most detailed. It is representative of many of the features of the vignettes in the *Inquiry* supplement and I will be clear where other vignettes differ from this one. Finally, later in the paper I will include some data from a different science classroom as an example of a different way of illustrating inquiry classrooms. That data comes from a fifth grade classroom discussing what causes a full moon, and that discussion spills over into the question of the moon’s phases more generally. So focusing this analysis on an episode that also addresses the moon’s phases presents an easier contrast.¹⁰

¹⁰ This vignette appears on pages 48 to 59 in the *Inquiry* supplement (NRC, 2000)..

An “image of inquiry” from the Inquiry supplement

The vignette begins by describing the teacher’s goals for the unit and describing relevant activities the students had previously done. It then describes the teacher, Mr. Gilbert, leading an in-class activity to solicit what the students know about the moon and questions they have about it. He asks the students to spend a few minutes writing down their personal responses to these prompts and then has them compare their lists with a partner. Following that Mr. Gilbert invites students to contribute what they know about the moon and questions they have about it to a class list. From the student responses he selects a few “...that he knows are crucial to [students’] understanding of the moon’s phases...” (p. 50) and writes them in two columns on the board.

Things We Know About the Moon

The moon changes shape.
The moon is smaller than the earth.
People have walked on the moon.

Questions We Have About the Moon

How can the moon be visible during the day?
Why don’t eclipses happen more often?
What causes the moon’s phases?

[Mr. Gilbert] asks several students how they know that the three items in the left column are true. Their responses include “Because I saw it on TV,” “My mother told me,” “I read it in a book my aunt gave me,” and “my fourth grade teacher showed us a video.” As the discussion proceeds, students recognize that these explanations are shallow compared to what they could learn from observing and collecting data over time about the changing shape of the moon. (p. 51)

Following that realization Mr. Gilbert introduces the students to the data collection portion of their investigation, a five-week long period of daily moon observations they make each night and bring to class the following day. During the five weeks of moon data collection the class works on other topics, though the data collection from each night is posted on a wall chart in the room. Once the data collection is complete Mr. Gilbert returns the students to considering moon phases.

On the last day of the five-week investigation period, the class returns to the moon unit, beginning a transition from collecting and analyzing data to developing new concepts about the phases of the moon.

As groups review their observational data on their charts, interesting discussions begin to occur. With some prompting from Mr. Gilbert, students begin talking about models that might account for the data they have collected – an important aspect of doing science. Mr. Gilbert decides to begin with a model that explains the phases of the moon recorded by students. (p. 52)

Mr. Gilbert then leads the students through an exercise intended to provide them with an experience that will prompt their consideration a particular model, one that is more or less correct.

Two common features of the vignettes

This example is representative of the kind of descriptions in the remainder of the vignette and also in the other vignettes. There are two common features evident in this part that are important for this analysis. First, there is a focus in the vignette on describing the instructional sequence. The vignettes explicitly discuss instructional sequencing. Each one is followed by analysis that addresses the instructional model. The analysis of this vignette characterizes the described portion of the vignette this way:

Instructional Sequence. The example just given of Mr. Gilbert and his students illustrates a way of sequencing learning and teaching activities that is consistent with the features of inquiry. The unit evolved from data collection, then using those data for concept development and the evaluation of models and explanations....Early in the sequence Mr. Gilbert helped his students become engaged in thinking about the moon phases by probing what they thought they knew about the moon and what they wondered about. Their study proceeded through a long period of observation and data gathering during which they recorded and then explored the patterns they observed in the moon's behavior. (p. 59)

You may recognize some common instructional sequences in this portion of the episode. The opening activity, students articulating things they know about the moon and questions they have about it, is the first two thirds of the “K-W-L” (Know, Want to know, Learned) instructional sequence (Ogle, 1986). In the same activity Mr. Gilbert

uses an instructional sequence commonly referred to as “think-pair-share”, students first individually generate a personal list, then compare their list with another student, and finally move into a whole class discussion about the ideas. And we also see the first three elements in the “5E” instructional model (Trowbridge and Bybee, 1990); engage, explore, and explain. The *Inquiry* supplement presents its own five-phase inquiry instructional model (p. 35) that is described as based on common components shared by other instructional models, and aligns exactly with the 5E model.

A second notable feature of the illustrations is that little description of what the students do is included. When it is included it serves to show that the instructional step was successful. The included student activity is consistent with the overall focus in the illustrations on sequencing the activities. The student comments and ideas that get included are in support of the instructional model. For example including a few of the student ideas about the moon and the questions they have about it shows that that instructional prompt generated what was needed for what follows. A particularly clear example of this comes from another of the vignettes in the *Inquiry* supplement, the 9-12 physical science vignette. In it a high school physics teacher, Mr. Hull, is beginning a unit on force and motion. He begins by soliciting student ideas about force and recording them on the board. Then he moves onto the next activity.

Mr. Hull wanted his students to be able to represent their understanding of forces, so he guided them in crafting their representations. He said: “It sounds like several of you are thinking of force as a push or a pull. What are some properties of pushes and pulls?” A student noted, “They are in a certain direction and they have a certain size.” “So force is a vector” said another student. Vector representation had been a part of an earlier unit on describing motion, and the students recognized a new context in which the idea applies.

Mr. Hull queried, “It sounds like vectors might be useful for representing force? How would you use them to represent forces?” (p. 60-61)

In this vignette Mr. Hull is in the midst of a sequence of activities intended to get students to confront a common, but incorrect view of the forces acting on an object at rest, like a book lying motionless on a table. Along the instructional way it is useful both as a step in the sequence and as a learning goal in its own right to make a connection between forces and vectors. In the cited portion above the student comments provide a bridge between the steps in the sequence. Essentially it is necessary to show that the students ‘get it’, there needs to be some statement that implies or states the activity has been a success. In this particular case the students need to recognize that force is a vector before they move on to the next activity, discussing how vectors can be represented graphically. So the included student ideas in the vignette merely facilitate the description of the sequence.

It is difficult to imagine students in Mr. Hull’s class not saying other things as well in response to his open-ended query about pushes and pulls unless his question is intended as a prompt to recall the conclusions of a recent class activity, and the vignette does not indicate this is the case. For example, it would be unsurprising to hear a student respond, “Pushes and pulls take energy”. But student ideas that do not contribute to the intended flow of the instructional sequence are not included.

The brief quotation from the account of Mr. Hull’s physical science class is typical of the kinds of included student comments in the illustrations provided in the *Inquiry* supplement. In addition there are many instances where the text of a vignette simply states that the students ‘get’ whatever the intended point of an instructional step is without any indication of what the students do or say that supports this apparent interpretation of the teacher. The middle school moon vignette frequently uses language

like; "...students recognize...", "They [students] are amazed to discover...", and "The students agree...". So the included student ideas and activity in these vignettes serve to show that the instructional sequence is successful.

The vignettes do little to prepare teachers to support student inquiry

The emphasis on instructional sequencing and omission of descriptions of what students do together imply a view of what is central to good science teaching – namely that good science teaching, at least for the beginner, is fundamentally about engaging students in the correct activities, in the correct sequence. By focusing the reader's attention on the teacher's actions and the particular sequences of activities they employ, accompanied by only minimal descriptions of student ideas and reasoning, the implied message is that good teachers know in advance what sequence of activities will successfully achieve the learning goals. But this is an inadequate representation of what makes a good science teacher.

In the vignettes the students appear intellectually passive, they are shown as receivers of instruction rather than intellectually active participants in their learning. Student achievement of learning goals is represented as a series of quick, relatively simple realizations rather than as wrestling with ideas. Consequently, the teaching appears quite straightforward. Teachers implement the instructional model and the learning goals follow. To a teacher experienced in trying to create these kinds of classrooms the illustrations in the vignettes feel scripted and overly simplistic. They do not communicate a sense of what such a classroom feels like. The teachers in them ask open-ended questions that should elicit a wide variety of plausible ideas from students. Such questions set up opportunities for rich student discussions about these ideas and can

serve as important instructional moments for progress toward both conceptual content and student inquiry goals. But the vignettes provide no description of such discussions.

In a chapter addressing the research base that supports the view of learning and teaching in the *Standards*, the *Inquiry* supplement identifies six research findings about learners and learning, among them that (a) “students build new knowledge and understanding on what they already know and believe”, (b) “students formulate new knowledge by modifying and refining their current concepts...”, and (c) “effective learning requires that students take control of their own learning”. (p. 117-119) This view of active learners building new understandings based on existing understandings is not a focus of the vignettes. This is a problem because this view of active learners has implications for teaching practice, and these implications are at odds with the view of teaching presented in the vignettes.

