Science
Education

Learning to Feel Like a Scientist

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Received 14 June 2014; accepted 20 July 2015
DOI 10.1002/sce.21202
Published online 27 January 2016 in Wiley Online Library (wileyonlinelibrary.com).

ABSTRACT: There is increased attention in the science education community on the importance of engaging students in the practices of science. However, there is much to be learned about *how* students enter into and sustain their engagement in these practices. In this paper, we argue that *epistemic affect*—feelings and emotions experienced within science, such as the excitement of having a new idea or irritation at an inconsistency—is part of what instigates and stabilizes disciplinary engagement. We first discuss affect as evident in accounts of professionals; we then show its emergence and role in 2 case studies of elementary school students. In the end, we argue that epistemic affect is part of the *substance* that students should learn in science, and we discuss implications for research and instruction. *Sci Ed* **100:**189–220, 2016

INTRODUCTION

There is increased attention in the science education community on the importance of engaging students in the practices of science. This attention is clearly evidenced in the *Next Generation Science Standards* (NGSS; Lead States, 2013), following *A Science Framework for K–12 Science Education* (National Research Council (NRC), 2011). The *NGSS* highlights students' "engaging in the practices of inquiry," as the first of three dimensions of pedagogical attention: (1) engineering and scientific practices, (2) disciplinary core ideas, and (3) crosscutting concepts. The previous *National Science Education Standards* (NRC, 1996) had highlighted the importance of students' "engaging in inquiries that are interesting and important to them," (p. 13) with inquiry "at the heart of science and science learning" (p. 15).

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The committees behind these reports were informed by scholarship on inquiry, much of which began from observing what learners can do. Hawkins' (1965) famous essay on "messing about in science," Duckworth's (2006) on "the having of wonderful ideas," and a wide range of studies (e.g., Gopnik, 2012; Gopnik, Sobel, Schulz, & Glymour, 2001; Metz, 2011; NRC, 2011) have examined learners' reasoning for emergent scientific thinking. Other work has focused on professional scientists to identify disciplinary practices as targets for instruction (e.g., Chinn & Malhotra, 2002; Driver, Newton, & Osborne, 2000; Nersessian, 2007; Osbeck, Nersessian, Malone, & Newstetter, 2011).

The *NGSS* draws on this work in positing eight practices, such as *asking questions* and *constructing explanations*. While the set of eight practices reflects an increased attention to the epistemic nature and processes of knowledge construction in science, there is still much to be learned about *how* students come to engage and persist in them. This gap motivates the need to examine how disciplinary engagement emerges and develops as learners pursue various epistemic goals.

Our general interest is to contribute to addressing this gap by exploring, in situ, the nature and dynamics of students' engagement in "doing science" in the scientific practices described in the *NGSS*. How does it form, and what contributes to its persistence? How might it become stable within classroom activities or in learners' more extended pursuits? In this article, we argue that the dynamics of learners' engagement is substantially affective: To understand the emergence and stability of students' scientific pursuits, it is essential to study their affect within those pursuits. Therefore, we examine affective dynamics within engagement, *within* as opposed to *toward* or *with respect to* science. We argue that affect inheres in and drives scientific practices for scientists and for students.

The article is organized in five sections. In the first, we cite the dimension of "practices" in the *NGSS* to highlight affective aspects in its description. We also note ongoing challenges for educators regarding students' engagement in these practices. These challenges motivate our research questions for this study regarding affective aspects of students' disciplinary engagement. Second, we review accounts of scientists to identify forms of epistemic affect evident in their practices. Third, we review prior accounts of affect in science education research to contrast the study of affect *about* science to the study of affect *within* scientific inquiry. We then present two case studies of elementary school students' inquiries to show beginnings of epistemic affect inherent in the *NGSS* and evident in accounts of scientists' experiences. We close with implications for instruction and research, including with respect to implementing visions of the *Framework* and *NGSS*.

UNDERSTANDING THE DYNAMICS OF ENGAGEMENT

The authors of the *Framework* (NRC, 2011), describing their use of the term "practices," explained:

> Part of our intent in articulating the practices in Dimension 1 is to better specify what is meant by inquiry in science and the range of cognitive, social, and physical practices that it requires. Our expectation is that students will themselves engage in the practices and not merely learn about them secondhand. Students cannot comprehend scientific practices, nor fully appreciate the nature of scientific knowledge itself, without directly experiencing those practices for themselves. (pp. 2–5)

Students, for example, should experience scientific questions as "driven by curiosity about the world, inspired by the predictions of a model, theory, or findings from previous investigations, or . . . stimulated by the need to solve a problem" (pp. 3–6).

Students should be *developing and using models* to the purpose of "representing . . . a system under study" (pp. 3–8) and *planning and carrying out investigations* in order "to describe the world, and to develop and test theories and explanations of how the world works" (pp. 3–9) and so on through the eight practices.

