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Engaging in science: a feeling for the discipline

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Abstract

Most accounts of affect and motivation in the science education literature have discussed them as relevant to, but distinct from, disciplinary pursuits. These include Pintrich's seminal work on affective and motivational factors in learning science (Pintrich, 1999, 2003; Pintrich & De Groot, 1990; Pintrich, Marx, & Boyle, 1993). Our purpose here is to build on those ideas, drawing as well on accounts of scientists' practices (e.g., Keller, 1984; Gruber, 1974) and of students' taking up disciplinary pursuits (Engle & Conant, 2002; Lehrer, 2009; Scardamalia & Bereiter, 1991, 2006), to propose that affect and motivation are inherent in the disciplinary practices of science. Thus, we introduce notions of epistemic affect and *epistemic* motivation, and we illustrate how these are evident in a case study of a student we have followed from fourth to seventh grade. We consider how this perspective aligns with and contributes to research on interest (e.g., Hidi, 2006; Hidi, Renninger, & Krapp, 2004; Sansone, 2009), and we discuss implications for research and instruction in science education. We argue that part of what should happen in the science class is to cultivate students' feelings and motivations within the discipline.

> "I was just so interested in what I was doing I could hardly wait to get up in the morning and get at it". "It never occurred to me that there was going to be any stumbling block. Not that I had the answer, but [I had] the joy of going at it." Barbara McClintock (in Keller, 1983)

> "It's like when you like somebody, it's like you and somebody else. I'm that somebody and science is the other person, that I'm hooked into." "That's why I like science, because one question can bring up EVERYTHING that you think about, [...] it can bring up EVERYTHING." Sandra in sixth grade

In recent years, there has been renewed attention to the problem of limited student engagement in areas of science, technology, engineering, and mathematics (STEM). Research in science education continues to document and analyze the problem, suggesting that it begins as early as the age of ten (e.g., Boe, Henriksen, Lyons, & Shreiner, 2011; Jenkins & Nelson, 2005; Osborne & Collins, 2001; Sjøbeg & Schreiner, 2005). A variety of governmental groups have underscored the need to address the problem, including the President's Council of Advisors on Science and Technology (PCAST), the National Science Board, the Department of Education, and the National Research Council:

> The United States cannot remain at the forefront of science and technology if the majority of its students – in particular, women and minorities underrepresented in STEM fields – view science and technology as uninteresting, too difficult, or closed off to them " (PCAST STEM report, 2010, p.16).

In this article, we present the case of Sandra, a Hispanic-American middle school student who, for the four years from fourth to seventh grade, showed a passion for science. Sandra came to our attention within a larger project on "responsive teaching"[1] in an episode we recount below from her fifth grade class, in which she challenged a fellow student's idea about what happens to water when it evaporates. We searched retrospectively for her within our corpus of video and identified her fourth grade science class in our data, including an episode in which she showed delight in the phenomenon of magnetism. Sandra was also in a project classroom in her sixth grade, and the first author took the opportunity to interview her, mainly about the fifth grade episode. During that interview, Sandra expressed her passion for science, comparing it to being "hooked into" another person. We saw Sandra as an example of what educators hope to achieve, and so we decided to study her case, to try to understand her motivation and interest.

In some respects, our case study of Sandra is similar to work by Brickhouse, Lowery, and Schultz (2000), who described four seventh grade girls' interest in and experience with science. Like those girls, Sandra came to identify with science, against the general trends in the larger culture. Unlike them, however, science for Sandra centered on what took place in the classroom and on her sense of science as about figuring things out for herself. As Brickhouse et al. (2000) illustrate in their case studies, we see a role of Sandra's identity construction in her engagement, but we begin with the

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question of why she came to construct that identity at all — what is it about her experience of science that had her so enthusiastic?

In part, then, this article is a presentation of a case study of one girl and her interest in science. The evidence suggests that Sandra relished her experiences within science as an author, critic, and developer of ideas. In this way, her case supports accounts in the motivation and interest literature (e.g., Gagné & Deci, 2005; Krapp, 2002, 2005; Minnaert, Boekaerts, & DeBrabander, 2007; Pintrich, 2003) on the role of autonomy and competence in generating student interest, as well as accounts on disciplinary learning of students' "epistemic agency" (Scardamalia, 2000, 2002) and their "having of wonderful ideas" (Duckworth, 2006) as centrally important for science education.

Our primary purpose in this article, however, is to build on those accounts, specifically with respect to affect and motivation. Watching Sandra in class, and listening to her talk about science in her interviews, we were struck by the centrality of affect in her experience of science. The evidence was not simply of motivation for science but of motivation within science: She looks like a student version of a Barbara McClintock, feeling the "joy of going at it" (Keller, 1983, p.125).

That is, studying Sandra led us to recognize how affect and motivation are inherent within disciplinary experience, and looking beyond Sandra we find that similar evidence is pervasive in accounts of student inquiry (e.g., Duckworth, 2006; Engle & Conant, 2002; Hammer, 1997, 2004; Warren, Ballenger, Ogonowski, Rosebery, & Hardicourt-Barnes, 2001) as well as in accounts of scientists' careers and pursuits (e.g. Fox Keller, 1983; Feynman, 1985; Gruber, 1974, Lorimer, 2008).

Thus we discuss how affect and motivation are inherent in scientific inquiry, in students' emergent "disciplinary engagement" (Engle & Conant, 2002), "epistemic agency" (Scardamalia, 2002), and "wonderful ideas" (Duckworth, 2006), as well as in scientists' developed professional practices. To see affect and motivation as inherent to science, we argue, is a shift from familiar conceptualizations, which have addressed motivation as a more general psychological construct (e.g., Pintrich, 2003), relevant to disciplinary pursuits, but distinct from them. It aligns however with some recent accounts in the interest literature which construe interest as a cognitive and an affective phenomenon encompassing knowledge, feelings, and values at different phases of its development (e.g., Ainley, Hidi, & Berndorff, 2002; Hidi, 2006; Hidi, Renninger, & Krapp, 2004; Krapp & Prenzel, 2011; Renninger & Riley, 2013). Still by and large, in the science education community, efforts have focused on students' motivations and goals to engage in science rather than on their motivations within that engagement.

The article is organized in three sections. In the first, we argue that affective dynamics are entangled with the conceptual and epistemological substance of science, and we contend that these affective dynamics play a central role in driving engagement in science. We illustrate these claims with examples from scientists and from accounts of disciplinary engagement in the science education literature. In the second section, we turn to Sandra, to show the emergence of epistemic affect in her experiences of science. Finally, we discuss theoretical and pedagogical implications of understanding affect and motivation as aspects of disciplinary learning, including we suggest, for cultivating student engagement and persistence in science.

Epistemic Affect and Epistemic Motivation

We titled this paper as an allusion to Evelyn Fox Keller's (1983) A Feeling for the Organism: The Life and Work of Barbara McClintock. McClintock received the Nobel Prize for her discovery of "jumping genes," transposable elements of DNA, based on her studies of corn kernels. She described the central importance of "a feeling for the organism":

> 'No two plants are exactly alike. They're all different, and as a consequence, you have to know that difference,' she explains. 'I start with the seedling, and I don't want to leave it. I don't feel I really know the story if I don't watch the plant all the way along. So I know every plant in the field. I know them intimately, and I find it a great pleasure to know them.' (p. 386)

McClintock, Keller recounted, described herself feeling the "joy" of her scientific pursuit. It gave her "the kind of understanding and fulfillment that others acquire from personal intimacy" (p. 390).

> 'One of my friends, a geneticist, said I was a child, because only children can't wait to get up in the morning to get at what they want to do.' (p.70)

There are similar themes across accounts of scientists. Feynman (1985) described his experience in science as playful:

> Why did I enjoy [physics]? I used to play with it. I used to do whatever I felt like doing - it didn't have to do with whether it was important for the development of nuclear physics, but whether it was interesting and amusing for me to play with. (p. 173)

Gruber's (1974, 2005) study of Darwin and other scientists describes the intellectual experience of scientists as an evolving organization of knowledge, purpose, and affect, whereby moments of insights and clarity, and longer-term periods of perseverance and passion, are linked together under a larger goal guiding the trajectory of the scientist.

It is not only renowned scientists that experience their intellectual journeys in this way. In his study of a national census of corncrakes, a rare migratory bird, Lorimer (2008) identified affective patterns that echo McClintock's experiences. He described how ornithologists and bird surveyors "tune in to the bird's ecology" and, despite low wages, how they were driven by the "intellectual and sleuthing challenge" (p.392) of their work.

Keller's and others' accounts depict affect both for its role within reasoning, the "jouissance" or "pleasure experienced in the presence of meaning" (Kristeva, 1982, cited by Lorimer, p.392), as well as for its role in motivating the pursuit of science. Burton (1999) similarly described mathematicians' experience in the doing of mathematics, particularly in states of uncertainty and in "aha" moments:

> You gain pleasure and satisfaction from the feelings that are associated with knowing. These feelings are exceptionally important since, often despite being

> unsure about the best path to take to reach your objective, because of your feelings you remain *convinced* that a path is there. Such conviction can feed enquiries that go on often over years before a resolution of the problem is completed. (Italicized in original, p. 134)

In other words, it feels good to have an idea, or even to sense the possibility of one, and that feeling serves both to signal the presence of the idea and to motivate its development.

These accounts call attention to affect as inherent in the work of science. As Varelas, Becker, Luster, and Wenzel (2002) note, “There is a continuous sense of engagement, intensity, commitment, dedication, disappointment, and satisfaction as scientists pursue their practice” (p. 582), feelings that are central to initiating and sustaining their inquiry.

These feelings fit larger patterns, as studied in motivational science (e.g., Gagné & Deci, 2005; Pintrich, 2003) and in research on interest (e.g., Dohn, 2013; Hidi & Renninger, 2006; Palmer, 2009). Here, we focus on what epistemologists and philosophers of mind have distinguished as “epistemic emotions” and “epistemic feelings,” specifically associated with epistemic experience (Arango-Muñoz, 2014; Brun & Kuenzle, 2008; de Sousa, 2008; Dokic, 2012; Goldie, 2004; Morton, 2010).

Arango-Muñoz and Michaelian (2014) provide an overview of the epistemic feelings and emotions that scholars have been recently paying attention to, including for example, the “feeling of knowing”, the “feeling of error”, and “epistemic anxiety”. The “feeling of knowing” refers to the “gut” sense that we will be able to retrieve an answer before it is accessible to our consciousness. The epistemic “feeling of error” is what we experience when something goes “wrong during the execution of a mental action of reasoning or decision making” (p. 101) that warns us of possible incoherence. “Epistemic anxiety” compels us to support our claims with more evidence and to thoroughly weigh in the evidence before making up our minds. Hookway (2002, p. 251) describes “emotional states” as contributing to “epistemic evaluations,” which influence reasoning. Thus, a feeling of knowing may drive extra effort to remember; a feeling of doubt may stimulate further inquiry (Arango-Muñoz & Michaelian, 2014).

In this article, we use the terms epistemic affect and epistemic motivation to refer to feelings and drives connected to epistemic experience and objectives in the doing of science. These might include the pleasure of abstracting ideas and building new theoretical connections, the desire to understand a puzzling phenomenon, and the thrill of a theoretical prediction borne out in an experiment. They are feelings and drives that arise within the doing of science, rather than feelings about science; they are entangled with the conceptual and epistemological substance of inquiry. It is epistemic affect to be troubled by a discrepancy in reasoning or evidence; it is an epistemic motivation to want to resolve it.

To be clear, not all affect and motivation associated with science, and the science class, are epistemic. The distinction is central for what follows, so we offer a few examples for contrast. The pleasure of winning an award, the pain of losing it to a rival, or the anticipation of either, could make a difference to a scientist’s professional engagement. But these matters of affect and motivation, as powerful as they may be, are not specifically epistemic.

In class, a student may feel happy about getting an A on an exam on material she did not feel she understood. The happiness of the achievement, in that situation, may be at odds with epistemic feelings of doubt. There may be similar tensions for students playing classroom games designed to motivate epistemic attainments with non-epistemic goals: A student who finds an answer that allows him to progress in the game may experience a conflict between that pleasure and the epistemic affect of lingering questions.

This is not at all to argue for eliminating non-epistemic goals, grades, and awards. We present these examples for contrast, to help clarify our focus. There is no question that other aspects of affect are important. We are arguing for particular attention in science education to epistemic affect and epistemic motivation, as essential aspects of disciplinary practices and engagement.

Evidence in Students' Inquiries

Research on learning in science has amassed substantial evidence of learners' intellectual resources for learning science (National Research Council [NRC], 2011). From young ages, this literature documents, children show conceptual and epistemological beginnings of science. At the same time, many of the same studies have provided evidence of nascent disciplinary affect and motivation.

Warren et al. (2001), for instance, presented two case studies to support their arguments for a view of "everyday and scientific knowledge and ways of knowing" as "fundamentally continuous," and in particular to "propose a framework for understanding the everyday sense-making practices of students from diverse communities as an intellectual resource" (p. 529). The authors largely aimed to challenge deficit-based accounts in the literature, in particular with respect to language.