In the literature of and about the *Standards*’ view of science education there is an oft-articulated view that good instruction involves teachers paying attention to what is going on in the instructional moment and being responsive to students through their instructional decisions. The *Standards* states: “Successful teachers are skilled observers of students, as well as knowledgeable about science and how it is learned. Teachers match their actions to the particular needs of the students, deciding when and how to guide – when to demand more rigorous grappling by students, when to provide information, when to provide particular tools, and when to connect students to other sources.” (p. 33) In a paper that aims to characterize what good science teachers know, Barnett and Hodson (2001) characterize good science teaching like this: “...teaching is a complex and uncertain enterprise in which teachers are required to ‘think on their feet’

and to constantly adjust their approach in order to ensure satisfactory learning progress for their students.” (p. 428) The consistent message across this work is that good science teaching involves close attention to students and flexible instruction that is responsive to assessments of the student activity.

The *Inquiry* supplement supports this view in a chapter on the role of assessment and makes a strong case for the role of formative assessment in support of the *Standards’* learning goals. Formative assessment is done along the way in a lesson to “...influence a teacher’s plans to meet specific student learning experiences and needs.” (p. 76) It goes on to note “...teachers in inquiry-based classrooms are continually assessing to know what to do next, what abilities are developing, which are still underdeveloped, and whether the objectives of a particular lesson or unit are being achieved.” (p. 76) In the section on formative assessment the *Inquiry* supplement emphasizes that simply listening to students provides useful insight into how the students are doing. In the view of a learner as intellectually active, formative assessment is an important aspect of teaching practice because it is important for a teacher to understand how students view the meaning of some activity, rather than to assume that students understand the meaning that the activity intends. By not providing detail about student ideas and reasoning the vignettes run the risk of being interpreted to mean that little attention need be paid to the students as long as the activity sequence is followed.

To be fair, the vignettes state that the teachers they depict are doing these things, and there’s no reason to doubt that they are. But because descriptions of what that looks like in a classroom are not included, there’s no way of knowing what the teachers see that provides insight into how things are going. For example in the vignette that describes

Mr. Hull's 9-12 unit on forces and motion the analysis at the end of the illustration says, "Through class discussion, Mr. Hull was able to evaluate student thinking and use this information to help structure the flow of the lesson." (p. 65) It states Mr. Hull did formative assessment, but the vignette's description of the classroom includes no indication of what evidence he based that assessment on or how an assessment he made resulted in some insight that allowed him to better structure the lesson. Mr. Gilbert's unit is analyzed this way in the section on formative assessment: "Mr. Gilbert listened as his students constructed their models of the earth-sun-moon system and asked questions to assess and further their understanding." (p. 76) But the vignette does not adequately describe this. It begins by stating what evidence Mr. Gilbert uses to make such assessments, the students' words and their drawings, so it is disappointing that no elaboration of those things are included.

Formative assessment is intended to inform a teacher's decision about how to proceed. This implies that teachers make instructional choices along the way based upon how students are doing; they modify their instruction to meet the needs of the learners in their classroom. In the section that characterizes appropriate instructional models and their role in instruction, the *Inquiry* supplement says this: "Teachers and others can be mislead into thinking of [instructional models] as lockstep, prescriptive devices – rather than as general guides for designing instruction that help learning to unfold through inquiry, which must always be adapted to the needs of particular learners, the specific learning goals, and the context for learning." (p. 35) However once again, though this is stated, the descriptions of classrooms provide little to help a reader understand on what basis or how an instructional model might be adapted. What could it mean to adapt an

instructional model to “...the context for learning...”? How is it supposed that teachers will develop the ability to adapt instructional models to “...the needs of particular learners...”? How do we expect teachers will get insight into these needs? These are imprecise phrases, open to a wide variety of interpretations, and so of little use in helping a teacher understand a basis on which a decision to adapt an instructional model might be made in the absence of some descriptions that help provide a sense of what it means.

A dominant focus on instructional model is both reasonable and unproductive

There is an easy response to the criticism the vignettes focus largely on instructional models at the expense of other important classroom features. For teachers who are just beginning to change their teaching practice, the intended audience of this document, a productive path is to first focus attention on the use of instructional models that are consistent with the characteristics of student inquiry. The focus on instructional sequence is intended to get them going and then they will gradually become more skilled at attending to student activity and refining their instruction as they become comfortable.

The *Inquiry* supplement (NRC, 2000) includes a teacher’s reflection on using an inquiry curriculum for the first time. (p. 106-108) In commenting on the reflection the supplement says:

Sandy’s story is likely to continue as she and her colleagues repeat the same units with new students the next year. As they increase their comfort with the materials, they will be able to focus on student thinking and learning and adjust their questioning, probing, and elaborating to deepen students’ understanding. (p. 108)

The presumption is that in the first year using the curriculum the teachers must focus primarily on the activities themselves. Another place one encounters such a view is in Trowbridge and Bybee’s (1990) science methods textbook. In discussing the role

instructional models play the text notes "...there are both planned and flexible components of instruction." (p. 303) It then elaborates:

The next section outlines models that will help you organize for effective instruction. These constitute the planned sequence of instruction. The flexible component is something you will develop with experience in science teaching. (p. 303)

But how will teachers develop it? Trowbridge and Bybee provide no insight. Their view is apparently that it will naturally happen as the new teacher begins to teach science. The tacit view of the *Inquiry* supplement appears to be the same. There is an acknowledgement that good teachers attend to what the students are doing and make instructional choices based upon that attention. But no insight is provided into what kinds of things good teachers attend to in their classrooms that allow them useful insight in making their instructional choices.

There is a reasonable basis for this view. In characterizing a generalized progression from novice to expert Dreyfus and Dreyfus (1986) observe that experts are quite flexible and sophisticated in how they engage in the activities associated with some skill. The development of expertise arises through engaging in the practice, and to begin to make progress novices initially require a clear, largely context-free set of rules that allows them to begin to engage. These rules serve to help them get the right thing going so expertise can begin to develop. For example when someone is learning to drive a stick-shift car they might be told, "Start in first gear. When you get to 10 mph shift into second gear. At 25 mph shift into third." And so on. A novice driver then develops expertise by spending time driving. They begin to see that these rules aren't always quite right. For example, when driving up a steep hill one shifts into higher gears at a little bit

higher speed. Soon enough her ability to shift becomes quite flexible. Eventually she is so skilled she can adapt to unfamiliar driving situations.

The tacit assumption of the view of Trowbridge and Bybee and the *Inquiry* supplement may be that learning to teach science in support of student inquiry is analogous to learning to drive a stick shift car. The focus in the vignettes on the context-free rules, on the instructional sequence, is what a novice requires to begin the process of becoming an expert science teacher. As the teachers begin to utilize those rules they will naturally develop teaching expertise.

Dreyfus and Dreyfus' characterization of the progression from novice to expert is consistent with novice-expert studies in many fields. And in arguing that the vignettes are poorly constructed to support teachers changing their practice I am not advocating we should ignore instructional models. Rather, the illustrations need to pay attention to more than *just* instructional models. It is useful to return to the stick-shift analogy to clarify this point. When one is learning to drive there is no ambiguity about what the purpose of the activity is, to get the car to move. If the novice driver is doing well or poorly she knows it, based on whether or not the car is moving. If she does something badly the car stops; there is unambiguous feedback upon which driving expertise can develop.

In the case of teaching in support of the learning goals of the *Standards* there are reasons to believe the feedback regarding the quality of the practice is less clear to the novice teacher than to the novice driver. As the *Standards* notes, typical school science practice is based predominantly on students demonstrating they have acquired canonically correct bits of knowledge. Teachers familiar with those learning goals, in either the role of a learner or a teacher, are likely familiar with some ways to assess

students' progress. In the analogy they have a sense of whether or not the car is moving when the goal is simple acquisition of canonical content.

But in its review of the research on learning the *Inquiry* supplement points out there is strong evidence for the claim "Understanding science is more than knowing facts." (p. 116). And the *Standards* (NRC, 1996) includes learning goals for students abilities to engage in student inquiry and come to understandings of scientific inquiry in addition to its conceptual content goals. Since these goals are largely different from what most teachers are familiar with there is reason to doubt teachers will know how to assess whether *that* car is moving. There is research that demonstrates many science teachers have views of scientific inquiry as naïve as their students (Lederman, 1992, Abd-El-Khalick & Lederman, 2000) and even preservice teachers with bachelors degrees in science begin teacher training programs largely unable to conduct investigations with important parallels to scientific inquiry (Windschitl, 2004).