It is not always an explicit emphasis in the *Framework* descriptions, but the conceptualization of practices concerns not only what professional or nascent scientists *do* but also what they are *trying to accomplish*. The objectives in Dimension 1 entail students' asking questions, developing models, planning investigations, and so forth, *as part of their epistemic pursuit* toward ends they come to value and seek. Students should experience science as a quest for understanding and become the epistemic agents animating that quest. Taking up practices of inquiry entails, in part, taking up "epistemic aims" and "epistemic values" of science (Chinn, Buckland, & Samarapungavan, 2011).

We also note how the *Framework's* description of practices involves references to affect: "The actual doing of science or engineering can . . . pique students' curiosity, capture their interest, and motivate their continued study" (p. 3-1). These references, we argue in this article, hint at something more important than science educators have explicitly considered, an *essential* role of affect in the doing of science at the core of epistemic agency: Students' or scientists' curiosity to explore and understand phenomena, their annoyance at inconsistencies, their seeking to formulate coherent explanatory accounts, and so on, drive their inquiries.

There is, meanwhile, extensive research documenting the difficulties educators face, specifically with respect to students' epistemic aims and values, which are typically quite different from those of science. Students often assess the quality of ideas, for example, by checking with authoritative sources, rather than through scientific practices of experimentation and argumentation (e.g., Hogan & Maglienti, 2001; Kuhn, 1991). Some of the challenges are that goals of students' engagement, Dimension 1 in *NGSS*, can be in tension with established core ideas and crosscutting concepts, Dimensions 2 and 3. Like scientists' inquiries historically, students' inquiries often lead in noncanonical directions, and instructional moves to guide them toward the canon can disrupt their pursuit of scientific aims and values (Berland & Hammer, 2012; Hutchison & Hammer, 2010; Leander & Brown, 1999). Students often end up "doing school" rather than "doing science" (Jimenez-Aleixandre, Rodriguez, & Duschl, 2000).

A major challenge for educators is thus coordinating these objectives: while we want students to learn the canon, we need to achieve this in ways that support, rather than disrupt, their pursuit of understanding. This tension prompts the question: How do students take up and persist in disciplinary practices such as those described in the Framework?

Answering that question, we argue in this article, requires attention to the role of affect. There are hints in that direction in the *Framework* descriptions; there are more in accounts of scientists, as we discuss in the following section. To be clear, we do not offer a complete answer to the overarching question of how students take up disciplinary pursuits or of how to coordinate the dimensions of the Framework. Our goal is more narrowly to show that affect plays a more substantive role than the science education community has appreciated to this point. The specific questions we ask are: What forms and roles of affect are evident in accounts of professional scientists? What forms and roles of affect are evident in student inquiry? How might affect be involved in students' engagement and persistence in science?

AFFECT IN SCIENTISTS' DISCIPLINARY PRACTICES

Evidence from scientists' ethnographies, biographies, and personal reflections shows that affect infuses disciplinary practices. We organize the discussion around five themes: the pleasure in studying phenomena, the feelings involved in scholarly interactions, empathy with the object of study, affective signals of cognition, and meta-affect.

Pleasure in Studying Phenomena

First, and maybe most obvious, scientists experience joy in discovery, "the splendid feeling, almost a lustful feeling, of excitement when a secret of nature is revealed" (biologist Gerald Edelman, quoted in Wolpert & Richards, 1997, p. 137), the "pleasure of finding things out" (Feynman, 1999). Microbiologist Félix d'Hérelle described the intense feeling he had upon his discovery of viruses infecting bacteria:

> On opening the incubator I experienced one of those rare moments of intense emotion which reward the research worker for all his pains . . . as for my agar spread it was devoid of all growth and what caused my emotion was that in a flash I understood: what causes my spots was in fact an invisible microbe, a filterable virus, but a virus parasitic on bacteria. (d'Hérelle as cited in Tobin & Dusheck, 2005, p. 206)

Scientists also describe pleasure in the study itself, before the discovery, perhaps partly out of anticipation for the joy of discovery. Geneticist Barbara McClintock said of studying corn: "I know every plant in the field. I know them intimately, and I find it a great pleasure to know them" (Keller, 1983, p. 386). She loved the pursuit itself, like "a child, because only children can't wait to get up in the morning to get at what they want to do" (p. 70). Physicist Carlo Rubbia said that "we are essentially driven not by, how can I say, not by the success, but by a sort of passion, namely the desire of understanding better, to possess, if you like, a bigger part of the truth" (Wolpert & Richards, 1997, p. 197).

There is no need to dwell on this, but we emphasize that we are describing enjoyment within doing science, pervasive in accounts of scientists (e.g., Dawkins 1998; Girod, 2007; Hadzigeorgiou, 2012; Keller, 1983; Polkinghorne, 1998).

Affective Aspects of Scholarly Interactions

It is also probably obvious that affective dynamics infuse social discourse in science, within collaborations and across rivalries. Collaborations often "provoke intense dialogues and principled disagreements, which can, at times, be daunting" (John-Steiner, 2000, p. 7). People become deeply involved in what they say in argumentative situations, experiencing feelings that span from uneasiness, impatience, excitement, irritation, triumph, and anxiety (Plantin, 2004). In partnerships, Mahn and John-Steiner (2002) contend, these dynamics create spaces for "emotional scaffolding" (p. 52) that is crucial for the give-and-take of ideas, constructive criticism, risk taking, and the collaborative construction of knowledge.