One case involved a group of Haitian immigrant middle-school students, some of whom had had "only irregular schooling before they came to the United States" (p. 534). A student, Manuelle, read a passage aloud about metamorphosis and then asked "why, if people eat and eat, don't they change their skin, don't they transform, the way insects do?" (p. 535). Another student, Jean-Charles, challenged the premise of her question, arguing that, "when you were a little baby, you had hardly any hair. Didn't that change?" (p. 536).

> At that point, the children exploded. Manuelle said that not all babies are born without hair. Marianne wanted to distinguish growth from change: You grow, you do not change, she told Jean-Charles. Jean-Charles responded to Marianne on the question of change versus growth: "When you were a baby, your eyes were closed." His implication was that clearly they were no longer closed; thus, she had changed [...] Manuelle listened to this and then stood up to exclaim, "Do I change my skin like this, vloop, vloop ?", pretending to unzipper her skin and climb out of it. (p.536)

The authors were not focused on affect, but it is evident in their account, here in the "explosion" of talk and in Manuelle's "exclamation" and dramatic enactment to show the absurdity of a sudden "vloop vloop" change of skin.

Engle and Conant (2002), for another example, studied episodes of "productive disciplinary engagement" to identify "underlying regularities" in what educators "did that may help explain the students' engagement" (p.401). They summarized these regularities as "guiding principles for fostering productive disciplinary engagement" and used them to understand a group of fifth-grade students' "emergent and sustained controversy over a species' classification," (p. 399) namely whether an orca is technically a whale or a dolphin.

The "students often expressed passionate involvement by making emotional displays," (p.402) and the account makes clear that these feelings were at the heart of the "eruption" and persistence of the controversy. The students' feelings were largely about what made sense to them. No doubt there were other aspects to the affect as well, including with respect to social positioning (Engle, Langer-Osuna, & McKinney de Royston, 2014), but the account gives clear evidence of students' epistemic affect. There are many other examples, including from the second author's previous work. He and his colleagues have focused on the conceptual and epistemological substance of student inquiry (Coffey, Hammer, Levin & Grant, 2011; Hammer, 1996, 1997, 2004; Hammer & van Zee, 2006), but affective dynamics are evident throughout.

Again for contrast, we note there are many accounts in the literature concerned with matters of affect that are not necessarily epistemic (Bettencourt, Gillett, Gall & Hull, 1983; dos Santos & Mortimer, 2003; Milne & Otieno, 2007; Olitsky, 2007; Roth, Ritchie, Hudson, Mergard, 2011). Tobin, Ritchie, Oakley, Mergard, and Hudson, (2013) discussed how a teacher's use of humor and role-play contributed "emotional energy" to support student learning. The authors describe the fluency, enthusiasm, and vibrant interactions in the classroom- the "collective effervescence"- when the teacher, Vicky, acted as a "television compère" (p.76) to introduce the winning model of a boat holding the most weight. It is clear that in these moments students displayed enthusiasm and excitement, as evident by their laughter and lively dialogue, and we do not question the value of these feelings for the classroom. It is not clear, however, how these feelings connect to students' specifically epistemic experience within science.

A Shift From Prior Accounts of Motivation

Prior work on affect in science education has, by and large, treated affect and motivation as factors related to science but distinct from it. Pintrich and his colleagues (Pintrich, 1999, 2003; Pintrich & De Groot, 1990; Pintrich, Marx, & Boyle, 1993; Pintrich & Schunk, 1996) took the first major steps to explore the role of affect in learning, building from and challenging a model of conceptual change (Posner, Strike, Hewson, & Gertzog, 1982) in "purely cognitive" terms (Pintrich et al., 1993, p.168). Pintrich et al. (1993) pointed to affective and motivational factors in the process of conceptual change, arguing for instance that "self-related beliefs about control over learning could direct the level of accommodation or assimilation to new information" (p. 189). Students who feel less control "might be less willing to try actively to resolve discrepancies between their prior knowledge and the new information" (p. 189). Pintrich and his colleagues built their theoretical arguments on an empirical foundation. Pintrich and De Groot (1990) for instance showed correlations between motivational factors as measured on a self-reported instrument and student performance on classroom assignments.

Features of that study illustrate general patterns in research on motivation. The instrument presented items such as the following, asking students to agree or disagree on a 7-point Likert scale:

> "I think what we are learning in this Science class is interesting."
> "It is important for me to learn what is being taught in this Science class."
> "When I study I put important ideas into my own words."
> "When I study for a test I practice saying the important facts over and over to myself."
> "I ask myself questions to make sure I know the material I have been studying."
> "I work hard to get a good grade even when I don't like a class." (p. 40)

The first two here were among the set of nine items that measured "intrinsic value," "concerning intrinsic interest in and perceived importance of course work, as well as preference for challenge and mastery goals" (p. 35). The next two were among 13 that measured "cognitive strategy use," the mean score of items "pertaining to the use of rehearsal strategies, elaboration strategies, such as summarizing and paraphrasing, and organizational strategies" (p. 35). The last two were among nine measuring "self-regulation." The authors found, for example, that

> [i]ntrinsic value was very strongly related to use of cognitive strategies and self-regulation [...] Students who were motivated to learn the material (not just get good grades) and believed that their school work was interesting and important were more cognitively engaged in trying to learn and comprehend the material. (p. 37)

This study and others (Dole & Sinatra, 1998; Linnenbrink & Pintrich, 2004; Pekrun, Elliot, & Maier, 2009; Pugh, Linnenbrink-Garcia, Koskey, Stewart, & Manzey, 2011; Sinatra, 2005) have produced extensive evidence in various forms that affective and motivational factors correlate with and influence how students "learn and comprehend the material" (Pintrich & De Groot, 1990, p. 37). Learning, this body of work has argued, is not a purely cognitive matter.

We are suggesting another step: The course "material" itself is not a purely cognitive matter, either. Part of this is a shift in instructional objectives, from focusing on conceptual change as students' "accommodation or assimilation to new information," (Pintrich et al., 1993, p. 189) to "fostering productive disciplinary engagement" (Engle & Conant, 2002) as students' taking up and developing disciplinary dispositions (Lehrer, 2009). And part is a shift in understanding affect and motivation as inherent in disciplinary engagement and dispositions. In other words, the move we are suggesting is to consider affect and motivation as part of the substance science educators intend students to learn.

The difference is more than rhetorical for at least two reasons. On the one hand, the measure of "intrinsic value" in Pintrich and De Groot's (1990) study asks students about their interest in science, not their interests within it. McClintock was interested in science, no doubt, but more directly she was interested in corn plants and the patterns of colors in their kernels that violated Mendelian genetics. Manuelle and Jean-Charles (Warren et al., 2001) may have thought science is important, but more directly, at least for the moment, they were interested to establish whether humans "transform the way insects do" (p. 535).

On the other hand, the measures of cognitive strategy use and self-regulation are situated within school: they presume activities involving information provided by the instructor or textbook. The study showed correlation between these measures and student performance on classroom assignments, but there are reasons to question the alignment with disciplinary practices. Strategies included within items on the instrument, such as “saying the important facts over and over to myself,” reflect conventional schooling more than disciplinary engagement. Classroom assignments, Pintrich and De Groot (1990) acknowledged, “may not be the most psychometrically sound assessments of student academic performance, but they are closely related to the realities of instruction and learning in most classrooms.” (p. 34).

The same realities of instruction can be at odds with science (NRC, 2011), and in particular with respect to assessment (Coffey et al., 2011). Science, for example, involves practices of assessing ideas for their explanatory and predictive power; ideas become “true” that make sense, that match the available evidence, that succeed in predicting new phenomena. Practices of assessing ideas in school often involve the authority of an answer key.

Thus, the shift we are proposing has substantive implications, both for research and instruction, which we discuss further at the close of the article. We now turn to more recent research on student interest that begins to integrate cognitive and affective components in students’ engagement in ways that closely intersect with our thesis in this paper.

Connection to Literature on Interest

Research on interest has studied ways in which learners engage with particular content in efforts to conceptualize student interest and engagement, and to identify factors that lead to persistence at a task in short and long terms.

In a comprehensive review on recent interest research, Hidi and Renninger (2011) categorized the ways in which researchers conceptualize interest, including for instance the emotional aspect of interest, the development of interest, environment or task features, perceived value, and vocational interest. Eccles, Schiefele, and colleagues (Schiefele, 2001, 2009; Wigfield, Eccles, Schiefele, Roeser, & Davis-Kean, 2006), for example, described interest in terms of students’ expectancies and perceived values of a task or an activity. Hidi and Renninger (2006) and Krapp (2002, 2007; Krapp & Prenzel, 2011) studied interest as a psychological state and a predisposition to engage in learning that develops and stabilizes over time. Sansone and colleagues’ work (Sansone, 2009; Sansone, Thoman, & Smith, 2010) has mostly considered students’ regulation of their engagement and their environment to maintain their interest within an activity. Socio-cultural accounts of interest in out-of-school and informal learning settings (e.g., Azevedo, 2006, 2011; Barron, 2006) have conceptualized interest as a practice-linked phenomenon that develops in interaction with the contextual events within which it is embedded.

Theoretical frameworks that focus on interest as an emotion (Ainley, 2007; Ainley & Ainley, 2011; Silvia, 2006) bring in the cognitive components of interest in learners’ appraisals of their experiences and in the choices and decisions they make during their engagement. Models that focus on the development of interest (Hidi & Renninger, 2006; Krapp, 2002, 2007; Krapp & Prenzel, 2011) incorporate affect and knowledge to varying degrees in the stages of interest development. For instance, Renninger and colleagues (Hidi & Renninger, 2006; Renninger & Hidi, 2002; Renninger & Riley, 2013) argue that, in its earliest phases, interest primarily consists of an emotional experience with minimal knowledge requirements. In order for interest to develop and stabilize, however, the affect must connect with knowledge and values which become more prominent in deeper stages of interest development. Sansone and colleagues (e.g., Sansone, 2009; Sansone & Harackiewicz, 1996; Sansone & Smith, 2000; Sansone & Thoman, 2005) similarly describe an "interest experience" as an evolving affective and cognitive experience in interaction with goals, activity structure, and features of the environment.

The case study we present below supports these views of entangled affect, epistemology, and conceptual content, in student engagement. What we argue in addition is that this entanglement is part and parcel of the disciplinary experience of science. In this, we distinguish affect *toward* the discipline from affect *within* the experience of science, in moments of engagement.

Sansone and colleagues (e.g., Sansone, 2009; Sansone, Thoman, & Smith, 2010) propose a similar theoretical distinction in what they term "experience-defined" motivation (motivation that arise within the activity) and "goal-defined" motivation (motivation associated with the goal to engage in an activity). Their research focuses on the experience of interest in the process of self-regulation, including for example how people strategically regulate the experience of interest to persist at a task and reach their aspired goals.

Our focus here is on the particular disciplinary nature of students' experience of interest within activity, the nascence of interests regarding sense-making and knowledge building. Our approach to this study complements Sansone and colleagues' work in another way as well, by examining and theorizing affect and motivation drawing evidence from close, qualitative analysis of data from the activities and from interviews.

Context of the Project

We met Sandra as part of a four-year, NSF project in elementary science education.[2] The project involved professional development, research on student and teacher learning, and curriculum design. The professional development focused on cultivating practices of "responsive teaching" – recognizing, interpreting, and responding to the substance of student thinking in class (Coffey et al., 2011; Hammer, Goldberg, & Fargason, 2012; Levin, Hammer, Elby, & Coffey, 2012), along with the teachers' own inquiries in science. The research studied various aspects of student progress in inquiry and conceptual understanding (Hammer et al., 2012; Sikorski, 2012; Weller & Finkelstein, 2011), as well as aspects of teacher progress in responsiveness (Lineback, 2012. 2014; Maskiewicz & Winters, 2012). Finally, the project has developed prototype materials for "responsive curriculum" to support teachers in responsive practice, with embedded video examples, teacher commentary, and menus of possible activities to choose from based on what has taken place in class[3].

All of the teachers involved in the project were new to thinking in these ways about science education, but all worked toward responsiveness, in particular during

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[2] NSF DRL 0732233, Goldberg et al. Funded for three-years, with a no-cost extension for a fourth.
[3] The materials can be accessed at http://cipstrends.sdsu.edu/modules/index.html.

specific "modules" for the project. Each module opened with a launching question designed to elicit rich student thinking. Within that thinking, the teachers, supported by project staff, looked for beginnings to cultivate scientific practices and ideas. One module, for example, began with a simple toy car and the question of how one could get it to start moving; another began with the question of how it is that a puddle on the ground in the morning could be gone by the end of the day. Project staff video recorded the learning and teaching that took place during these modules.

Analytical Methods

We use qualitative video analysis and recruit tools from discourse and interactional analysis (Jordan & Henderson, 1995) to explore moment-to-moment classroom interaction with an eye on affective, conceptual, and epistemological dynamics. Video provides rich data for studying interactions, as it has the potential to "fixate" as well as "reiterate" action for the researcher (Derry et al., 2010). We continually engage in iterative and collaborative video watching (Jordan & Henderson, 1995) with other researchers where we expose the data and our analysis to public scrutiny at various stages of the research, to challenge, revise, and refine our interpretations.