If someone has a sense of the goal of an activity then work like Dreyfus and Dreyfus (1986) gives us reason to think that given some rudimentary description of relevant practices an individual will naturally begin to progress toward more expert like abilities. But in the absence of a clear idea of the goal there is no reason to doubt they will make such progress. And we should expect this is the situation many science teachers and preservice science teachers find themselves in. Given this, there is a need for documents like the *Standards* and the *Inquiry* supplement to illustrate the goals. The *Standards* spells out in detail what the various goals are, but what do they look like in the classroom? This is a role that the vignettes are well suited to play. It is important to

illustrate this characteristic of classrooms for teachers, administrators, and professional developers who desire to align classroom instruction with the *Standards*.

In some sense this is an issue of framing, to use the language of the preceding chapter. Teachers come to teaching situations with expectations about the goals of the activity and their roles in relation to those goals. They also have expectations about learners and learning. There is evidence to suggest that some teachers' common framing of teaching science is unproductive in a similar sense to how the previous chapter argued student framing can be unproductive. One way to think about the vignettes is to view them as an opportunity to help teachers re-frame the activity of teaching. To consider using them in a way that could help to activate more productive expectations about teaching. Thinking of the vignettes in relation to teacher framing also raises the issue that they may unintentionally reinforce the common, unproductive teaching expectations teachers have. If they do that then they not only don't help, but they may make the task of changing practice more difficult. In that case the vignettes are more than unproductive; they are counter-productive.

A dominant focus on instructional model is counter-productive

The argument up to this point is the vignettes fail to provide important, necessary support for readers, that the vignettes are unproductive as the heading of the previous section points out. But there is a stronger argument to make about the vignettes regarding their potential impact on teaching practice. Not only are they unproductive, but also there is a risk that they are counter-productive.

Counter-productive conceptions of pedagogy

Constructing the vignettes this way can negatively impact teacher conceptions of what constitutes pedagogy. Research in teacher professional development documents that when practicing teachers discuss what they notice in classrooms they overwhelmingly focus on teacher actions, even when there is evidence of significant student reasoning present. (Sherin & Han, 2004; Sandoval, Deneroff, and Franke, 2002) This work finds it is challenging to engage teachers in discussions of student ideas and reasoning in the classroom. This is problematic from the standpoint of professional development, where the aim is to help teachers refine their ability to attend to student ideas. The vignettes in the *Inquiry* supplement present an opportunity to model this kind of pedagogical attention, but instead they present a characterization of pedagogy that is consistent with common pedagogical rhetoric of teachers that focuses on teacher actions. The lack of attention given to students may serve to reinforce the notion that pedagogy is comprised by teacher actions.

The concern is teachers consider pedagogy to be fundamentally about the things that they do and the activities they guide students through. This is a subtle point. I am not arguing that teachers should not guide students. But that guidance should be justified by what goes on in the classroom. In contrast a curriculum developer justifies an instructional model *a priori*. For example the *Inquiry* supplement justifies its instructional model based on alignment with the five essential features of inquiry. Other models are justified on a psychological or an empirical basis, they align well given what we know about how people learn or the sequence worked well in test-classrooms. But for teachers the sequence of activities they implement in their classroom needs to be justified

by what goes on in the classroom. It is reasonable to begin with a plan that plan that is justified in some *a priori* way. This leads us to hope it will work well in our classroom. But we cannot assume that it will work well. Thus there is a need for teachers to be attentive to what students are doing in their classrooms and have an understanding of what is desirable student activity on which to base decisions of how to proceed. (Black & William, 1998; Akins & Coffey, 2003)

Of course different teachers will be more or less skilled in their ability to do this. And it is plausible that inexperienced teachers will tend to be less skilled. What classroom illustrations can do to support this goal is provide descriptions of classrooms that include significant attention to how the teacher justifies her or his instructional choices. Be clear about what they attend to – model exemplary teacher attention. Along the way they can begin to communicate what desirable student activity looks like in a classroom and how a teacher may leverage that in pursuit of learning goals associated with student inquiry.

In the absence of this sort of description, the view that pedagogy is comprised by the activities may be understood as implied, especially for readers who bring such expectations to reading them. Among the meanings of ‘inquiry’ in the *Standards* is one that refers to instructional strategies; what I call inquiry pedagogy. The distinction here can be understood as the difference between a narrow view and a broad view of inquiry pedagogy. In the narrow view inquiry pedagogy refers to instructional models, particularly those that are seen as consistent with the *Standards* learning goals. In this view it is the implementation of these models in the classroom that results in the learning goals. In contrast to this view is a broad understanding of inquiry pedagogy that refers

not only to instructional models, but also the many other things teachers can do to collect information that facilitates their flexible instructional response. In this view instructional models are tools teachers use in the process of supporting learning goals, and the tools a teacher might use are not limited to inquiry instructional strategies. In the narrow view, the instructional models are central; in the broad view, the decisions teachers make in support of learning goals are central.

We want teachers to conceptualize inquiry pedagogy broadly, to think about teaching in support of student inquiry goals as more than the implementation of instructional models. Much of what the *Standards* and the *Inquiry* supplement say about teaching supports this view. The *Standards* has this to say regarding pedagogy:

Although the *Standards* emphasize inquiry, this should not be interpreted as recommending a single approach to science teaching. Teachers should use different strategies to develop the knowledge, understandings, and abilities described in the content standards. Conducting hands-on science activities does not guarantee inquiry, nor is reading about science incompatible with inquiry. Attaining the understandings and abilities described in Chapter 6 cannot be achieved by any single teaching strategy or learning experience. (p. 23-4)

This clearly distinguishes what it is hoped teachers will do in support of student inquiry from any particular instructional model. Unfortunately both the *Standards* and the *Inquiry* supplement are imprecise in their language regarding inquiry pedagogy – often using the term ‘inquiry’ to refer to specific instructional models and at other times being ambiguous. Coupled with limiting the focus of the vignettes to what the teacher does and says, without insight into how activity, particularly student activity, in the class influences instruction, the vignettes provide a simplistic view of the teaching practices that the *Standards* views as necessary to achieve the student inquiry learning goals. In the absence of this kind of information there is a risk that a reader will conflate an instructional model with teaching that supports student inquiry. That is, they will think

that what a teacher needs to do to support student inquiry is simply use an inquiry instructional model, and then quality student inquiry will be a consequence of that correct sequence of activities.

Counter-productive conceptions of what constitutes good student inquiry

In the absence of illustrating what good student inquiry might look like in a classroom the vignettes run the risk of inadvertently communicating to readers that the acquisition of correct conceptual understanding is a reasonable basis on which to assess the quality of student inquiry. This problematic view is made more likely by the fact that the students in the vignettes always seem to get the right answer, implying to a reader that students who are capable of engaging in good student inquiry will arrive at correct answers. This is rather odd, as the history of science is full of examples of well-known scientists who got it wrong from time to time, despite doing good inquiry. (Darden, 1998) The fact that the instruction always works out presents a version of classrooms that is not only unrealistic but also misleading. There is practitioner research that points out teachers should expect there to be moments in the classroom when the conceptual content learning goals and inquiry goals are at odds. (Hammer, 1997; and in mathematics Ball, 1993) This work suggests that as teachers begin to be able to ‘see’ good student inquiry in their classrooms they will encounter moments when the students are doing good inquiry but come to conclusions that are not consistent with canonical knowledge. The illustrations need to be clear that good inquiry and correct conceptions do not always go hand in hand. How teachers negotiate these moments when they arise is an important issue for supporting student inquiry goals, and teachers need to anticipate they will arise and be prepared to negotiate them. If a teacher always comes down on the side of

correctness then the tacit message to students is that conceptual correctness is the thing that is truly valued in instruction, and the student inquiry goals are just window dressing.

Counter-productive conceptions of learning

An argument for teachers to be attentive to student ideas and reasoning in the moment is the basic constructivist tenant that learners are not passive receivers of knowledge but active constructors. Therefore, there is a need for teachers to be attentive to what meaning students make of the activity in classrooms rather than presume that students who engage in an activity will understand it to mean what the teacher or curriculum designer intends them to understand. The vignettes' thin description of student ideas and reasoning coupled with the fact that the students are routinely represented as quickly understanding the intended meaning of activities paint a picture of learning at odds with the constructivist characterization of learning spelled out in the *Inquiry* supplement. In the vignettes, students are shown complying with the sequence of activities the teacher instructs them to engage in and then 'getting it', with little evidence of an active role in constructing their understandings. In two of the four vignettes in the *Inquiry* supplement, students do play some active role, selecting the particular question they ultimately investigate. Presumably this is seen as a mechanism for enhancing students' interest in and sense of ownership of the investigation. While this is a desirable attribute of student participation, it does not diminish the fact that the vignettes fail to represent students as constructors of their own understandings, and this presents an overly simplistic view of learning.

In addition this view under-represents what students, even quite young ones, are capable of with respect to student inquiry. There is research literature that documents

some of the relatively sophisticated abilities students have to engage in and guide their own student inquiry. (May, Hammer, & Roy, 2006; Rosenberg, Hammer, & Phelan, 2006; Louca et al, 2004) This is not to argue that young students left on their own will engage in high quality student inquiry. Rather, it supports the view that students are capable of some of the things that we think of as elements of sophisticated scientific inquiry. Teachers can encourage these abilities if they observe them in their classrooms. An important role classroom illustrations like the vignettes could play is first providing descriptions of some of the productive things young students can do and then showing how teachers encourage them. By providing the simplistic view of learning the vignettes imply that students bring few if any productive resources for guiding their own student inquiry and require significant scaffolding/direction to be able to engage in it productively.

An alternative image of student inquiry

What follows is an example of an alternative image of inquiry, one that aims to provide a better sense of what the students in a class do, what evidence the teacher sees of good student inquiry, and how the teacher makes decisions about what to do based on attention to student ideas and reasoning. The episode I use here comes from a teacher, Mary Bell, who was participating in a project that aimed to produce teacher-authored case studies of K-8 students' reasoning about the physical sciences. In addition to the video and transcript of the class this illustration is informed by a draft case study Ms. Bell wrote, though this episode was not included in the published set of case studies that is the product of that project. (Hammer and van Zee, 2006) The descriptions of the teacher's

attention and decision-making are largely drawn from that case study.¹¹ While the events of the class are edited, omitting some portions of the discussion, and paraphrasing others, the portions of transcript that are included are not edited. They represent the actual events of the classroom. The episode comes from a fourth grade classroom where Ms. Bell was not the regular classroom teacher but regularly co-taught reading, science, and math with the classroom teacher. Ms. Bell is a Special Educator and Reading Recovery Teacher and was assigned to co-teach in this class because all twenty-six students tested below grade level in reading at the beginning of the school year.

Ms. Bell was beginning a unit on the solar system, and chose, as she usually did in such situations, to start by posing a lead in question and giving them some time to think about it and discuss it as a class. In these discussions Ms. Bell tried to find questions about the causes of phenomena she thought students might have a variety of ways of explaining. She used these discussions as an opportunity to get some insight into what ideas about the topic students had, and also to assess their progress in reasoning scientifically. From the very beginning of the school year the students seemed to enjoy the discussions. But for much of the first half of the year Ms. Bell was not satisfied with them. Initially the students were happy to offer their own ideas about how things might work, but rarely paid any attention to the ideas of their peers. Ms. Bell knew that science was about more than proposing ideas, it was also about assessing whether or not the idea

¹¹ This is a situation where the expectation that a dissertation have a single author is at odds with the reality of the work. To provide the kind of description of this episode needed I must write about what the teacher noticed and thought, but this teacher isn't me. However, I have access to something she wrote that describes some of that. Typically I would do this by quoting directly from her case study and denote those quotations in the usual way. But in this case that would be cumbersome, and still would not fully acknowledge the extent of the influence of her case study on what is in this chapter. So this footnote serves to acknowledge the significant role Mary's case study played in informing this description, identifying her as co-author of this portion of the work in fact if not in name.

was a good one, or which idea among several was the best. So she frequently modeled the kinds of questions she wanted the students to ask, and often explicitly prompted them to consider an idea another student proposed.

During December, the students began to occasionally question one another during the discussions without prompting. Ms. Bell began to see evidence they were listening to each other's thoughts, agreeing or disagreeing with them and feeling comfortable about expressing their own conclusions about other students' ideas. She was happy about what was taking place but wanted the students to do more. She wanted them to continue their good thinking but also to use this thinking to develop a theory that would stand up to the scrutiny of their peers. She wanted them to feel free to express their ideas, think about these and other ideas, "punch holes" in ideas if they could, and develop lines of reasoning that would lead to scientific principles.

The unit on the solar system was to begin in the first week of March, and among the conceptual learning goals for the unit was to understand what causes the moon's phases. Ms. Bell thought a good question to propose to the students in the opening activity was "What causes a full moon?" In part she felt this was a good question because it was a question she and the students discussed previously, and posing it again would give her some idea of how far they had come in being able to make progress in these kinds of discussions. The preceding Halloween happened to coincide with a full moon. Since there was much discussion of this fact around that time Ms. Bell chose to ask this very question in class on Halloween day. At the time the students came up with lots of ideas; the planets surround the moon and give it light, the planets line up behind the moon and give it light, the moon reflects the sun's light, the sun's light surrounds the

moon like a fog, and the moon is like a street lamp and gives its own light. But in that earlier discussion Ms. Bell found it difficult to get the students to think about whether these ideas were reasonable, or to consider which ideas were better than others. She asked the students many questions about the ideas, and they would answer her, but did not question one another. At the end of that class Ms. Bell simply noted to the students that the different possibilities students brought up could not all be true.

Ms. Bell began the class in early March by telling the students they were going to consider the same question they discussed the previous Halloween. She had the sense from looking at their faces that most of them did not remember that discussion, but she was not terribly concerned by those who appeared to. There had been no lessons since then that would have answered the question, so they'd still have to think their way through the question.

Before talking about the question Ms. Bell gave the students five minutes to draw or write down their ideas about it. She commonly did this to both give the students an opportunity to think about the question before talking about it and it also gave her some data to see how their ideas changed as a result of the discussion. She would ask them to do the same thing again at the end of the discussion. Once the five minutes was up Ms Bell asked for their ideas. Several students raised their hands and she called on Henry.

Henry: I think what makes a full moon is, um, like-like when it gets dark the sun goes behind the moon and, um, and when it reflects against the moon but sometimes the sun will move and that's what makes a half-moon too.

Teacher: Okay, the sun is behind the moon, where is the earth?

Henry: The earth, uhm, is in front of the moon.

Ms. Bell was a bit confused about what Henry was thinking. She asked him to come to the blackboard and draw a picture of his idea. This was something she occasionally did if she thought it would help a student to explain his or her idea. While Henry was at the board a second student, Calvin, was called upon and began to explain a different idea.

Calvin: I think it's the sun and its ray reflecting on the moon making it (inaudible word) and the moon's ray reflecting the earth.

Teacher: Okay, let's take a look and see how Henry's drawing this, and see if you agree with this.

Calvin: Can I draw mine?

Teacher: Hold on. Okay, why don't we use "s" for sun. Put an "s" on where the sun is. Where is the moon? And where's the earth? Okay. Now, Henry's saying here's the earth, we're on the earth. You can sit down. Here's the moon, and the sun is kinda behind the moon and that's what lets us see a full moon. Do you agree with that, Calvin? What do you say?

Calvin: I said the sun is on both sides, the moon is...

Teacher: Okay, come up and draw yours. We're going to number this number one. Okay. Number two.

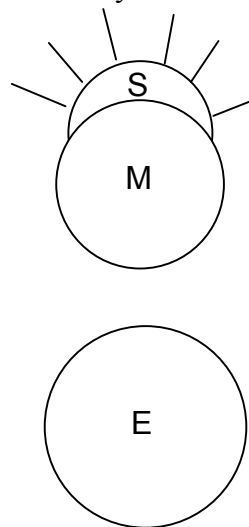


Figure 4-1: Henry's diagram

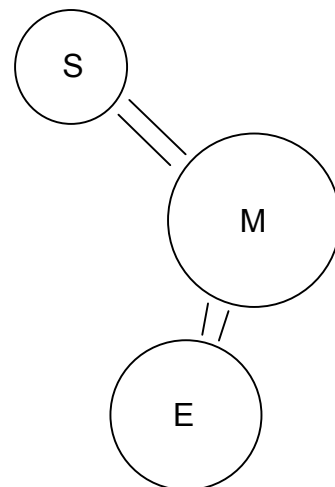


Figure 4-2: Calvin's diagram

Ms. Bell asked Calvin to wait to draw his idea for a couple of reasons. First, she didn't know exactly what his idea was and wanted to be sure it was different from Henry's. And second she didn't want the lesson to become a drawing spree. She wanted to take the diagrams one at a time, carefully label them, and try to make sure students understood them. The point was to use the diagrams to further the class discussion about the different ideas. When Calvin finished his diagram and labeled the sun, earth, and moon Ms. Bell asked him to explain his diagram.

Teacher: Calvin, explain yours.

Calvin: The sun, moon, the sun is formed, is shining on the moon and the other side is dark, so...