We adopt a multi-modal approach (Stivers & Sidnell, 2005) to identify affective markers in action, as expressed and organized within the flow of activity. Markers of affect comprise overt utterances that indicate emotions such as fascination, curiosity, frustration, boredom, surprise, etc. (e.g., "Oh that is cool!", "I am confused", "Wow!") as well as paralinguistic channels of communication through register and prosody (e.g., raised intonation, sing-song tone, cut-offs, sound stretches), body postures and movement (e.g., head movement, standing up, postural shifts), facial expressions and gaze, turn-taking patterns, and temporal coordination of gesture and talk (e.g., Goodwin, 2007; Goodwin & Goodwin, 2000; McDermott, Gospodinoff, & Aron, 1978; Schegloff, 1984; Schegloff, Jefferson, & Sacks, 1977).

The Case of Sandra

Sandra came to our attention during a fifth grade class discussion about why a puddle disappears. She was challenging a student, Andrew, about his idea when she added, "I'm not trying to hurt you." We were struck by her initiative in this moment, as we discuss below, how it was at once epistemic in her engagement with the ideas, and affective in her attention to how Andrew might interpret her behavior. Having noticed Sandra in this episode, we looked for her in our corpus of videos from the previous year, and found videos of her during work on the toy car module. We kept track of her for the subsequent two years, and the first author interviewed her each of those years about her experiences in science.

In this section, we present our case study of the emergence and development of Sandra's interest, engagement, and identity as someone "hooked into" science. We base our interpretations on data from Sandra's engagement in science classes, in fourth and fifth grades, and from interviews in six and seventh grades, as summarized in Table 1 in the Appendix. We cannot draw definitive conclusions about her trajectory, although we will argue the evidence is suggestive. Our main purpose however, is to motivate and illustrate the pervasiveness of epistemic feelings and epistemic motivation in her story.

Below we provide a brief description of Sandra's engagement in science, drawing on classroom and interview data. We then we present detailed analysis of two classroom episodes.

Sandra's Engagement in Science

In classes with 25 or more students, Sandra contributed often to discussions about science. Our data includes multiple examples of her asking questions and offering ideas, for example:

- "Once I was little and I tasted [rain] water and it didn't have salt in it so I was wondering if it goes into- when it rains, how does the fresh water from the rain, turn into salt water in the ocean?" [10/ 20/2009];
- "What do worms eat?" [05/17/2010];
- "The clouds need to be charged up with water and when they run out of water, they move to a place where they can 'get more water' like the ocean" [10/08/2009].

It also includes multiple examples showing evidence of Sandra's paying attention to other students' ideas:

- "I guess what he meant is..."[10/06/2009];
- "…is it always moving?" (responding to a student's suggestion) [10/20/2009].

On many occasions, she reflected on the nature of her reasoning and her revision of ideas:

- "I think this is a question that could be answered by 'yes', 'no', or 'maybe'" [10/13/2009];
- "I think I want to change my theory" [10/15/2009]).

Sandra helped design and refine experiments (e.g., commenting on controlling the size of containers to test for the rates of evaporation of ocean water and tap water) and making predictions ("the tap water will evaporate twice as much as the ocean water" [10/15/2009]), and at times as in the episode with Andrew that we discuss later, she challenged others' thinking (e.g., "how do trees find shelters from the fire?" [06/03/2010]).

In sum, Sandra was an active participant in science class, offering and assessing ideas, asking questions, seeking clarity, engaging with students' ideas, and reflecting on the nature of the conversation in the science class. In what follows, we study two episodes of Sandra's participation analyzing them in particular to illustrate the entangled role of affect in Sandra's experiences in science. We begin with her work in the toy car module in fourth grade and then present her interaction with Andrew from the water cycle module in fifth grade. We then turn to what she had to say about her interest in science and science classes, during her sixth and seventh grade interviews with the first author.

Fourth Grade Exploration of Magnetism

The earliest data we have showing Sandra's engagement in science is from the second day of the toy car module, in her fourth grade class with Mrs. Hill. The students were working in groups of four, with the open-ended task of exploring ideas. At Sandra's suggestion, she and her group explored using magnets to get the toy car moving.

Sandra was concerned that the magnet would not work since the car is made of plastic and not of metal. Another student, Tanner, suggested that they tape one magnet onto the car and hold another magnet in their hand to make the car move (see Figures 1 &

2). It took some trial and error for them to make the idea work, but they did. There is evidence of their affect in these activities throughout the video, including when they finally got the car to move forward and backward: they were thrilled, as evidenced by their facial expressions, smiles, and enthusiastic exclamations.

Tanner: Oh so it does actually work!
Sandra: That's so COOL[4]!

Figure 1. Toy car and magnet.

Figure 2. Students exploring various configurations.

That afternoon, Sandra went home to explore the magnetism further with her father. On the following day, Mrs. Hill asked Sandra to present to the whole class what her group figured out. Sandra first explained how she came up with the idea of magnetism.

> How I figured this out was my group and I were talking about magnetism: "well, magnetism- how can we use MAGNETism on the toy car?", then I remembered what Sergio was doing, my brother, he brought magnets home and he tried it on something, I guess it's something like that-

[4] Capitalized words indicate raised intonation and emphasis.

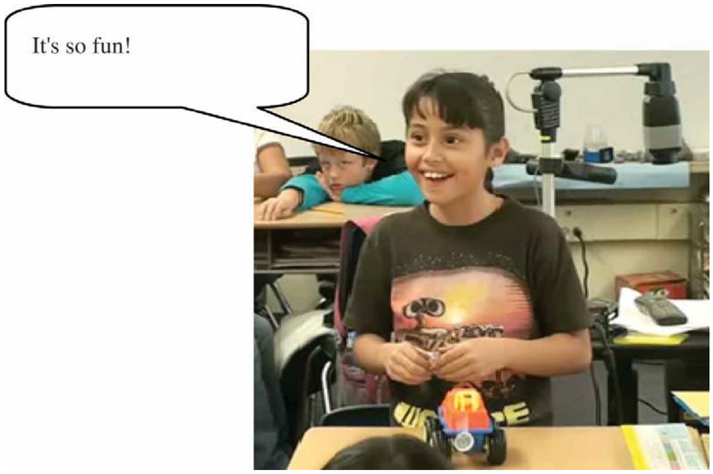

Figure 3. Sandra demonstrating how to move the car with magnets.

She went on to show how her group tried different configurations in order to find the right position and distance between the magnets to get the car to move. All through the demonstration, Sandra expressed her joy with various comments such as "that's cool!" and "it's so fun!" (Figure 3). She was especially animated in her presentation over the sensation of attraction and repulsion, even during her demonstration.

> I can feel two magnets coming together, it's like, I can feel the two magnets TRYING TO COME TOGETHER! [...] see I can feel it right now, it's trying to stick together to the other magnet. But I'm not letting it do that [...] I can feel it's getting kind of stronger.

Other students became intrigued by the idea of magnetism and joined Sandra in her wonderment; they engaged in an animated discussion about the nature of magnetism, what magnets are made up of, whether they contain electricity, and the forces involved in making the car move with the use of magnets. Much as we hope happens in responsive curricula, Mrs. Hill decided to let students pursue the topic for most of their science time that day, about 25 minutes.[5]

Sandra mentioned magnetism in both of her interviews, in sixth and seventh grades, as a phenomenon that interests her significantly. In both interviews, she explained how she planned to pursue it for her project in eighth grade. In her seventh grade interview, she described her interest as having begun in her fourth grade explorations:

> What I want to do [in my eighth grade project] is do it on magnetism. I just love it so much. This is just one of the things I love doing. [...] [W]here I got interested in magnetism was in fourth grade when we actually worked with it, it just FASCinated me and I wanted to learn MORE. That's exactly what I did in fifth grade. I learned more and I did a science project about it.

We certainly do not claim to have discovered anything new or unusual in a child's fascination with magnets; everyone knows children are curious and interested in

[5] See Sikorski (2012) for further details and analyses of students' coherence seeking evident in this conversation.

phenomena. We simply suggest recognizing Sandra's delight as an emergence of epistemic affect. Like McClintock's fascination with her corn kernels, the "great pleasure" (Keller, 1983, p.198) she found in knowing them, Sandra took pleasure in the phenomena themselves. Part of learning science is learning that it involves these feelings.

What may be unusual is Sandra's persistence over several years, planning ahead as early as in sixth grade for what she will do for her eighth grade project. There is evidence here, we suggest, of the importance of her sense of agency, over the years as we discuss below as well as within the episode. In thinking about motion and in trying to figure out ways to get the car moving, Sandra came up with an innovative idea: use a magnet to cause motion. The idea did not work immediately—in part because it needed two magnets—but the children felt it could and so they persisted with it. Their excitement for what they were doing is evident throughout, and especially when they managed to start the car moving with the magnets.

The children's persistence within the episode shows affective dynamics that are not simply pleasure in phenomena but also pleasure in the ways they could generate and pursue ideas for themselves. Part of what Sandra and her group showed in this episode was "the having of wonderful ideas" (Duckworth, 2006), an instance of "epistemic agency" (Scardamalia, 2000, 2002) that, we propose, involves the affect evident in the students' engagement.

Moreover, the originality and difficulty in using magnets to make the toy car move were a central part of the dynamics here. In related ways, research on interest has identified novelty and challenge as essential triggers of student interest (e.g., Mitchell, 1993; Palmer, 2009; Silvia, 2006). It has also highlighted the importance of autonomy, competence, and social relatedness. Nolen (2007), for example, found that instructional activities that allowed students to interact with each other contributed to their interest in reading and writing tasks. Hidi, Weiss, Berndorff, and Nolan (1998) showed that when assigned the role of group expert and the responsibility to demonstrate knowledge during a science museum visit, students' interest, particularly in the case of boys, was triggered. Similarly, Cobb, and Hodge (2004) reported that assuming the role of data analysts, crafting arguments for a broad audience, supported the generation and development of interest.

The dynamics in this magnet episode also resonate with Barron's (2006) and Azevedo's (2011, 2006) research on hobbies and students' out of school activities. We see Sandra and her peers taking up a "personal excursion" (Azevedo, 2006) to explore magnets as a way to make the toy car move. Like Azevedo, we believe that the emergence of Sandra's engagement in this moment was supported by multiple factors that go beyond Sandra's personal topical interest in magnets, to include various contextual and social factors: these might include the teacher's responsiveness, the students' roles in supporting the idea of using magnets, and the availability of time and material resources (e.g., magnets, cars) to pursue the excursion. In Azevedo's (2006) words,

> personal excursions allow students to build connections between the local environment– including proposed learning goals and resources – and their personal agendas. We believe this to be a strong generator of energy for students, as well as a good way to personalize the learning experience. (p. 86)

To this account we add that, in such moments, students are experiencing epistemic feelings and epistemic drives, including the pleasure of having ideas and pursuing them, and, sometimes, the exhilaration of having one's ideas succeed. Part of learning science, we argue, is in the activation and recognition of these feelings.

Finally on another level, this episode, and Sandra's interviews in the two years that followed, make salient an aspect of interest development and stability over years that resonates with Hidi and Renninger's (2006) four-phase model. The authors argue that a locally triggered and maintained situational interest could develop into an enduring interest, one that outlasts the specific, original situation. Sandra's interest in this episode was triggered and locally maintained by her emergent interest in exploring and using magnets to make the toy car move. This event, and the feelings she experienced within it, left a lasting mark on Sandra. It became a point of reference for her plan to pursue a project on magnetism, a phenomenon that she still identified as her favorite science topic two years later.

Fifth Grade Questions about Water

We turn now to the episode that first caught our attention, during a discussion on the first day of the water cycle module in Mr. Mason's fifth grade class. Earlier in the class, Mr. Mason had posed the launching question:

> Suppose that one night it rains. When you arrive at school, you notice that there are puddles of rainwater in the parking lot. But as the school day ends, you notice that the puddles are gone. What happened to the rainwater?

Students offered and considered various explanations, including that it soaked into the ground, animals drank it, people's shoes carried it away, as well as that "it dried up," "it evaporated," and it "turned into mist." About forty minutes into the discussion, the class was beginning to converge around the idea that clouds act as "a giant vacuum in the sky" and "suck up" the water from the puddles.

At this moment, Andrew suggested an alternative.

Andrew:	Um I, I kind of have um a different theory than a giant vacuum in the clouds.
Mr. Mason:	What's your theory?
Andrew:	I don't, I kinda think the clouds have nothing to do with it. (pauses for effect, sounds of reaction including "what?" from other students) I think when water, um, evaporates um, I think that some of its remains go up to the clouds and that's when it happens. I think the sun, um, evaporates some of the water in the ocean (quietly, as an aside) because there is so much ocean that it really can't suck it all up, (louder again) so um, I think that really, um, the sun evaporates some of the water and some of the water's remains in the sky float up. Um, it's just a theory, but-(pause, gesture and face showing irresolution)
Mr. Mason:	How do you come about that theory?