Teacher: You mean behind the moon? Okay, and this side's light.

Calvin: It shines on the other half of the earth, on the other side, and the sun shines on the side we are in.

Teacher: Okay, so you're saying that the sun is shining on the moon and the moon's reflecting? And, we can see it from the earth. Dominique?

Calvin was struggling a little to explain his idea. But his words and gestures indicated that he was distinguishing between the lit side of the earth (day) and the unlit side (night), as well as a lit and unlit side of the moon. He didn't explicitly say day and night, but his phrase "the other half of the earth" appeared to refer to the night side. The "It" that shines on this other half refers to the moon, not the sun, as his gestures to the parts of his diagram made clear. Calvin's idea is that the sun lights up the moon, which then shines on the dark part of the earth. Ms. Bell recognizes that this may be an indication Calvin thinks we only see the moon at night, which isn't the case. But that he is introducing the idea that the sun only lights up half of the earth and moon is an important idea. As she often does, Ms. Bell restates and hopefully clarifies what Calvin

says, both for his benefit and the benefit of other students. While she is doing this Dominique raises his hand and Ms. Bell calls on him.

Dominique: I have a question. I agree with Henry but I have a question about like what Henry and Calvin said.

Teacher: Okay

Dominique: Okay, like for Henry, when you said that when you have the moon...when the sun's behind the moon and then like when like when sometimes when there's a full moon, like when there's a half moon or a full moon, how do we get to see the half moon and the full moon? And then, like, the one about Calvin, well like some of the places in the United States still have the same moon, so how could there be one half side and then we... because if the sun was just like right there, we could see all of it. It would just be showing everyday that the moon was full. But, I don't see how it could show a half moon if its in behind and it's sometimes moves on the east or it's on the west.

Teacher: Okay, so Dominique brought up a good question. He's trying to figure out, okay, if you're saying this is how we see the full moon, how are we going to see like a half of moon, which is exactly what we see now in the sky?

Dominique's questions pleased Ms. Bell. Without any prompting Dominique was paying attention to the models that Henry and Calvin introduced and asking questions about them. He appeared to be using the models to try and explain not only the original question about possible causes of a full moon, but now also wondering how these models would also explain the moon's phases. He was doing more than thinking about Ms. Bell's question, he was also beginning to ask his own related questions, evidence to Ms. Bell that Dominique was becoming invested in this discussion.

Another student, Kyle, raised his hand while this was going on. When Ms. Bell called on him he had difficulty expressing his idea and asked to go to the board. While he was drawing his diagram Ms. Bell called on another student.

Teacher: Okay, number three. While Kyle's drawing, and then he'll explain it, Ariel, what did you have to say?

Ariel: Um, I have – I agree with Dominique because like-like, I want, cause how if we're going to see the half moon if the sun is goin' towards the moon and when it's half how we gonna see, like, how we gonna see it? It might have to be...

Teacher: Okay, so you're kinda-you don't-you're saying that they're saying that the sun's shining on that moon, right? And it's reflecting to us. And how come sometimes we only see only half a moon? Dominique and Ariel want to know that. So, Henry, come back up here.

Since Ariel was the second student to voice this question Ms. Bell decided to ask the students who proposed the ideas on the board to address it. She had hoped that Calvin or Henry would offer answers to Dominique's questions without prompting, but now that Ariel asked the question again it seemed to her like the time to step in and explicitly ask them to respond. Since Henry was the first to draw a model she asked him to respond first. Ms Bell also remembered that when he explained his model Henry mentioned the half-moon, and so she thought he may have an answer to this question already. Henry walked up to the board and surprisingly began to use Calvin's diagram to explain what causes a half moon.

Henry: Um, well, what Calvin kinda drew is like a half moon, because what happens when it's on the side of the moon, only the sun shines on one part, and then that's the shadow, and that's what makes a half moon.

Teacher: So the sun-you're saying that the sun... Henry's I think saying – and correct me if I'm wrong – that the sun shines on certain places on the moon and that's how come sometimes we see a full moon, and sometimes we see a half. Is that what you're saying?

Henry: Yeah

Henry's explanation using Calvin's diagram seems to indicate that he has something like a correct idea; he gestures at the moon in Calvin's diagram indicating where the sun is shining on it and where the "shadow" part is. So Henry's idea appears to be when the sun is behind the moon it appears full, and when it's off to the side of the moon the moon is half. Dominique has been listening intently to Henry's explanation and has a question for him. Dominique walks up to the board to be able to gesture at Calvin's diagram to better explain his question. One of the interesting things evident in the video of this episode is that most of the students in the class appear to be paying close attention to this interaction between Dominique and Henry.

Dominique: Um, what I have a question to ask, Henry, is like when you - can I go up, kinda like explain. Like when you said that, um,...

Teacher: Remember, that's Calvin's.

Dominique: Okay, when you said, Calvin, and Henry when you came up here just to say like it's half moon, well, the sun would just like really be tilting, so the moon would just be right here in the sun, but just like kinda like tilt the moon so – you know graze over. It wouldn't do anything. It would just stay there.

Unidentifiable Student: Yeah, that's what I'm talking about.

Henry: Actually the moon would not stay there because if you ever, like, um, like used – see at night it goes behind the moon...

Teacher: Okay

Henry: ...so, the moon can reflect. Kinda like a mirror. The moon's kinda like a mirror. And, the sun would move behind and in the morning the sun comes up.

Ms. Bell struggles to understand what precisely about the model Dominique is objecting to. It's evident to her he is trying to explain how he sees some aspect the model as lacking, but precisely what that feature is she can't make out quickly from what he says and does. She values clear articulations of all student ideas, they are necessary for the kind of discussion she wants the students to have about the ideas. So, for example, we often see her repeating back a student's idea in an effort to make it clear. One possibility for her in this moment is to take some time and try to help Dominique clarify his idea for both himself and for the other students. In this instance though she chooses to hold off on that. Ms Bell brought some manipulatives along with her to class in anticipation they would help students test out different models, various balls for the earth and moon and flashlights for the sun. She thinks that when the class gets to this part of the lesson she will try and look for an appropriate moment to revisit Dominique's question with him. Another thing Ms. Bell notices is that Henry's answer seems to have a contradiction. If the sun is behind the moon, and the moon reflects the light, then how could we see the light from the earth? It should reflect back toward the sun.

Teacher: Henry, how can you see the moon if the sun's behind the moon, and the moon's reflecting the sun's light?

Henry: How can we see the moon?

Teacher: Yes.

Henry: Because the moon's like, okay, say like the sun is the lamp...

Teacher: Uh-huh

Henry: ...and the moon's the lampshade...

Teacher: Mm-hmm

Henry: ...it makes it a little bit darker and you can look at it.

Henry's response is interesting to consider. While he is of course wrong, the idea is plausible. Certainly he's familiar with lampshades and how they work. Why couldn't the moon be a sort of a lampshade? Now Ms. Bell could, in this moment, choose to simply tell him he's wrong. But her desire is to help her students not only learn correct conceptual content, but also learn how to engage in good student inquiry. And specifically help them engage in inquiry in a way that complements their ability to learn conceptual content.

By one account Henry is doing pretty good student inquiry. When confronted with an inconsistency in his explanation he 'repairs' it by using his personal sense of how the physical world works to propose a physically plausible revision. We want students to rely on their understandings of how the physical world works as a basis for making sense of phenomena. Scientists operate this way as they struggle to make sense of new phenomena, and since we're trying to help students engage productively in activity similar to scientific inquiry we need to recognize this idea of Henry's as a step in that direction. Of course what is plausible to Henry is different from what might be plausible to a scientist, but that doesn't change the fact that both rely on their sense of how the world works. It is among the things we want Henry to learn about scientific inquiry.

In another sense Henry's student inquiry is lacking. He seems not to understand that he needs to consider the implications of his ideas in relation to other things he knows. That this is one way scientists use to gauge the relative merits of an idea. So Henry seems quite content in this moment, he has answered Ms. Bell's question in a way that is satisfying to him. And indeed, if the sun were behind a lampshade-esque moon

would see the moon light up. But Henry knows other things about the sun-moon-earth system that this explanation is inconsistent with. A hallmark of scientific knowledge construction is the search for consistency among ideas. So in this respect Henry needs some help in developing his student inquiry abilities.

Ms. Bell is interested in getting students to listen to and critique one another's ideas in part because she wants them to model for each other how to do this. There are times when she does it, when she thinks it needs to be done and doubts another student will do it, but there are also times when she hopes a student will take on this role. It is Ms. Bell's expectation that as this kind of interaction becomes more common students will begin to examine their own ideas critically, if for no other reason than to try and anticipate the kinds of questions their peers may pose to them. In this instance a student named Alisha takes on this role immediately after Henry's explanation.