Andrew: Because, I think that sunlight, um does, um, evaporate water um, and I think that, um, maybe um, (looking at his classmates) don't you guys think that maybe the sun evaporates only some of the ocean? (several students respond "no" before he finishes)

Andrew was suggesting the sun as the causal agent, rather than the clouds, which he suggested were "the remains" of the water. In describing his idea, he focused on the quantity of water in the ocean, apparently to explain why it is that the ocean does not all evaporate — "there is so much ocean." He was hesitant in presenting his idea, both in tone and in hedging that "it's just a theory," perhaps because he was challenging a class consensus. Indeed, when he started to ask "don't you guys think," a number of students called out "no," before he finished his question. Once he did, a few called out "yes," but the general reaction of the class was resistance.

Mr. Mason invited students to "talk to us about why you're disagreeing," adding "or maybe those of you who are agreeing," and Sandra was the first to speak.

Sandra:	I actually have a question for Andrew.
Mr. Mason:	OK.
Sandra:	I don't really understand what you're saying. May- maybe I'm not hearing this right but to me you're saying that, that some of that water evaporates into the cloud and some of it just- (shifted her gaze away from Andrew to an empty space)
Andrew:	Disappears.
Sandra:	(repeating after Andrew) Disappears
Andrew:	Yes.
Sandra:	Where does it go to? If it doesn't go into the cloud-
Andrew:	(in a jesting tone and smiling) I think I have no idea!
Sandra:	If it goes-
Andrew:	(in a low voice) Water evaporates.
Sandra:	If it goes, no ah ah if some of it goes into the clouds, like let's say um half of it goes into the clouds you're saying that the other half of it rises up, where does it rise up INTO, if it doesn't rise up into the clouds? (Silence) (Andrew looks away from Sandra, agitatedly moving his leg and hand) I mean that doesn't really make sense to me. I'm not trying to hurt you but I'm just saying that if, um, if some of it goes into the cloud and you're saying that the rest of it stays there, and it rises up into the sky-
Andrew:	(in a low voice) I never said that it stays there.

Sandra:	Well, well, you said that some of it evaporates into the cloud and some of it rises up into- just rises up. Does it rise up into the cloud? Does it rise up into the sun? Does it rise up and go to the ocean? Where does it go to?
Andrew:	(In a jesting tone) Well... now that you think of it, I still have NO idea!

Figure 4. Sandra engaging with Andrew's ideas.

The conversation continued, with Andrew's idea having a clear influence on its substance. Another student, Matt, picked up on the question of why the ocean does not evaporate, and this line of inquiry continued for several days, leading them to design experiments to test whether ocean water evaporates and to consider what factors might affect the rate of evaporation, including water depth, water "thickness" (from salt and/or dirt), whether it is in the sun or in the shade, as well as the surface on which it is spilled (cement, school desk, etc.).

We note several aspects of this exchange. First, the teacher had invited students to "talk to us," that is the rest of the class, to explain their reactions to Andrew's idea. Sandra's request for the floor, "I actually have a question for Andrew" (line 1), shows her sense that she was not quite doing what Mr. Myers had asked as well as her sense of agency: she could alter, in this moment, what was taking place in the conversation.

In the first part of the exchange, we see Sandra initially addressing Andrew by revoicing what she heard him say (O'Connor & Michaels, 1993) to check and affirm her understanding of his idea, before she begins to evaluate it (on line 3: "May- maybe I'm not hearing this right but to me you're saying that, that some of that water evaporates into the cloud and some of it just-"). Her wording and the use of the pronouns "I" and "me" in talking about Andrew's ideas communicate that Sandra is not evaluating Andrew's idea yet, but that she is evaluating *her own understanding* of his idea (“maybe I’m not hearing;” “to me, you’ re saying”). Watching her exchange with Andrew in a stimulated recall interview, Sandra explained:

> Sandra: I was asking him, ‘where does it go when it rises up?’ Because I didn’t really understand. Because he said some goes to the ocean, and some goes to the clouds, but where does the rest go to?

As Sandra uttered: “and some of it just--” on line 3, she shifted her gaze away from Andrew to an empty space in the room. This “projection space” (Schegloff, 1984) often communicates to others a sense that an idea is in progress and has not yet been fully formed or articulated, which might suggest in this interactional moment that Sandra is joining efforts with Andrew to help construct and develop his ideas. These various discursive and paralinguistic markers suggest that Sandra was trying to create a space to explore Andrew’s ideas more deeply, which might be indicative of Sandra’s interest in and desire to participate with Andrew in building an understanding of what happens to the rest of the water.

On the other hand, Andrew’s concise replies: “disappears,” “yes,” “I think I have no idea,” and “water evaporates- I don't know,” convey his reluctance to engage in the conceptual challenge that Sandra is inviting him to join. Having already taken an emotional risk by offering a different account from that of the class, Andrew was no doubt experiencing an intellectually and affectively difficult moment here, being put on the spot to elaborate and justify his reasoning, a reasoning that may not have been fully-formed yet for him at this moment. Andrew was clearly showing discomfort, verbally in his brief responses as well as in his use of self-deprecating humor and jesting tone as he uttered: “I think I have no idea.” Moreover, he sent various affective cues non-verbally with his body language and gaze: he looked away from Sandra, agitatedly moving his leg and hand.

In response to Andrew’s first bid for closure when he first stated “I have no idea,” Sandra maintained her focus on the inquiry. With a serious expression on her face, she cut Andrew off, with a “no, ah ah;” markers that often alert the recipient to the possibility of imminent repair (Schegloff, Jefferson, & Sacks, 1977), and redirected the conversation to her original question (“if some of it goes into the clouds, where does the rest of it go?”).

Andrew fleetingly interjected to correct Sandra as she rephrased his idea, by saying dismissively “I never said that it stays there.” Sandra seemed to notice that she might be pressing too much on Andrew. She responded by rephrasing what she heard Andrew say and presenting a list of questions (on line 13), that seemed more like a menu of possibilities from which Andrew could draw on to address Sandra’s challenge. This interpretation is supported in the follow-up stimulated recall interview:

> Sandra: I didn't want him to think I was trying to correct him. I was just trying to get what he was trying to say. "Half of it goes to the clouds, and then half of it rises up." Where does it rise to? So I didn't want him to think, "Oh, I'm disagreeing with you", or "Oh, you're wrong" (in a voice that conveys a sense of challenge). I didn't want him to think

> that. So that's why I said, "I'm not trying to hurt you. But I'm just wondering: where does it go up to?" [...] I want him to think, "Well, Andrew, I think you're right, but I just don't understand where it goes up to." That's what I was trying to say.

Sandra described "trying to get what he was trying to say." When Andrew didn't seem to understand her question, she said, she "reworded it [...] to use a quote from him to say it."

> Sandra: So I took a quote from what he was saying so he would say, Oh, yeah, I said that, didn't I? Like that.
>
> Lama: I see what you mean, so you were trying to rephrase your understanding of what he was saying? And then you started suggesting those things, why did you do that? Like the ocean, 'does it go up to the sun, does it go up into the ocean?'
>
> Sandra: Because I didn't know if he had an idea, so to, I was trying to give him ideas. Of, 'where do you think it goes up to, the ocean, or where?' Because maybe I thought if I give him ideas, maybe he might give me an answer [...] so that maybe he could answer one, and I could understand a little bit of what he was saying.

And later she continued:

> Sandra: I was asking questions to give him ideas. […]. So I gave him ideas to think: 'maybe it goes there, or do you think it goes there, stuff like that.

Even within the interview context, Sandra displayed interest in understanding Andrew's reasoning, and concern about Andrew's feelings and how he might be experiencing this interaction. She explained that her motivation to pursue the inquiry was rooted in her desire to better understand the physical phenomenon of water evaporation, and Andrew's reasoning about it, while at once holding Andrew's ideas accountable to her own sense that the water cannot simply disappear.

What first struck us about this moment, as we noted above, was Sandra's comment, "I'm not trying to hurt you." It showed she was concerned about how Andrew might be experiencing the situation, probably because she noticed other students' reaction to his idea as well as signs of his discomfort. It also showed her sense of agency- that she could speak in this way to Andrew, to explain what she was trying and not trying to do.

What is of central importance here is that Sandra's messages to Andrew, which she communicated in words and non-verbal signals, were both epistemological and affective, reflecting her experience of the moment and her anticipation of his. She was effectively telling him: "I see a discrepancy in your ideas and it bothers me. So I am asking you questions to try to understand what happens to the water. I am not trying to hurt you personally."

In this way, we suggest, Sandra's engagement gives evidence of emergent epistemic motivation and affect. Her motivation is to identify and resolve an inconsistency in the reasoning – that water cannot just float up or "disappear." And at the same time, in this moment, she is showing an awareness of argumentation as a kind of intellectual activity concerning ideas, as different from—but possible to confuse with—personal confrontation. Part of learning science involves becoming familiar with the experience, including the affective feelings, of challenging and being challenged.

We have focused our attention mainly on Sandra, but it is worth a brief digression to consider Andrew. His original motivation to speak was, apparently, to challenge the consensus that was forming around the notion that clouds “suck up” water from the puddles. He started to say “the clouds have nothing to do with it,” that the sun is what “evaporates water.” The clouds, that is, are only a by-product of evaporation, not its cause. By the time he was finished speaking, however, the main point he was articulating and asking the class to confirm, was that “the sun evaporates only some of the ocean.” There is clear evidence that this was a difficult moment for Andrew, in part no doubt for the reactions from other students while he was speaking. His discomfort, it seems, made it difficult for him to keep track of his thinking. Part of learning science, perhaps, involves learning resilience in presenting and defending unpopular ideas.

Reflections on Science and Science Learning

Video data of Sandra in class provide evidence of affect and motivation within science, when she is thinking about magnets and how to understand what happens to water in puddles and the ocean. We turn now to the interviews.

The first author, Lama, conducted two interviews, in each January of Sandra’s sixth and seventh grade years.[6] The author’s initial interest was to hear Sandra’s reflections about her moment with Andrew, but the conversation quickly became about science and science learning more generally. We focus primarily on the first interview.

Sandra was the first to speak in that first interview, having heard only that it would be about science.

Sandra:	I like science.
Lama:	You do?
Sandra:	Yeah, I'm not a big social studies- I'm not that good at social studies, but I'm good at science.
Lama:	What makes science interesting for you?
Sandra:	It's just, I don't know, I guess I just like doing it and doing experiments. And finding out stuff. I guess I just like doing it. I don't know why.

To be clear, Sandra's opening statements, that she likes and is "good at science," are not evidence of affect within the epistemic activities of science, which we have been emphasizing. Lama prompted for more, specifically with respect to Mr. Mason’s class the previous year, asking for “the things you liked most” and “the things you didn't like so much.” Sandra answered that she liked “the whole science program” and added “I love science.” When Lama asked if any particular topic interested her, she said “magnetism,” and mentioned her plan to “expand more on magnetism” in her eighth grade project, a plan, as we noted, she mentioned again the next year.

Lama shifted the interview to focus on fifth grade, noting that she had a video clip to show, and reminded Sandra of Mr. Mason’s question about the puddle.

[6] The timing of these interviews was entirely practical: January was when the author was free each year to travel to San Diego.

Lama: The question was that Mr. Mason asked, that you came once to school, and it was raining, and the puddle formed, then you went home and the puddle wasn't there anymore. What happened to the water? Is that about it?

Sandra: I remember something about that. And then he started asking us, What do you think happened to the water? Evaporation, really grew inside that class, because we were talking a lot about puddles and water. Because we didn't really use the book, it was mostly just a talk, that we had a lot of talking inside this class. I liked that, because in a book, when you're reading a book, you can't express what you want to.

Sandra went on to contrast science in Mr. Mason's class to others, again around the role of the book.

Sandra: I don't really like looking in the book and answering the questions. I like to have a discussion, where the questions are added in, instead of just reading a book. Because reading out of a book, I can avoid the questions. But I like reading, just not reading out of a book for the lesson.

Lama: I see what you mean. So when you think of science, what is it that you think of? Like when you say, just what you told me, you like Science. What is it in science that attracts you and makes it interesting to you?

Sandra: I guess it's just the way that it is, it's just a way that science is to me. See, when I have science, it really, it's like something that makes me happy when we do science, it's something that makes me really happy [...] When I read out of a book, it didn't really make me that happy, because you couldn't really get involved. But when you had a [discussion] circle, that's what attracted me most to science is group discussions, because you could talk about it.

As she remembered more of the conversation, still before watching the clip, Sandra elaborated how talking about the puddle helped students get past simply knowing the term "evaporation."

Sandra: When you talk about it, you get a better understanding [...] Especially when we talked about the puddle, most kids, they stuck with the same thing, "evaporation", "evaporation". But then everybody's mind exPANDed into different things of what happened to the water.

Again, she contrasted this with "reading out of a book."

Sandra: Reading out of a book, it's what they think. But when you have a good discussion, it's what you think. And when you have group discussion and somebody says something. You say, 'Oh, yeah, I want to add on that.' On a book, it says what the author thinks, it doesn't say what the kids think.

This, she said, was different about science in Mr. Myers' class.

Sandra: Social studies, you read, answer questions out of a book. Then we did the same thing for English and math. So really science was the only time that you could all talk. And say what you think about the subject, instead of just looking at numbers or history or stuff out of a book. You didn't have to use the book, what you had to use was your mind. And you had to listen to what other people would say. So that when they said something, you can go on and expand it more. Or you can deny it and say why.

Lama: So is that something that you used to feel okay about?

Sandra: Yeah! When I said something in science, I actually didn't expect everybody to agree with me. Because it was what I thought. It's not what other people think. So if somebody disagreed with me, I thought, okay. And I'll hear what they have to say why they disagreed with me. And then I'll think, Maybe they are right, or I'll think, Huh? Or I'll think, How is that? I'll think different things, but a lot of times I'll think, Hey, they're right.

These excerpts illustrate Sandra's agency in science and her interest in contributing her own ideas, listening to, and drawing from others, in making sense of phenomena. Her experiences in science entailed a sense of autonomy in authoring and assessing ideas, and, consistent with findings in motivational science (e.g., Gagné & Deci, 2005; Pintrich, 2003), that sense of ownership and self-determination was in part what drove her engagement and motivation.

Lama went on to show Sandra the video clip of the interaction above. Along the way, she described it as an example of why she likes science.

Sandra: (Smiling) WOW! There were so many different opinions! It was so different! In fact, when [Mr. Mason] first stated that question [about water evaporating from a puddle], there were so many different responses flying back and forth, back and forth [...] And just by that one question, all those opinions came flying out. That's why I like science, because one question can bring up EVERYTHING that you think about. That's what I think, it can bring up EVERYTHING!

Figure 5. Sandra reacting to the fifth grade episode.

This is another moment where Sandra seemed to enjoy going on a "personal excursion" (Azevedo, 2006), where she could engage with ideas, exchange perspectives, and form deeper and more expansive meanings. In such "exploration zones" (Azevedo, diSessa, & Sherin, 2012), Sandra seems to be developing a passion for the give-and-take of ideas, and what she describes in this moment resembles a pleasure trip to an uncharted idea territory that only her science classes have afforded her so far.

Toward the end of the interview, Lama asked Sandra whether she remembered ever "feeling uncomfortable" in Mr. Mason's class. Lama was asking mainly to follow up on a conversation with Mr. Mason, in which he had expressed concern about students' comfort.

Lama: Do you remember at any time feeling kind of uncomfortable about what you're doing, in terms of sharing things out loud and trying out ideas?
Sandra: No.
Lama: No? It never felt like that?
Sandra: Not me, I don't know about other kids, because I know there's some shy kids inside that class. But I don't really know how they felt, because in science, when we had science was like, me-science (gesturing the connection), it's like when you like somebody, it's like you and somebody and else. I'm that somebody and science is the other person, that I'm hooked into.
Lama: You compare your relation with science to a relation with another?
Sandra: Yeah! I don't know why, that's what first popped into my head.

Most of our analysis has focused on Sandra's affect and motivation within science; here is evidence of her feelings toward science more directly comparable to accounts in the literature: Sandra expressed a passion for science and was, evidently, highly motivated to pursue it further. Her passion toward science was largely informed by her experiences and feelings within the work of science. This theme was evident throughout her interviews not only in her explicit comments but also in her non-verbal expressions, her bright smile watching and talking about what she saw in the video of the class discussion (Figure 5), her animation in talking about science and why she enjoys it.

This analysis intersects with the model put forth by Sansone and colleagues (e.g., Sansone, Thoman, & Smith, 2010), which distinguishes between "goal-based" motivation and "experience-based" motivation. In line with these authors' findings, the evidence here suggests the interplay between interest within experience (in the doing of science in this case) and motivation towards achieving a more distant goal (studying and pursuing science as a discipline). In this way, the evidence of Sandra's experience of interest within classroom activity, and in her reflections on that activity during interviews, supports Sansone's findings. It also intimates the need to examine the reflexive relationship between these two interrelated motivational dynamics, over time, and in the context of particular disciplines, such as science.

Studying the experience of interest *in situ* affords further insight into the dynamics of how that experience evolved, including with respect to other aspects of the activity, such as interactions among epistemic and other affect, experience of phenomena, and conceptual understandings of mechanisms. As we show in what follows, we can begin to theorize about possible underlying mechanisms via which epistemic feelings and emotions (i.e., feelings within the epistemic practices of science) stabilize into long-term stances and dispositions toward disciplinary engagement and the pursuit of scientific studies.

One theme in Sandra's account is the importance of students having the chance to talk and explore and argue ideas for themselves, in contrast, as she kept repeating, with what happens in most classes, namely getting information from a book. She introduced this idea into the discussion, first in response to Lama asking her if she remembered the conversation about the puddle, and she kept returning to it. She had a variety of ways of articulating it, that "you could talk about it," "be involved," "use your mind," and the theme continued in seventh grade:

> Sandra: Having kids gather around in a circle and talking about- and in the beginning giving couple of ideas in there and then just step back and let them take it on from there, let them take the reins [...] the teacher starts it and then let the kids do it. [...] Because it's great to have some ideas out there and to have fun with it! I remember the fourth and fifth grades, those are the best science years I've ever had because I just had fun. Both teachers just bring in a couple of ideas and just let you take it on from there. So it was FUN!

In classroom data, we see Sandra forming and expressing ideas, raising questions, taking initiative in conversations—that is, we see her epistemic agency (Scardamalia, 2002). Throughout her interviews, she describes that agency and identifies it as a primary reason she enjoyed science class, more in fourth and fifth grades than later. In seventh grade, in contrast, Sandra said science class was more about "getting the stuff implanted into your head, talk about it for a while, and watch a video."

Another theme in the interviews, again supportive of the classroom analyses, is Sandra's interest in forming and connecting ideas, \ in reconciling inconsistencies among ideas, and her coming to recognize that these are central aspects of doing science that she enjoys. That is the "fun" she describes, what she expects the students to do with the reins, if the teacher will let students take them. The evidence for this comes before she watches the clip from Mr. Mason's class, in her comments about how students' thinking about evaporation "really grew" and "expanded" through their work together, and in her comments about expecting and valuing disagreements, including how they can result in her coming to a new understanding. The evidence comes as well in her comments about the clip, including with respect to her wanting to understand what Andrew had said, and in her excitement for the moment as an example of why she "likes science," with "so many different responses flying back and forth," and how "one question can bring up everything."

Sandra's Epistemic Feelings and Motivation

We contend two things from these data: First that it shows Sandra's nascent disciplinary engagement, and second that affect and motivation are inherent in those beginnings. In other words, the episodes in class and the data from interviews show evidence of Sandra's epistemic affect, affect that is inherent in the epistemic states and epistemic practices of science.

Within the classroom episodes, there is evidence of Sandra's affect and motivation, moment-to-moment. The first episode shows her pleasure in the sensation of magnetic repulsion, her interest to have and test and refine an idea for how to make the car move, and her joy at the result. The second episode shows her interest to identify and articulate an inconsistency in Andrew's reasoning, perhaps to find a way to resolve it. She enjoys "the having of wonderful ideas" (Duckworth, 2006).

The interviews support the evidence from the classroom, adding evidence on longer time scales. Sandra's explicit comments show her abiding interest in magnetism—remembering her discoveries in fourth grade and planning to make it the focus of her eighth grade project. Her comments about students getting to say what they think support the interpretation of classroom data that she loves to "be involved" in the give and take of ideas, such as in fourth grade, coming up with a way to make the car move, and in fifth grade, taking part in the argumentation over what makes the puddle disappear. As well, Sandra's evident delight watching the video—her face bursting into a smile over all the "many different responses flying back and forth," over how "one question can bring up everything!"— supports our sense of her enjoyment in the moment.

The interviews also give data about Sandra's interest and motivation toward science, more directly comparable to accounts in the literature. She loves science and wants to pursue it further, not because it is useful or will further her career or societal goals, but because it is "fun." Within class, we see her experiencing epistemic affect and motivation; in the interviews, we hear her saying, in effect, that these feelings are central to what draws her to science, and she wishes for more science classes that allow her to experience them.

To be sure, Sandra's interest and identification with science might have evolved in response to a number of factors, both in and out of school. Understanding interest and engagement requires examining "a broad network of variables both within the time frame of a classroom activity but also going beyond to include broader personal orientations and characteristics as well as a myriad of contextual factors" (Ainley, 2012, p. 296). We do not have data from Sandra's out of school life experiences, and we do not doubt their relevance. We do not claim to have a full picture of Sandra's interest and motivation. We do claim, however, that the data we have is evidence of epistemic affect as integral to her experience in school, within her nascent engagement in science.

Finally, it is essential to be clear that we are not suggesting it is sufficient to appreciate Sandra's affect and motivation. To be sure, the data is rich in evidence of conceptual and epistemological resources, such as of her sense that water must be conserved, in the puddle's disappearance, and her sense that ideas should cohere. These have been the focus of research on learning, in particular with respect to disciplinary engagement, as we discussed in the introduction, and we could have made them the focus here. Our point, rather, is that affect and motivation are dynamically entangled with those resources and their activation.

Feelings in the Discipline

Our purpose in this article has been to introduce the notions of affect and motivation within science, as part of science itself. The experiences of a new theoretical connection, of an experimental confirmation of an hypothesis, of discovering a new phenomenon, all involve feelings; so do the experiences of having one's findings challenged by opposing arguments, of having one's explanations misunderstood by an audience, of discovering a gap in one's reasoning. These feelings are part of engaging in science, and learning science is in part meta-affective (deBellis &Goldin, 2006), as students come to anticipate the "pleasure of finding things out" (Feynman, 1999), to manage frustrations, to notice and follow up on affective cues that "something seems wrong."

In this way we are arguing for a shift from treatments of affect and motivation in the literature. At the same time, we are building from that literature, which has emphasized affective and motivational dynamics in learning, owing largely to Pintrich's seminal body of work (Pintrich, 1999, 2003; Pintrich & De Groot, 1990; Pintrich et al., 1993; Pintrich & Schunk, 1996; Sinatra, 2005). We have argued that affect and motivation are not only part of the dynamic of students' "learning the material"; it is part of the "material" to learn. We are also building from accounts of students' epistemic agency (Scardamalia, 2000; Scardamalia & Bereiter, 2006), disciplinary engagement (Engle & Conant, 2002) and dispositions (Lehrer, 2009), all of which, we argue, implicate affect and motivation as inherent in science.

Additionally, our case study of Sandra builds on and supports findings in recent literature on interest which point to the entwinement of affect and cognition in learners' engagement. The data gives compelling evidence to the role of autonomy, meaningfulness, and competence in Sandra's interest in science. Her sense that she could challenge and refine ideas and participate in knowledge building was central to her interest and engagement. This directly connects to accounts in interest and motivational science, including with respect to the constructs of self-regulation and self-determination (Gagné & Deci, 2005; Pintrich, 2003). That is, part of what motivates learners in science, be they students or scientists, reflects what motivates people across many endeavors, that they experience a sense of autonomy in what they do and think. It also informs theoretical models in recent interest literature, specifically in Sansone and colleagues' work (Sansone, 2009; Sansone & Smith, 2000; Sansone, Thoman, & Smith, 2010) on the underlying dynamics between the experience of interest and longer term, goal-directed motivations.

In this way, we propose, research on motivation within science can also inform understanding of motivation toward science. For Sandra, the evidence suggests, her attraction to science grew from her experiences within it. Thus we note two levels of affect evident in Sandra's case. The first resides within the experiences of doing science – e.g., in investigating a question, in reconciling an inconsistency. The second is her awareness of the first, her meta-affect (deBellis & Goldin, 2006), part of her sense of what science involves. This entanglement of affect and epistemology contributes to her forming a stable disposition with respect to science as a discipline.

Possibilities for Research

Affect and motivation within disciplinary engagement are difficult targets for investigation, for a number of reasons. One is that by definition they occur *in situ*. Evidence is possible through analyses of data from learners' activities, such as of Sandra's participation in class, wherein tools from multimodal and interactional analysis can be recruited to analyze affect (see Goodwin, 2007; Stivers & Sidnell, 2005). Among these tools is a range of visuo-spatial and discursive markers including behaviors, gestures, facial expressions, explicit utterances indicating emotions, and paralinguistic channels of communication (such as intonation, turn-taking patterns, cut-offs, sound stretches, temporal coordination of gesture, gaze and talk, and so on). For instance, we see Sandra's joy in the phenomena of magnetism drawing evidence from the co-occurrence of her facial and verbal expressions of happiness with her manipulations of the materials.

In Sandra's case, there is also valuable evidence in what she said during interviews, as there is in McClintock's and other scientists' reflections about their experiences. This form of evidence however requires reflective awareness of the feelings that occur within the activities. Not all children, or even older learners, will be reliable informants with respect to what they feel within disciplinary activities, especially when they are new to those activities and feelings. To be sure, in some domains of psychology it is well established that people can be unaware of affective aspects of their reasoning (Tversky & Kahnman, 1981). Similar challenges might limit the effectiveness of survey instruments in capturing feelings within learning, although these instruments and interviews could be effective means of studying disciplinary affect at the meta-affective level we noted above.