Alisha: I disagree with of the pictures up there because how... If the sun's behind the moon, how can the other side of the earth, 'cause on the other side of the earth right now it's nighttime. So, how can it not, cause the sun's supposed to be on the other side of the earth when it's nighttime here...

Teacher: Mm-hmm

Alisha: ...and I think that the- when the sun's on the other side, it shines through...

Teacher: Okay, see what Alisha's saying? The sun – this side right here that's facing the moon would be daytime – is that what you're saying?

Alisha: And that would be night, and...

Teacher: Nighttime's over here. How are they seeing the moon full?

Alisha recognizes that Henry's model is inconsistent with how she understands night and day. She knows that night and day are caused by the earth rotating on its axis, a

concept she explained during the October conversation and one Ms Bell knows is taught in the first grade in this school district. When people are on the side facing the sun it is day, and when facing away it is night. But in Henry's model the side of the Earth that is being lit is also the side the moon is on, meaning the moon would not be visible to the people on the night side.

By this time Kyle has finished drawing his model and quietly returned to his seat. Out of the corner of her eye Ms. Bell sees the model and thinks it may add to the ongoing discussion, so she asks Kyle to explain his model to the class.

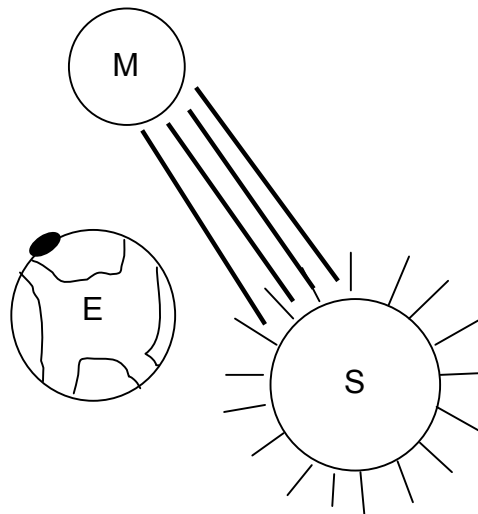


Figure 4-3: Kyle's diagram

Teacher: Kyle, you haven't gotten a chance to explain your drawing.

What are you saying?

Kyle: I'm saying that the sun's light goes and reflects the moon and the big [black] dot is where we are so we can see the full moon and the other side is having daytime.

Teacher: This is the daytime – the side that's near the sun?

Kyle: We're the nighttime.

What immediately struck Ms. Bell about Kyle's diagram was that he indicated where the observer was. It helped her realize that perhaps not all students were operating from such a clear understanding of where the observer was positioned, and what a student understood one of the diagrams to mean depended on where they thought the moon was being observed from. The diagrams that students were drawing could be challenging to interpret because the students had to imagine how the moon would look what if they were in the diagram. Ms. Bell had been interpreting the diagrams with that in mind, but that didn't mean all the students understood that was how they should think about them.

Ms. Bell thought this was a good time to introduce the manipulatives she brought. There were a couple of ideas that the students could use the balls and flashlights to start trying to model. It would also provide a break in the student discussion so she could explain to them that they had to imagine what the 'moon' ball would look like if they were very small and standing on the 'earth' ball. She told the students that she needed a minute to organize the things she'd brought along with her.

While she got the things ready the students continued talking to one another about the ideas that had been presented. Ms. Bell heard Leslie explain to Kyle that she disagreed with his idea because it looked like the sun was shining on half of the earth as well. Kyle replied that the sun did shine on the earth, and this appeared to confuse Leslie. She also noticed Dominique talking with Calvin, who sat next to him, about his earlier critique of Henry's idea. Calvin was interested, and Ms. Bell remembered it was Calvin's diagram Dominique and Henry had been referring to when they were up at the board together. Other students were talking about the ideas as well. What Ms. Bell noticed was that some of these discussions were exactly what she wanted the students to

be doing, listening to one another's ideas and trying to figure out if they seemed like good ones or not. She made the decision to put away the manipulatives and let the class discussion continue, her sense was that there was good student inquiry happening and she wanted it to continue.

Her decision was based on more than a sense that the students were quite engaged by this discussion, though that was a part of what played into her choice. Beyond that the three diagrams up on the board looked like a progression that was moving toward a correct model. While the specific question had to do with a full moon, Ms. Bell knew they would also want to explain the moon's other phases and this looked like a good beginning for that. So she saw some value in giving the students more time to continue talking about the good and bad parts of the models and hopefully she could help them continue to refine them. She also knew that in scientific inquiry there is a balance between theory and observation. This class discussion seemed like a good example of how students' theoretical discussions in the classroom might drive some observations they could make. Ms. Bell hoped that the discussion about models would progress to a point where there were two or more models different students were willing to defend, and then perhaps she and the students could think about observations that would help them decide which model was better than the other. She saw several ways allowing the discussion to continue would contribute to her learning goals for this activity.

So the class discussion continued, focusing on thinking about the implications of the different models, including a couple of new ideas. Among the things Ms. Bell did was help students make sense of the models that had already been presented. Two times students proposed what they thought were new models, but after explaining them and

with the help of Ms. Bell, comparing their idea to one of the diagrams already on the board they recognized that theirs was similar to one on the board. Toward the end of the period there were a few minutes left and Ms. Bell decided to quickly demonstrate a few of the ideas students still seemed willing to publicly defend. This was not ideal, as Ms. Bell had hoped to let the students do this work on their own in small groups. But she could begin the following lesson with that activity, and if nothing else this would model for the students what would be useful for them to do then.

Ms. Bell quickly led the whole class through a couple of the models. None of them seemed to work out just right and some students were confused about whether the balls indicated the different models were good ones or not. Some students complained about the flashlight not being a very good model for the sun because it didn't shine in all directions, which Ms. Bell acknowledged. In the midst of this Leslie raised her hand and asked to introduce a new idea. Ms. Bell invited her to describe it with the flashlight and balls rather than draw it. Leslie explained a model of the moon orbiting the earth, and identified a full moon when the moon is directly opposite the sun and a half moon when the moon is off to the side. Ms Bell was inwardly ecstatic, wanting to yell out "Look, she's got it! She's got the right model!" But in this particular situation Ms. Bell chose to leave it to the students to come to that realization on their own. She believed that many students had thought about it enough that they would see Leslie's model satisfied the criteria different students brought up. Since there were only a few minutes left there was time for a couple of students to ask Leslie questions about her model and then with Ms. Bell asked the students to write down on the other side of their paper their thoughts about

what makes a full moon. There was work to still to do, but Ms. Bell knew she would return to this in the next science lesson.

Afterward, Ms. Bell was amazed as she looked at the students written responses from the beginning and the end of the lesson. Before the discussion, four students drew something like Henry's model and six students mentioned that the moon reflected the light from the sun though did not include information about the relative position of the sun, earth, and moon. Those were the two most common responses: other answers varied from “the sun touches the moon when it is full”, to “the sun turns into the moon”, to “the molecules of two half moons touch”. In the responses from after the discussion, five students agreed with Henry’s model, one student agreed with a model that had the moon emitting its own light, four students mentioned the planets but wrote nothing conclusive, and eleven students drew a picture that more or less correctly indicated the positions of the earth, moon and sun during a full moon.

After looking at the students written work Ms. Bell decided to let the students to try out the various possibilities using manipulatives, though she made arrangements to have several overhead projectors in the room in place of the flashlights. The next day, the students were divided into groups and given balls. Ms. Bell got another idea when she talked with a colleague about her concern that students had to remember to imagine what they would see from the earth. She encouraged students to, literally, use their heads as the earth in their models. She explained to them that this was easier than imagining what they’d see, it was what they actually saw! It was fun to see the students’ excitement as they tried the various models. Although every group eventually made the correct model and saw a full moon and a half moon, Ms. Bell could tell that for some students

this wasn't enough. Some were hesitant in responding to her questions, or looked to their classmates for help. So Ms. Bell brought a computer and an LCD projector to the following class and showed the students an animation of the moon orbiting the earth on a website recommended in an NSTA article she had read. The students were able to see an enactment of what happens during the moon cycle with a running view of how the moon looked when seen from the earth. Then Ms. Bell lead them in a discussion of how their own models compared to the one shown on the website.