Thus there are methodological challenges for research on affective dynamics within reasoning, and especially for the design of large-N studies. These methodological challenges, of course, mesh with theoretical challenges of understanding the dynamics of experience within activities.

Some approaches might adapt or build onto existing work. For example, studies by Bromme and his colleagues (Kienhues, Bromme, & Stahl, 2008; Porsch & Bromme, 2011; Scharrer, Bromme, Britt, & Stadtler, 2012) involve experiments to influencing subjects' epistemological stances. Scharrer et al. (2012) described "the seduction of easiness," presenting subjects with texts that varied in readability. Easier prose led to less critical stances with respect to ideas. We expect the dynamics of that influence involved affect. Perhaps, to speculate on possible methods, analyses of subjects' facial expressions during these studies could provide evidence of those dynamics.

There is, meanwhile, much more to be gained from case studies. Recent work in science and math education calls for the need to develop fine-grained models of affective dynamics within learning (e.g., Evans, Morgan, & Tsatsaroni, 2006; Gupta, Danielak, & Elby, 2010; Op 't Eynde, Corte, & Verschaffel, 2006; Op 't Eynde & Hannula, 2006). In this line of research, "emotions are not treated as objects that can be studied as independent and detachable from the individual's processes and context." (Op 't Eynde & Turner, 2006, p.370). Gupta et al. (2010), for example, explored how emotions play out in the moment-to-moment conceptual and epistemological dynamics of an engineering student reasoning in a clinical interview about her electrical circuits course. The authors show how the student's stance toward conceptual reasoning was disrupted by an affectively positive experience within the interview. They conclude that a dynamical and context-specific analysis of affect in moment-to-moment interactions has explanatory power to account for local coherences and shifts in coherences in students' reasoning.

Similarly, we are interested in the dynamics of student engagement and persistence in inquiry, and we expect that affect plays a central role. In exploring ideas and questions of interest to them, learners activate a variety of affective resources that can hinder or promote their efforts to sense-make. There is a large range of possible dynamics to observe and understand. How might children's feelings of excitement and curiosity, their feelings of frustration and fear, interact with conceptual and epistemological aspects of their engagement? Case studies of affective dynamics within students' inquiry can begin to illuminate these questions and to refine the field's understanding of the nature and role of affect within learning.

We are also interested in the dynamics on longer time scales. In Sandra's case, we have noted, the evidence is suggestive that her experiences in local moments contributed to her forming long term interest, including identifying herself as "hooked into" science. That is, her identification with and connectedness to science seem to have emerged from the feelings she experienced in particular moments such as we observed. Sandra came to appreciate and recognize these moments as something she connects to and finds gratifying, particularly as she contrasted them with other science learning experiences that were not as supportive of her epistemic agency. In this way, these episodes became more than a fleeting or passing situational interest and developed into a more stable individual interest that became part of who Sandra is. This interpretation is consistent with literature on interest development, particularly as described in Hidi and Renninger's (2006) four-phase model. Sandra's interest in these episodes of inquiry would fit in the category of what Hidi and Renninger refer to as "triggered" - and perhaps locally maintained situational interest - that could potentially develop into an individual interest that will outlast the specific events and social contexts in which it arose, thus becoming an aspect of the person's identity. These findings motivate further research on the dynamic relationship between "interest-defined motivation," specifically with respect to epistemic activity, and the more distal "goal-defined motivation," while adding empirical support to Sansone and colleagues' (Sansone, 2009; Sansone & Smith, 2000; Sansone, Thoman, & Smith, 2010) conceptual model of self-regulation of motivation.

Sandra's case also sheds light on the importance of considering interest as a situated, practice-linked phenomenon that develops in interaction with the contextual factors and events within which it is embedded, as theorized by Barron (2006) and by Azevedo (2006, 2011) and his colleagues (Azevedo, et al., 2012). While these researchers have mostly focused on interest in out-of-school and informal learning settings, their work has the potential to inform our thinking on interest development in the context of the classroom. As we saw in Sandra's story, having opportunities to engage in "exploration zones" (Azevedo et al, 2012) and "personal excursions" (Azevedo, 2006) whereby students could play with ideas, negotiate what is taking place, and embark on self-initiated pursuits, could bear directly on the possibility of students' extended engagement and interest. These accounts, as well as Sandra's, draw attention to the important roles of the classroom activity's structural resources and the features of the interactions between participants, including the processes for collaboration and idea sharing, as essential resources for the emergence and persistence of interest.

This interpretation seems to align as well with accounts of identity and engagement from socio-cultural perspectives (Brickhouse, Lowery, & Schultz, 2000; Brown, 2004; Carlone & Johnson, 2007; Nasir & Hand, 2008; Tan & Calabrese Barton, 2008). This body of work suggests that learning environments that provide students with opportunities to participate meaningfully in the discipline and in authoring knowledge foster students' identification with the discipline. As we have seen in the case of Sandra, in addition to other compelling evidence across various projects (Conlin, Richards, Gupta, & Elby, in preparation), opportunities for students' self-expression and for taking up integral roles in their learning impact how they engage and identify with the discipline. This, we posit, supports and contributes to findings on the role of classroom ecology, including classroom norms, interactional dynamics, and discursive practices, on the accomplishment of disciplinary identities and disciplinary dispositions in learning (Gresalfi, 2009; Lehrer, 2009; Varelas, Martin, & Ken, 2012).

We believe further work should include exploration of the interplay of affect and identity development, across multiple scales of students' experiences in science to integrate contextually-triggered and locally-situated moments of interest to broader and longer-term dynamics of identity formation and the recognition of interests at a meta-affective level.

Implications for Instruction

For the most part, the implications of this work for instruction reinforce prior calls for greater focus on practices (NGSS, 2012). Researchers have long argued for the importance of students' experiencing science as a pursuit, to promote students' "disciplinary engagement" (Engle & Conant, 2002), "disciplinary dispositions" (Lehrer, 2009), and "epistemic agency" (Scardamalia, 2000, 2002).

Such calls, in fact, were central motivation for the Responsive Teaching project[7], in its emphases on close attention to the substance of student thinking (Hammer, Goldberg, & Fargason, 2012; Lineback 2014; Maskiewicz & Winters, 2012). Sandra's fourth and fifth grade teachers were part of that project, working to center their teaching on students' inquiries. That meant creating opportunities for students to initiate questions, formulate and evaluate ideas, and author explanations about natural phenomena. It also meant attending closely to the students' thinking, working to understand what students were saying and doing, responding substantively, and delving into students' reasoning. Sandra evidently recognized this emphasis, explaining as we quoted above how much she enjoyed being able to express and discuss ideas with other students: "Reading out of a book, it's what they think. But when you have a good discussion, it's what you think."

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[7] http://cipstrends.sdsu.edu/modules/index.html.

We have argued that part of the importance of these experiences for students is in epistemic affect, in students' learning and becoming familiar with the feelings involved in doing science. For Sandra, we claim, epistemic affect within her science classes in fourth and fifth grade played a role in her forming an interest in science. She came to recognize a kind of activity that she enjoyed.

A further implication of this work is to extend the earlier notions of responsive teaching to include affect and motivation as part of the disciplinary substance. Students' affective displays within the work of science may not only be reflections of engagement; they may also be evidence of substantive disciplinary work, and both teachers and students need to recognize them as such.

We have focused on Sandra, but epistemic affect was evident for other students as well. Andrew showed disciplinary motivation in his interest to challenge the class consensus and offer a new possibility (that it is not clouds but the sun causing evaporation), and it was an important contribution to the class. At the same time, he showed discomfort to have an idea at odds with the mainstream, evident in his hedging and hesitancy. Other students in the class, in their quick rejection of his reasoning, showed irritation at his challenging what they had established. These suggest areas for instructional attention, with respect to epistemic affect, for Andrew and the class.

Following deBellis and Goldin (2006), we think more generally of meta-affect, which they describe as, for example, what "enables people, in the right circumstances, to experience fear as pleasurable (e.g., in experiencing a terrifying roller coaster ride as fun)" (deBellis & Goldin, 2006, p.136). Similarly, students may come to experience challenges within science as pleasurable, challenges such as having an idea at odds with a class consensus or encountering a particularly thorny problem. They may come to enjoy the "irritation" of a discrepant line of reasoning.

Elsewhere (Jaber, in press), the first author focuses on the teacher. Part of what we have learned, in this project, is that for some teachers, attention to students' ideas and reasoning naturally involves attention to their feelings and emotions within that reasoning. This entails that teachers be attuned to students' wonderings and affective experiences, and that they feel comfortable engaging children in new and unforeseen lines of inquiry, at times relaxing their concern about canonical knowledge and accurate terminology. When children's questions, speculations, and curiosities become the resources that organize and structure the learning activity, children take more ownership and develop epistemic confidence in their roles as meaning-makers in science as we see in the case of Sandra and in a number of published studies (e.g., Engle & Conant, 2002; Scardamalia & Bereiter, 1991, 2002; Siry & Max, 2013).

A further implication for instruction is heightened need to accommodate a range of norms regarding emotional expression. Learners vary significantly with respect to how they experience, express, and regulate how they are feeling, both across and within cultures (e.g., Briggs, 1970; Goetz, Spencer-Rodge & Peng, 2008; Horchchild, 1979; Mead, 1961; Shweder, Haidt, Horton, & Joseph, 2008). Affective "cultural scripts" (Miyamoto & Ryff, 2011) may vary on multiple grain-sizes across different socio-cultural groups. These issues may be more familiar under the general category of "classroom management"; our arguments in this article imply that they bear on the substance of learning as well.

In closing, Lehrer (2009) maintains that "designing to support disciplinary learning involves orienting one's commitment toward what it means to know and understand in that discipline" (p.760, emphasis added). We have argued that forming such commitment involves becoming familiar with what it means to feel in the discipline. Our perspective on epistemic affect implies that identifying, eliciting, and cultivating the beginnings of science in children's thinking necessitate attention to their affect within science. The emergence and stability of students' epistemic drives and motivations then becomes a fundamental instructional goal.

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References

Ainley, M. (2007). Being and feeling interested: Transient state, mood, and disposition. In P. Schutz (Ed.), *Emotion in education* (pp. 141–157). New York, NY: Academic Press.

Ainley, M. (2012). Students' interest and engagement in classroom activities. In S.L. Christenson, A. L. Reschly, & C. Wylie (Eds.), *Handbook of research on student engagement* (pp. 283-302), Springer Science.

Ainley, M., & Ainley, J. (2011). Student engagement with science in early adolescence: The contribution of enjoyment to students' continuing interest in learning about sciences. *Contemporary Educational Psychology, 36*(1), 4–12.

Ainley, M., Hidi, S., & Berndorff, D. (2002). Interest, learning, and the psychological processes that mediate their relationship. *Journal of Educational Psychology, 94,* 545–561.

Arango-Muñoz, S. (2014). The nature of epistemic feelings. *Philosophical Psychology, 27*(2), 193-211.

Arango-Muñoz, S., & Michaelian, K. (2014). Epistemic feelings, epistemic emotions: Review and introduction to the focus section. *Philosophical Inquiries 2/1*, 97–122.

Azevedo, F. S. (2006). Personal excursions: Investigating the dynamics of student engagement. *International Journal of Computers for Mathematical Learning*, *11*, 57-98.

Azevedo, F. S. (2011). Lines of practice: A practice-centered theory of interest relationships. *Cognition and Instruction*, *29*(2), 147-184.

Azevedo, F. S., diSessa, A. A., & Sherin, B. L. (2012). An evolving framework for describing student engagement in classroom activities. *Journal of Mathematical Behavior*, *31*(2), 270-289.

Barron. B. (2006). Interest and self-sustained learning as catalysts of development: A learning ecologies perspective. *Human Development*, *49*, 193-224.

Bettencourt, E., Gillett, M., Gall, M., & Hull, R. (1983). Effects of teacher enthusiasm training on student on-task behavior and achievement. *American Educational Research Journal, 20,* 435-450.

Boe, M. V., Henriksen, E. K., Lyons, T., & Schreiner, C. (2011). Participation in science and technology: young people's achievement-related choices in late-modern societies. *Studies in Science and Education, 47*(1), 37-72.

Brickhouse, N. W., Lowery, P., & Schultz, k. (2000). What kind of a Girl Does Science? The Construction of School Science Identities. *Journal of Research in Science Teaching, 37*(5), 441-458

Briggs, J. L. (1970). *Never in anger: Portrait of an Eskimo family.* Cambridge: Harvard University Press.

Bromme, R., Kienhues, D., & Stahl, E. (2008). Knowledge and epistemological beliefs: An intimate but complicate relationship. In M. S. Khine (Ed.), *Knowing, Knowledge, and Beliefs: Epistemological Studies Across Diverse Cultures* (p. 423 - 444). New York: Springer.

Brown, B. (2004). Discursive identity: Assimilation into the culture of science and its implications for minority students. *Journal of Research in Science Teaching*, *41*(8), 810-834.

Brun, G., & Kuenzle, D. (2008). Introduction: A new role for emotions in Epistemology? In G. Brun, U. Doğuoğlu, & Kuenzle, D. (Eds.), *Epistemology and emotions* (pp. 1-31). Ashgate.

Burton, L. (1999). The practice of mathematicians: What do they tell us about coming to know mathematics. *Educational Studies in Mathematics, 37,* 121-143.

Carlone, H. B., & Johnson, A. (2007). Understanding the science experiences of successful women of color: Science identity as an analytic lens. *Journal of Research in Science, 44*(8), 1187–1218.

Cobb, P., & Hodge, L. (2004, June). An initial contribution to the development of a design theory of mathematical interests: The case of statistical data analysis. Paper presented as part of the symposium Design Theories of Interest, Motivation, and Engagement for the Learning Sciences, *Sixth International Conference of the Learning Sciences*, Santa Monica, CA.

Coffey, J. E., Hammer, D., Levin, D. M., & Grant, T. (2011). The missing disciplinary substance of formative assessment. *Journal of Research in Science Teaching, 48*(10), 1109-1136.

Conlin, L.D., Richards, J., Gupta, A., & Elby, A. (in preparation). Bring it on: Explaining an 8th grader's impassioned pursuit in science at the intersection of identity and epistemology.

DeBellis, V.A., & Goldin, G. (2006). Affect and meta-affect in mathematical problem solving: A representational perspective. *Educational Studies in Mathematics, 63*(2), 131-147.

Derry, S. J., Pea, R. D., Barron, B., Engle, R. A., Erickson, F., Goldman, R., Hall, R., Koschmann, T., Lemke, J., Sherin, M., & Sherin, B. L. (2010). Conducting video research in the learning sciences: Guidance on selection, analysis, technology, and ethics. *The Journal of the Learning Sciences, 19*(1), 3-53.

de Sousa, R. (2008). Epistemic feelings. In G. Brun, U. Doğuoğlu, & Kuenzle, D. (Eds.), *Epistemology and emotions* (pp. 185-204). Ashgate.

Dokic, J. (2012). Seeds of self-knowledge: Noetic feelings and metacognition. In M. Beran, J. Brandl, J. Perner, & J. Proust (Eds.), *Foundations of metacognition* (pp. 302-321). Oxford University Press.

Dohn, N.B. (2013). Upper Secondary Students' Situational Interest: A case study of the role of a zoo visit in a biology class. *International Journal of Science Education, 35*, 16, 2732–2751.

Dole, J. A., & Sinatra, G. M. (1998). Reconceptualizing change in the cognitive construction of knowledge*. Educational Psychologist, 33*(2/3), 109-128.

dos Santos, F.M.T., & Mortimer, E.F. (2003). How emotions shape the relationship between a chemistry teacher and her high school students. *International Journal of Science Education, 25*(9), 1095-1110.

Duckworth, E. (2006). *"The having of wonderful ideas" and other essays on teaching and learning* (Third). New York, NY: Teachers College Press.

Engle, R. A., & Conant, F. R. (2002). Guiding principles for fostering productive disciplinary engagement: Explaining an emergent argument in a community of learners classroom. *Cognition and Instruction, 20*(4), 399-483.

Engle, R. A., Langer-Osuna, J. M., & McKinney de Royston, M. (2014). Toward a Model of Influence in Persuasive Discussions: Negotiating Quality, Authority, Privilege, and Access Within a Student-Led Argument*. Journal of the Learning Sciences, 23*(2), 245-268.

Evans, J., Morgan, C., & Tsatsaroni, A. (2006) Discursive Positioning and Emotion in School Mathematics Practices. *Educational Studies in Mathematics: Affect in Mathematics Education: Exploring Theoretical Frameworks, A PME Special Issue, 63*(2), 209-226.

Feynman, R. P. (1999). *The pleasure of finding things out*. Cambridge, MA: Perseus.

Feynman, R.P. (1985). *"Surely you're joking, Mr. Feynman!": adventures of a curious character.* New York: W. W. Norton.

Gagné, M., & Deci, E. L. (2005). Self-determination theory and work motivation. *Journal of Organizational Behavior, 26,* 331-362.

Goetz, J., Spencer-Rodgers, J., & Peng, K. (2008). Dialectical Emotions: How cultural epistemologies influence the experience and regulation of emotional complexity. In R. Sorrentino, & S. Yamguchi, (Eds.). *Handbook of motivation and cognition across cultures.*

Goldie, P. (2004). Emotion, feeling and knowledge of the world. In R. Solomon (Ed.), *Thinking about feeling: Contemporary philosophers on emotion.* (pp. 91-104). Oxford & New York: Oxford University Press.

Goodwin, C. (2007). Participation, stance and affect in the organization of activities. *Discourse and Society, 18*(1), 53-73.

Goodwin, M. H., & Goodwin, C. (2000). Emotion within situated activity. In N. Budwig, I. C. Uzgiris, & J. V. Wertsch (Eds.), *Communication: An arena of development* (pp. 33-54). Stamford, CT: Ablex.

Gresalfi, M. S. (2009). Taking up opportunities to learn: Constructing dispositions in mathematics classrooms. *Journal of the Learning Sciences, 18*(3): 327-369.

Gruber, H. E. (1974). *Darwin on man: A psychological study of scientific creativity.* Chicago: University of Chicago Press.

Gruber, H. E. (2005). The creative person as a whole: The evolving systems approach to the study of creative work**.** In H. E. Gruber, & K. Bödeker (Eds), *Creativity, psychology and the history of science*. (pp. 35-104). Netherlands: Springer.

Gupta, A., Danielak, B. A., & Elby, A. (2010). Understanding students' difficulties in terms of coupled epistemological and affective dynamics. *Proceedings of the 2010 Frontiers in Education Conference (ASEE/IEEE)*.

Hammer, D. (1996). Misconceptions or p-prims: How may alternative perspectives of cognitive structure influence instructional perceptions and intentions? *Journal of the Learning Sciences, 5*(2), 97-127.

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

Hammer, D. (2004). The variability of student reasoning, lectures 1-3. In E. Redish & M. Vicentini (Eds.), *Proceedings of the Enrico Fermi Summer School, Course CLVI*. Bologna: Italian Physical Society.

Hammer, D., & van Zee, E. H. (2006). *Seeing the science in children's thinking: Case studies of student inquiry in physical science*. (Book and DVD) Portsmouth, NH: Heinemann.

Hammer, D., Goldberg, F., & Fargason, S. (2012). Responsive teaching and the beginnings of *energy* in a third grade classroom. *Review of Science, Mathematics and ICT Education, 6*(1), 51-72.

Hidi, S. (2006). Interest: A motivational variable with a difference. *Educational Research Review, 7,* 323–350.

Hidi, S., & Renninger, K. A. (2006). The four-phase model of interest development. *Educational Psychologist, 41(2),* 111-127.

Hidi, S., Renninger, K. A., & Krapp, A. (2004). Interest, a motivational variable that combines affective and cognitive functioning. In D. Y. Dai & R. J. Sternberg (Eds.), *Motivation, emotion, and cognition: Integrative perspectives on intellectual functioning and development* (pp. 89–115). Mahwah, NJ: Erlbaum.

Hidi, S., Weiss, J., Berndorff, D., & Nolan, J. (1998). The role of gender, instruction and a cooperative learning technique in science education across formal and informal settings. In L. Hoffmann, A. Krapp, K. A. Renninger, & J. Baumert (Eds.), *Interest and learning: Proceedings of the Seeon conference on interest and gender* (pp. 215–227). Kiel, Germany: IPN.

Hookway, C. (2002). Emotions and epistemic evaluations. In P. Carruthers, M. Siegal, & S. Stich, (Eds.), *The cognitive basis of science (*pp. 251-62). Cambridge University Press.

Jaber, L.Z. (in press). Attending to students' epistemic affect. In A. D. Robertson, R. E. Scherr & D. Hammer (Eds.), *Responsive teaching in science and mathematics*. New York, NY: Routledge.

Jenkins, E. W., & Nelson, N. W. (2005). Important but not for me: students' attitudes towards secondary school science in England. *Research in Science & Technological Education, 23*(1), 41-57.

Jordan, B., & Henderson, A. (1995). Interaction analysis: Foundations and practice. *Journal of the Learning Sciences, 4*(1), 39-103.

Keller, E. F. (1983). *A feeling for the organism: The life and work of Barbara McClintock*. New York: W. H. Freeman and Company.

Krapp, A. (2002). An educational–psychological theory of interest and its relation to SDT. In E. L. Deci & R. M. Ryan (Eds.), *Handbook of self determination research* (pp. 405–427). New York, NY: University of Rochester Press.

Krapp, A. (2005). Basic needs and the development of interest and intrinsic motivational orientations. *Learning and Instruction, 12,* 383–409.

Krapp, A. (2007). An educational–psychological conceptualization of interest. *International Journal of Educational and Vocational Guidance, 7,* 5–21.

Krapp, A., & Prenzel, M. (2011). Research on interest in science: Theories, methods, and findings. *International Journal of Science Education, 33,* 27–50.

Lehrer, R. (2009). Designing to develop disciplinary dispositions: Modeling natural systems. *American Psychologist, 64*(8), 759-771.

Levin, D.M., Hammer, D., Elby, A., & Coffey, J. (2012). *Becoming a responsive science teacher: Focusing on student thinking in secondary science*. Arlington VA: NSTA Press

Lineback, J. E. (2012). *Mrs. Miller's evolution in teaching science as inquiry: A case study of a teacher's change in responsiveness. Doctoral dissertation. San Diego State University, San Diego, CA.*

Lineback, J. E. (2014). The redirection: An indicator of how teachers respond to student thinking. *Journal of the Learning Sciences*, 24(3), 419-460.

Linnenbrink, E. A., & Pintrich, P. R. (2004). Role of affect in cognitive processing in academic contexts. In D. Y. Dai & R. J. Sternberg (Eds.), *Motivation, emotion, and cognition: Integrative perspectives on intellectual functioning and development* (pp. 57- 87). Mahwah, NJ: Lawrence Erlbaum.

Lorimer, J. (2008). Counting corncrakes: The affective science of corncrake surveillance, *Social Studies of Science*, *38*, 377-405.

Maskiewicz A, & Winters, (2012). Understanding the Co-Construction of Inquiry Practices: A Case Study of a Responsive Teaching Environment. *Journal of Research in Science Teaching, 49*(4), 429-464.

McDermott, R., Gospodinoff, K., & Aron, J. (1978). Criteria for an ethnographically adequate description of concerted activities and their contexts. *Semiotica, 24*, 245–275.

Mead, M. (1961). *Coming of age in Samoa: A psychological study of primitive you for western civilization.* New York: Morrow.

Milne, C., & Otieno T. (2007). Understanding engagement: Science demonstrations and emotional energy. *Science Education, 91,* 523-553.

Minnaert, A., Boekaerts, M., & DeBrabander, C. (2007). Autonomy, competence, and social relatedness in task interest within project-based education. *Psychological Reports, 101,* 574–586.

Mistler-Jackson, M., & Butler Songer, N. (2000). Student Motivation and Internet Technology: Are Students Empowered to Learn Science? *Journal of Research in Science Teaching*, *37*(5), 459-479.

Mitchell, M. (1993). Situational interest: Its multifaceted structure in the secondary school mathematics classroom. *Journal of Educational Psychology, 85,* 424–436.

Miyamoto, Y., & Ryff, C. (2011). Cultural differences in the dialectical and non-dialectical emotional styles and their implications for health. *Cognition and Emotion, 25,* 22–30.

Morton, A. (2010). Epistemic emotion. In P. Goldie (Ed.), *The Oxford handbook of philosophy of emotion* (pp. 385-400). Oxford: Oxford University Press.

Nasir, N. S., & Hand, V. (2008). From the court to the classroom: Opportunities for engagement, learning and identity in basketball and classroom mathematics. *Journal of the Learning Sciences, 17*(2), 143-180.

National Research Council (2011). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. Washington, DC: The National Academies Press.

Next Generation Science Standards (NGSS). (2012). *Next generation science standards for today's students and tomorrow's workforce.* Washington, D.C.: Achieve, Inc. Report at http://www.nextgenscience.org/next-generation-science-standards. Accessed 2/23/2014).

Nolen, S. B. (2007). Young children's motivation to read and write: Development in social contexts. *Cognition and Instruction, 25,* 219– 270.

O'Connor, M. C., & Michaels, S. (1996). Shifting participant frameworks: Orchestrating thinking practices in group discussion. In D. Hicks (Ed.), *Discourse, learning and schooling* (pp. 63–103). Cambridge: Cambridge University Press.

Olitsky, S. (2007). Promoting student engagement in science: Interaction rituals and the pursuit of a community of practice. *Journal of Research in Science Teaching, 44,* 33-56.

Op' t Eynde, P., & Hannula, M. S. (2006). The case study of Frank. *Educational Studies in Mathematics: Affect in Mathematics Education: Exploring Theoretical Frameworks, A PME Special Issue, 63*(2), 123-129.

Op' t Eynde, P., De Corte, E., & Verschaffel, L. (2006). Accepting emotional complexity: A socio-constructivist perspective on the role of emotions in the mathematics classroom. *Educational Studies in Mathematics: Affect in Mathematics Education: Exploring Theoretical Frameworks, A PME Special Issue, 63*(2), 193-207.