Comparative analysis of this image of inquiry and those in the Inquiry supplement

There are several important differences between this image of inquiry and those presented in the *Inquiry* supplement. Most notable are the inclusion of lots of student ideas and reasoning, and description of how the teacher's attention to that influenced what she chose to do. These are absent in the descriptions from the *Inquiry* supplement. Like the *Inquiry* supplement, this vignette includes descriptions of the teacher's actions, but those actions are clearly connected to assessments she makes about how the class is going. Again, this contrasts the descriptions of teacher actions in the *Inquiry* supplement that, in the absence of such connections, imply the instructional sequence is of primary importance in the teaching Mr. Gilbert does. In describing Ms. Bell's teaching practice the feature of primary importance is what the students do and how well they are do it. In the Ms. Bell vignette the instructional sequence is flexible and responsive to the students. We get insight into Ms. Bell's moment-to-moment formative assessment, and are provided a sense of how that assessment influences her instructional plan.

The inclusion of a significant amount of student discourse also shows what the beginnings of good student inquiry can look like in a classroom. This provides a sense of

what teachers should look for in their own classrooms. The students in this vignette are doing good student inquiry. They are listening to explanations proposed by other students and thinking critically and logically about the relationships between those explanations and the evidence they have available to them at this point in their investigation. Both of these are abilities necessary to do scientific inquiry in the 5th - 8th grade content standards. And the description of Ms. Bell's struggle over the course of the school year to get the students to where they are is an important message for readers as well. What we see the students doing is a result of Ms Bell's continued efforts over the course of most of a school year, not something that happened immediately.

This vignette also provides evidence of the aspects of student inquiry young students are capable of. We see them generating and evaluating explanations, often unprompted by Ms. Bell. And there is progress in their explanations toward more scientific sophistication. It is worth returning to the observation at the beginning of this vignette that this is a class of students who all tested below grade level in reading ability at the beginning of the school year. These are typical fourth graders, if anything they are on the low end of the academic achievement spectrum. It is important to communicate to readers that given the opportunity, any student is capable of participating productively in student inquiry.

Another important difference between this vignette and those in the *Inquiry* supplement is the view it presents of the learning process. In this vignette progress is a slow process that involves students grappling with ideas, trying to figure them out, and then considering the plausibility of them based on a number of criteria. There is progress evident in the vignette, the successive models different students propose form a sequence

that looks more and more like a correct model. This may be due to the criticisms that some students offer of the models along the way. In the vignettes of the *Inquiry* supplement understanding is usually presented as a binary system, either the students get it or they don't. And in those illustrations the transition from one state to the other is presented as a quick realization. Progress is shown as a properly sequenced series of these quick realizations. But as the research cited in the *Inquiry* supplement shows, substantive student learning is not a series of quick realizations. It is important that readers be presented with an image of the kind of progress they should expect to see in their classroom so they have a sense of what to look for as evidence that things are going well.

What actually happened in Mr. Gilbert's classroom could be similar to what happened in Ms. Bell's. The difference may lie in what gets emphasized in the two descriptions. The Mr. Gilbert vignette says at one point that "...interesting [student] discussions begin to occur." (p. 52) Those discussions may have looked a lot like the discussion in Ms. Bell's classroom, but no description of them is provided. To help teachers, administrators, and professional developers facilitate the kind of student inquiry we see going on in Ms. Bell's classroom, we need to help them understand what makes a student discussion interesting and productive, and vignettes like the ones in the *Inquiry* supplement are a place to begin to do that.

Chapter 5: Conclusion

Looking across the chapters

The three preceding chapters considered some classroom and professional development implications of working to support science students not only engaging in activity that “looks” like science in important ways, but also viewing their own activity as *authentically* making sense of natural phenomena. That is, the purpose of the activity is to arrive at explanations of the phenomena under investigation that are sensible and plausible. Notably for this work the determination of what is sensible and plausible is problematic in a science classroom, and this issue is introduced in chapter 2 through the concept of authenticity as it is used in the science education literature. The difficulty lies in the fact that there are two different possible arbiters of sensibility and plausibility “present” in a classroom, the students themselves and the discipline of science.

The chief problem that arises from this is that what is sensible and plausible to one might not be to the other. The goal for a science educator (whether teacher, curriculum designer, or researcher) is to help students come to understand how those within the discipline go about constructing explanations that are viewed as sensible and plausible within the discipline. So in this sense the discipline’s perspective is given a privileged status over the students’. However, there is a danger in interpreting this privileged status to mean that the disciplinary view of sensible, plausible ways to make sense of phenomena is the best view to take in all classroom moments. The danger is that when this version of sensibility is repeatedly imposed on students for whom the sensibility is not evident, some students may come to view science in undesirable ways;

whether that is coming to see themselves as people who can't do science, seeing school science as a process of memorizing facts and applying quantitative algorithms, viewing professional science as a straightforward process of applying a 'scientific method', or any combination of these.

Chapter 2 looked closely at this issue in the science education research literature that uses the concept 'authenticity' to refer to some desirable aspect of science student participation. Much of that literature cleaves quite nicely when one uses the distinction of which arbiter of sensibility and plausibility is considered primary, the students or the discipline. But to privilege one or the other presents problems, either the problems associated with privileging the discipline mentioned in the previous paragraph or the problem of placing too much emphasis on the student view and running the risk of communicating a poor version of what members of the discipline do. In that chapter I proposed a view of authenticity in which there is alignment between student and disciplinary views of sensible activity. This is a goal of science classroom activity, though not one that is possible in all moments, nor easily achieved in select moments. However, it serves as a description of what we are aiming for.

One of the more important challenges to this kind of authenticity is the way school can alter the meanings of disciplinary activities when they become a part of schooling. Students in science classes have expectations about school activity based on past school experiences that influence how they interpret the meaning of activity. Of particular note in is the observation that the purposes of 'typical' school activity are markedly different from the purposes of the activity of professional science. This is a

marked contrast to scientists whose activity is related to constructing explanations for natural phenomena.

One important implication of this concern is that the classroom teacher must play a central role in working to align the potentially differing views of the discipline and the student. While the curriculum designer can use disciplinary criteria to justify a curriculum *a priori* with regard to disciplinary standards, she or he cannot anticipate how a student or a group of students will understand the activity as meaningful, and thus a curriculum cannot be justified *a priori* as authentic with regard to the student. There are a variety of ways students can understand the meaning of an activity, and since we are interested in aligning student views of meaning with disciplinary views, it is instructionally necessary to be attentive to how the particular students in a classroom see the activity as sensible. Of course this is something a curriculum designer cannot do, and thus the teacher takes on a central role given this goal.

The third chapter focuses on the teacher's role in supporting epistemologically authentic student activity. Though it first introduces the notion of framing as a mechanism for how school can alter the meaning of disciplinary concepts and practices. This difference in framing the purposes of activity presents challenges to the teacher who aims to support student activity in science classrooms that is epistemologically similar to activity in science. In order for students to engage in activity that is authentic it is necessary for them to view the purpose of their activity at some level as constructing explanations of natural phenomena. For many students this requires a re-framing school science activity, and even when students frame activity productively it can be for short

periods of time, their productive framing functions as if it is unstable, and easily reverts back to the more robust, but far less productive framing of typical schooling.

Given this, a teacher's challenge in relation supporting productive framing is at least two-fold. Or characterized a different way, there are two sets of skills teachers require to support productive framing. First, there are skills needed to assess when students are framing classroom activity more or less productively. What does 'good' framing look like? What does 'bad' framing look like? In order to be able to support productive framing instructionally teachers must first assess how students are currently framing activity. The second challenge involves skills to be able to act instructionally in ways that support productive framing. Teachers are in the classroom with the students, they can take instructional actions that influence how students frame the classroom activity. In fact whether they are aware of it or not, their actions *do* influence student framing...for better or for worse.

It is these two challenges that really form the basis of the third chapter. After introducing the notion of framing and connecting it to existing literature on how typical schooling functions, the chapter focuses on one interesting episode from my own classroom to provide examples of what good framing can look like in a science classroom and how instructional actions can influence student framing, both for better and for worse. The chapter is provocative to some because it calls into question the conventional wisdom of science teaching. The chapter looks at an instance of schooling when the teacher, upon being prompted by students to correct what they perceive to be a simple error he made in writing down a familiar formula for the concept of density, questions the purpose for changing the formula rather than simply correcting the error. While the

students are technically correct from the perspective of how the scientific community defines density I argued that, in this instance, staying true to scientific definitions would move students away from scientific reasoning.

Because of that challenging the students' suggestion that the formula be corrected was a productive instructional response for those students. So in addition to attending to what evidence of productive and un-productive framing looks like, the paper also discusses the role teacher instructional decisions can play in influencing student framing.