Osborne, J., & Collins, S. (2001). Pupils' views of the role and value of the science curriculum: A focus-group study. *International Journal of Science Education, 23*(5), 441-467.

Palmer, D. H. (2009). Student interest generated during an inquiry skills lesson. *Journal of Research in Science Teaching, 46,* 147–165.

Pekrun, R., Elliot, A. J., & Maier, M. A. (2009). Achievement goals and achievement emotions: Testing a model of their joint relations with academic performance. *Journal of Educational Psychology, 101,* 115-135.

Pintrich, P. R. (2003). A motivational science perspective on the role of student motivation in learning and teaching contexts. *Journal of Educational Psychology, 95*, 667–686.

Pintrich, P. R., & Schunk, D. H. (1996). *Motivation in education: Theory, research, and applications*. Englewood Cliffs, NJ: Merrill.

Pintrich, P. R., Marx, R. W., & Boyle, R. A. (1993). Beyond cold conceptual change: The role of motivational beliefs and classroom contextual factors in the process of conceptual change. *Review of Educational Research*, *63*(2), 167- 199.

Pintrich, P.R. (1999). The role of motivation in promoting and sustaining self-regulated learning. *International Journal of Educational Research, 31*, 459-470.

Pintrich, P.R., & De Groot E. (1990). Motivational and self-regulated learning components of classroom academic performance. *Journal of Educational Psychology, 82*(1), 33-50.

Porsch, T., & Bromme, R. (2011). Effects of epistemological sensitization on source choices. *Instructional Science, 39*(6), 805-819.

Posner, G.J., Strike, K.A., Hewson, P.W., & Gertzog, W.A. (1982). Accommodation of a scientific conception: Towards a theory of conceptual change. *Science Education, 67*(4), 489-508.

Pugh, K. J., Linnenbrink-Garcia, L., Koskey, K. L. K., Stewart, V. C., & Manzey, C. (2010). Motivation, learning, and transformative experience: A study of deep engagement in science. *Science Education*, *94*, 1-28.

Renninger, K. A., & Hidi, S. (2002). Student interest and achievement: Developmental issues raised by a case study. In A. Wigfield & J. S. Eccles (Eds.), *Development of achievement motivation* (pp. 173–195). New York, NY: Academic Press.

Renninger, K. A., & Hidi, S. (2011). Revisiting the conceptualization, measurement, and generation of interest. *Educational Psychologist*, 46(3), 168-184.

Renninger, K.A., & Riley (2013). Interest, cognition and the case of L- and science. In S. Kreitler (Ed.), *Cognition and motivation: Forging an interdisciplinary perspective* (pp. 352-382). Cambridge University Press.

Report to the President: Prepare and Inspire: K-12 Education in Science, Technology, Engineering and Math (STEM) for America's Future, September 2010 Prepublication version; President's Council of Advisors on Science and Technology: Washington, DC, 2010. http://www.whitehouse.gov/sites/default/files/microsites/ostp/ pcast-stemed-report.pdf

Roth, W. M., Ritchie, S. M., Hudson, P., & Mergard, V. (2011). A study of laughter in science lessons. *Journal of Research in Science Teaching, 48*, 437–458.

Sansone, C. (2009). What's interest got to do with it?: Potential trade-offs in the self-regulation of motivation. In J. P. Forgas, R. Baumiester, & D. Tice (Eds.), *Psychology of self-regulation: Cognitive, affective, and motivational processes* (pp. 35–51). New York, NY: Psychology Press.

Sansone, C., & Harackiewicz, J. M. (1996). “I don’t feel like it: The function of interest in self-regulation. In L. Martin & A. Tesser (Eds.), *Striving and feeling: Interactions between goals and affect* (pp. 203–228). Hillsdale, NJ: Erlbaum.

Sansone, C., & Smith, J.L. (2000). Interest and self-regulation: The relation between having to and wanting to. In C. Sansone & J. M. Harackiewicz (Eds.), *Intrinsic and extrinsic motivation: The search for optimal motivation and performance* (pp. 342–371). New York, NY: Academic Press.

Sansone, C., & Thoman, D.B. (2005). Interest as the missing motivator in self-regulation. *European Psychologist, 10,* 175–186.

Sansone, C., Thoman, D.B., & Smith, J.L. (2010). Interest and self-regulation: Understanding individual variability in choices, efforts and persistence over time. In R. Hoyle (Ed.) *Handbook of Personality and Self-Regulation* (pp. 191-217). Wiley-Blackwell.

Scardamalia, M. (2000). Can schools enter a Knowledge Society? In M. Selinger, & J. Wynn (Eds.), *Educational technology and the impact on teaching and learning* (pp. 6-10). Abingdon, RM.

Scardamalia, M. (2002). Collective cognitive responsibility for the advancement of knowledge. In: B. Smith (Ed.), *Liberal education in a knowledge society*. (pp. 67-98). Chicago: Open Court.

Scardamalia, M., & Bereiter, C. (1991). Higher levels of agency for children in knowledge-building: A challenge for the design of new knowledge media. *The Journal of the Learning Sciences, 1*(1), 37-68.

Scardamalia, M., & Bereiter, C. (2006). Knowledge building: Theory, pedagogy, and technology. In K. Sawyer (Ed.), *Cambridge Handbook of the Learning Sciences* (pp. 97-118). New York: Cambridge University Press.

Scharrer, L., Bromme, R., Britt, M.A., & Stadtler, M. (2012). The seduction of easiness: How science depictions influence laypeople’s reliance on their own evaluation of scientific information. *Learning and Instruction. 22*(3), 231-243.

Schegloff, E. A., Jefferson, G., & Sacks, H. (1977). The preference for self-correction in the organization of repair in conversation. *Language, 53*, 361–382.

Schegloff, E.A. (1984). On some gestures’ relation to talk. In J. M. Atkinson, & J. Heritage (Eds.), *Structures of Social Action* (pp. 266-296). Cambridge: Cambridge University Press.

Schiefele, U. (2001). The role of interest in motivation and learning. In J. M. Collis & S.Messick (Eds.), *Intelligence and personality: Bridging the gap in theory and measurement* (pp. 163–194). Mahwah, NJ: Erlbaum.

Schiefele, U. (2009). Situational and individual interest. In K.Wentzel & A. Wigfield (Eds), *Handbook of motivation at school* (pp. 197–222). New York, NY: Routledge.

Shweder, R.A., Haidt, J., Horton, R., & Joseph, C. (2008). *The cultural psychology of emotions: ancient and renewed.* In M. Lewis, J. Haviland-Jones, and L. Barrett (Eds.) Handbook of Emotions (3rd Edition). New York: Guilford Press.

Sikorski, T. (2012). *Developing an alternative perspective on coherence seeking in science classrooms. Doctoral dissertation. University of Maryland, College Park, Maryland.*

Silvia, P. J. (2006). *Exploring the psychology of interest*. New York, NY: Oxford University Press.

Sinatra, G. M. (2005). The warming trend in conceptual change research: The legacy of Paul R. Pintrich, *Educational Psychologist, 40*(2), 107-115.

Siry, C., & Max. C. (2013). The collective construction of a science unit: Framing curricula as emergent from Kindergarteners' wonderings. *Science Education, 97* (6), 878-902.

Sjøbeg, S., & Schreiner, C. (2005). How do learners in different cultures relate to science and technology? Results and perspectives from the project ROSE. *Asia Pacific Forum on Science Learning and Teaching*, 6(2), 1-16.

Stivers, T., & Sidnell, J. (2005). Multimodal interaction. Special issue of *Semiotica*, *156*(1/4), 1-20.

Tan, E., & Calabrese Barton, A. (2008). From peripheral to central, the story of Melanie's metamorphosis in an urban middle school science class. *Science Education*, *92*(4), 567-590.

Tobin, K., Ritchie, S. R., Hudson, P., Oakley, J., & Mergard, V. (2013). Relationships between emotional climate and the fluency of classroom interactions. *Learning Environments Research*, *16*(1), 71–89.

Tversky, A., & Kahneman, D. (1981). The framing of decisions and the psychology of choice. *Science, 211*, 453-458.

Varelas, M., Becker, J., Luster, B., & Wenzel, S. (2002). When genres meet: Inquiry into a sixth-grade urban science class. *Journal of Research in Science Teaching, 39*(7), 579-605.

Varelas, M., Martin, D., & Kane, J. (2012). Content learning and identity construction (CLIC): a framework to strengthen African American students' mathematics and science learning in urban elementary schools. *Human Development, 55,* 319-339.

Warren, B., Ballenger, C., Ogonowski, M., Rosebery, A., & Hudicourt-Barnes, J. (2001). Rethinking diversity in learning science: The logic of everyday sense-making. *Journal of Research in Science Teaching, 38*(5), 529-552.

Weller, D., & Finkelstein, C. (2011). From "adding inquiry" to "doing science". *Science and Children. 48*(7), 49-53.

Wigfield, A., Eccles, J., Schiefele, U., Roeser, R., & Davis-Kean, P. (2006). Development of achievement motivation. In R. Lerner & W. Damon (Series Eds.) and N. Eisenberg (Vol. Ed.), *Handbook of child psychology: Vol. 3. Social, emotional, and personality development* (6th ed., pp. 933–1002). New York, NY: Wiley.

Appendix

Table 1

Sandra's data across the four years

Day	Grade	Description of episode	Sandra's participation
October, 2008	Grade 4	Discussion on biomimicry	- Sandra attempts to explain biomimicry using pictures from a science magazine.
November 10, 2008	Grade 4	Discussion of designs to make the toy car move	- Sandra explains one of her group's idea to attach a rope to a car and pulling on it to make the car move.
November	Grade 4	Activity to label the different	- Sandra questions the nature of the questions in

12, 2008		ways of making the toy car move under different categories (blowing air, using one's body, pulling, etc.)	the assignment.
	Grade 4	Group discussion on making the car move using magnets	-Sandra wonders how a magnet can be used on plastic. -Sandra and her group mates discuss design ideas to attach the magnets onto the car to make it move. Sandra takes a leading role in the group.
November 13, 2008	Grade 4	-Demonstration of Sandra's group idea: moving toy car using a magnet -Discussion on making the car move with wind -Sandra's group fails to make the car move with the rubber band	- Sandra demonstrates the group's design to the class and engages the class in a discussion about magnets. - Sandra argues that making the car move by blowing on it is due to "wind" not to "body movement." - Sandra excited to explain why the demonstration did not work by noting that the rubber band was getting wrapped around one tire.
November 14, 2008	Grade 4	Demonstration of making a toy car move using a fan	- Sandra and her group mates present their idea of making the car move using a fan.
December 3, 2008	Grade 4	Group activity to make the bulb light up using batteries and wires	- Sandra presents her group's design
October 6, 2009	Grade 5	Discussion on clouds and evaporation	- Sandra revoices a student's idea regarding clouds acting as "vacuum" to "suck up" water, but struggles to express the idea. - Sandra suggests an explanation of the role of the "sun's rays" in evaporating the puddle of water, and again struggles to convey her thinking. - Sandra challenges Andrew's account of evaporation.
October 8, 2009	Grade 5	Discussion on water vapor	- Sandra explains how water in a puddle changes to water vapor that goes into the sky. - Sandra shares an idea related to the clouds needing to be "charged up," suggesting that when clouds "run out" of water, they move to a place where they can "get more water" like the ocean.
October 13, 2009	Grade 5	Discussion on factors needed to cause rain	Sandra responds to the teacher's question: "in order for it to rain, it has to rain the day before?" by commenting on the nature of the question as one that "could be answered by yes no or maybe."
October 15, 2009	Grade 5	-Discussion on the rate of evaporation of tap water and ocean water -Designing an experiment to test the rates of evaporation of ocean water and tap water	- Sandra makes a prediction that the tap water will evaporate twice as much as the ocean water. - Sandra explains that she changed her theory about the evaporation of salt water. -Sandra comments on the size of the containers needed for the experiment to test the rates of evaporation of ocean water and tap water.
October 20, 2009	Grade 5	Discussion of the results of the experiment on the evaporation of tap and ocean water	-Sandra asks a question on how the ocean water becomes salty if it is made of rain water that is fresh. - Sandra attempts to pursue her question by relating it to Andrew's question about how rain

			water becomes fresh if it were made of ocean water.
May 17, 2010	Grade 5	Discussion on composting	- Sandra asks a question about worms. - Sandra raises her hand saying that she has three questions but the teacher redirected the conversation asking her to keep the questions for later.
June 3, 2010	Grade 5	Discussion on burnability: substances that can burn	- Sandra suggests ideas of things that can burn. - Sandra disagrees with some students' suggestions.
	Grade 5	Discussion on burnability: substances that can burn	- Sandra asks a question to challenge a student's idea: how do trees find shelters from the fire?
January 6, 2011	Grade 6	Reflection on fifth grade science and stimulated recall interview on the Sandra-Andrew episode	Sandra's first interview
May 12, 2011	Grade 6	Reflection on fifth grade science	Sandra in a focus group interview
January 11, 2012	Grade 7	Reflection on science learning experiences in Sandra's life so far and on her future plans	Sandra's second interview