After chapter 3 explores some science classroom implications of the view of authenticity presented in chapter 2, the question of how to prepare teachers to support this kind of authenticity in science classrooms follows quite sensibly, and this is the focus of chapter 4. The teaching described in chapter 3 is consistent with characterizations of reform science teaching in the research literature. Teaching science with the aim of supporting authenticity is 'complex', 'unpredictable', and necessarily 'responsive' to the needs of the students.

The chapter looks first at significant documents in the current science education reform literature (NRC, 1996; NRC, 2000) and argues that these descriptions are not only unproductive, but that they may actually be counter-productive. Those representations are compared with the view of science teaching as complex, unpredictable, and responsive and found to be not at all in line with that view. In contrast, they portray good science teaching as largely adherence to a prescribed instructional sequence that elicits ideal responses from students. There is no apparent unpredictability in these images of 'good' science classrooms, and while the descriptions include the rhetoric of responsiveness, few details are provided that give insight into how and on what basis the

teachers are responding instructionally. Not only do they fail to provide important supports for developing teachers' productive views of the practice of science teaching, but they may actually promote views of teaching (close adherence to instructional guidelines) that will discourage teachers from attending closely to what students are doing.

In contrast, what is needed to support teachers' developing productive views of are descriptions of teaching practice that make evident the complex, unpredictable, and responsive aspects of it, the kinds of descriptions, for example, that Lampert (2001) provides of math teaching. Chapter four concludes with an example of this kind of thing based upon an unpublished case study written by a teacher participating in a project studying K-8 students' reasoning in the physical sciences. The description I provide in chapter 3 of my own teaching is similarly intended to provide a view of science teaching, from the teacher's perspective, as rich and complex. Both of these are examples of the kinds of images of science teaching that might be more productive supports for teachers new to the game of reforming science teaching than those currently provided by significant documents in the reform literature.

Issues for further investigation

The story told by these chapters raises questions for me related to how to support the kind of student activity it envisions in the context of public schooling. I will briefly introduce three questions and offer some preliminary thoughts on them. The point of doing so is to suggest a few possible directions my research might go as I move beyond the graduate student phase of my academic career. The three questions I'll address are: (1) How practical is it to assess student purposes? (2) How might we prepare teachers to

support this kind of student activity? And (3), what can curriculum look like that might support this?

The first question is methodological. Central to this view of desirable student activity is the notion that the student's purpose is an important aspect of assessing whether the activity is epistemologically authentic or not. Hammer et al. (2008) recently proposed defining the term 'inquiry' as an activity in which individuals are "...trying to form coherent, mechanistic accounts of natural phenomena." (p. 150) This too characterizes inquiry as an activity with a certain purpose (among other things). So in this view to assess the quality of student activity in a science class one must know something of how students perceive the purpose of their activity. The methodological question this view raises is how can we know a student's purpose?

Assessing for purpose is a problematic notion. At first glance it might appear that it is something we simply can't do. We generally consider an individual's purpose a property of their mind (another problematic concept!) that is not directly observable. Further, we often presume an individual is either not explicitly aware of their own purposes or will not be forthcoming about their true purpose if asked directly to characterize it, meaning we can't simply ask people to explain their purposes. And on top of all this there can be multiple levels of simultaneous purposes, immediate and long-range purposes, 'big picture' purposes and subordinate purposes in support of the big picture. Which are the important purposes to attend to in science classrooms? Given all of this, a focus on student purposes might appear to lack workability. And yet, as this work argues, a focus on student perceived purposes in science classrooms is important.

There is reason for hope. Recall the physics students using the ideal gas law equation as a part of their method for producing a numerical answer. When I watch the video of those students their purpose seems pretty clear. When I use that data in presentations it is not difficult to convince people that the students purpose is what I say it is. And when writing about the episode in chapter 3 it didn't feel difficult to construct a compelling argument in support of the claim that their purpose was to produce a numeric answer in a particular way. (Though of course you may disagree with my assertion it's compelling!)

Assessing purposes or intentions is a common activity for people, we do it all the time. For example when someone asks a question that appears to come out of the blue we immediately speculate about their purpose in asking the question. In fact the notion of 'out of the blue' indicates the purpose is not apparent. Furthermore, teachers regularly attend to student purposes in classrooms, though I suspect they are mostly aware of recognizing negative examples. Many science teachers are familiar with the situation where they are trying to help a student reason to some conclusion and the student says something like "Can't you just tell me the answer?" Or as a student in my college physics class once asked me "If you don't tell us the answers how will we know what's right for the test?" Surely something about what that student sees as the purpose of school science is evident in that statement. Beyond what students say there are other things teachers are attentive to that give insight; body language, tone of voice and inflection, facial expression. Again, teachers are not unique in this, we are all attentive to these kinds of clues in social situations.

Now, all of this is not to say assessing intentions is a simple activity. The problems with attending to purposes on the previous page are not intended as a ‘straw man’. It *is* a problematic activity, but one that is necessary and there is reason to believe science teachers have some abilities that can serve as the basis for developing the skill of doing it well. A part of the challenge lies in articulating what the goal is, how do we characterize what purpose or purposes are desirable? The activity of science is diverse, and there is no broad agreement among those who aim to find ways to characterize it as to how to best describe the activity of professional scientists. Beyond that there is work to do in articulating what the beginnings of this might look like in a classroom. And also work to do aimed at understanding how teachers use instructional guidance to create opportunities rich in assessment data that gives insight into this question. That is, how can we get students to tell us what purposes they perceive? Broadly, there is much work to do in considering how to assess student activity in science classrooms for intent.

That work focuses on what teachers might see in classrooms that would provide them with evidence that ‘good stuff’ is happening. The next question is how to prepare science teachers, either practicing or pre-service, to be attentive to those kinds of things, a question of professional development. During the time of my graduate work I had the opportunity to work in several professional development efforts, both with pre-service and in-service teachers. I hope those experiences will be useful to me as I move forward. Because of them I have gained some familiarity with the scholarly literature around professional development, and so I am aware this is an issue that is under investigation by a community of scholars.

What strikes me as a promising possibility for professional development that comes out of my work is the notion of framing as means of providing a language for engaging teachers in discussions of student intentions. When I present the work in chapter 3 to groups of teachers I have the sense that it resonates with many of them. In those presentations I use the terms *answer-making* and *sense-making* to refer to particular undesirable and desirable ways students frame activity in science classrooms. I chose not to use those terms in chapter 3 because they are difficult terms to define with adequate precision, particularly the term sense-making. I suspect this is so because it is based on how scientists frame the activity of science, and there is little consensus on that. None the less, my experience is that these terms resonate with science teachers, suggesting they put a label on something many teachers already attend to, though perhaps tacitly. This leads me to hope that the terms and the broader notion of framing can be useful in engaging teachers and future teachers in discussions about student intentions.

Finally, there is the question of curriculum. What do we give to science teachers in hopes of supporting this kind of student activity? Like teacher professional development, this is a question that many are already at work on, and much of the disciplinary authenticity literature I reviewed in chapter 2 is a part of that. There is a good deal of curriculum work already associated with the idea of authenticity. The problem with much of that work is that it aims to remove teacher decision making from the process. The notion of ‘fidelity’, close adherence to the curriculum’s instructional sequence, is considered a good thing by many curriculum designers. But by removing a teacher’s ability to make curricular decisions in response to what the students are doing, we ultimately deny students the opportunity to assume the important roles of generating

and assessing the quality of knowledge claims. We deny them epistemic agency. To support that teachers must be in the position to turn over the direction of the class to students.

What does curriculum look like when a curriculum designer has the expectation that students will introduce ideas that are unexpected? The current view of curriculum is fidelity, is the teacher doing what the curriculum intends? But in this case the curriculum would intend that the teacher be ready for the un-expected. So carefully sequencing tasks and/or the introduction of canonical ideas isn't possible. At the opposite end of the spectrum are advocates of letting the content go where students choose. Investigating phenomena that the students bring up because they have some particular interest in it. While this is a laudable goal, it puts tremendous demands on teachers and isn't likely to be successful on a large scale.

I suspect that there is a fruitful middle ground. Based on my experiences teaching the physics course for elementary education majors, and discussions with others who have taught it, I can begin to imagine a model for curriculum. This curriculum would specify some particular topic to be investigated and provide an introductory activity to get the students going, to get them "...trying to form coherent, mechanistic accounts of natural phenomena." (Hammer et al, 2008) After that how precisely the class proceeded would depend on what the students do. The curriculum would include many possible activities that a teacher could choose from based upon what went on in her classroom, but no sequence would be prescribed, and there would be no expectation that all of the included activities would be completed. What any particular class ended up doing would be a function of what the students did and the teacher's close attention to it.

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