Rivalries inspire effort. Thagard (2008) recounts how "Watson and Crick were very worried that the eminent chemist Linus Pauling would discover the structure of DNA before they did, and they also feared that the London researchers, Rosalind Franklin and Maurice Wilkins, would beat them" (p. 240). Their feelings of fear and frustration over impediments or others' failing to acknowledge their work drove them to invest relentlessly in their ideas.

Fear of being misunderstood or rejected for one's ideas, if at odds with dominant views, might impact how scientists share and position their work, at times motivating further care in constructing claims to bolster validity, replicability, and reliability. Darwin, for instance, was reluctant to share his new theory of evolution (Gruber, 1974), waiting more than 20 years to publish it.

Empathy With the Object of the Study

At a very different level, various accounts present evidence of scientists empathizing with the object of their study. Virologist Jonas Salk described how he pictured himself "as a virus or a cancer cell ... to sense what it was like to be either and how the immune system would respond" (Salk, 1983, p. 7). Ethologist Desmond Morris similarly recounts:

> With each animal I studied I became that animal. I tried to think like it, to feel like it. Instead of viewing the animal from a human standpoint—and making serious anthropomorphic errors in the process—I attempted as a research ethologist, to put myself in the animal's place, so that its problems became my problems. (Morris, 1979, p. 58)

McClintock "could write the 'autobiography' of each plant she worked with" (Keller, 1983, p. 104), developing "a feeling for the organism" in the process:

> I found that the more I worked with [chromosomes] the bigger and bigger they got, and when I was really working with them, I wasn't outside, I was down there. I was part of the system... these were my friends ... As you look at these things they become part of you. And you forget yourself. The main thing is you forget yourself. (p. 117)

Lorimer (2008) described similar feelings in his ethnography of bird surveyors, who worked to "tune in to the bird's ecology" (p. 377) and developed "a form of 'molecular proximity' with the chosen organism" (Deleuze & Guattari, as cited in Lorimer, 2008, p. 384).

Ochs, Gonzales, and Jacoby (1996) documented physicists' making progress in part "by taking the perspective of (empathizing with) some object being analyzed and by involving themselves in graphic (re)enactments of physical events" (p. 330). The physicists, for example, would speak as if they were electrons: "as you go below the first order transition you're still in the domain structure and you're trying to get out of it" and "when I come down I'm in the domain state" (p. 339). There was similar evidence in the scientists' gestures and graphic representations of the physicists putting themselves in the place of the electron, a metaphoric connection that evidently helped them make sense of and reason about mechanism by imagining what the electron was "trying" to do.

Affective Signals of Ideas or Questions

Another role of affect is metacognitive. Having a question, for example, often comes with a sense of restlessness, and that feeling is part of the experience of a question; that feeling may be the first conscious signal that something is amiss. Similarly, having an idea comes with a feeling of excitement.

In his account of "aesthetic cognition" in science, Root-Bernstein (2002) quoted a series of scientists describing their experience of reasoning in this way: Botanist Agnes Arber spoke of "intense effort" raising "discursive reasoning ... to a level at which it lends itself united indissolubly with feeling and emotion" (p. 62). Physicist Wolfgang Pauli said "that scientific thinking begins within the 'unconscious region of the human soul', where 'the place of clear concepts is taken by images of powerful emotional content'" (p. 62). Chemist William Lipscomb described how he

> felt a focusing of intellect and emotions which was surely an aesthetic response. It was followed by a flood of predictions coming from my mind as if I were a bystander watching it happen. Only later was I able to begin to formulate a systematic theory of structure, bonding and reactions for these unusual molecules. (p. 62)

Einstein described a "feeling of direction" as he worked on the special theory of relativity: "During all those years there was a feeling of direction, of going straight toward something concrete" (Einstein, 1949, as cited in Keller, 1983, p. 150). His sense of unease with quantum mechanics—"an inner voice tells me that it is not yet the real thing" (1926, p. 91)—drove him to construct a "paradox" to prove it must be incomplete.

Similarly, Burton (1999) argued that mathematicians are often guided by "feelings that are associated with knowing" (p. 134), particularly in states of uncertainty and in "aha" moments:

> 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 text in the original, p. 134)

Aldous (2007) analyzed mathematicians' verbal reports during problem solving to show they frequently referred to feeling an idea, a problem, or a solution. She described their "feeling of cognition" or a feeling for "a new intellectual order" (Aldous, 2007, p. 181), concluding that feeling an idea is central to its construction.

These accounts of professional reasoning resonate with findings from studies in social psychology that explore affect as a kind of information (Clore, 2001; Schwarz, 2012), as well as findings from neuroscience research (Damasio, 1994; LeDoux, 1996). Damasio (1994), for example, found that patients with brain lesions that damaged their emotional responses became incapable of rational decision-making; a good choice should *feel* good, and when it doesn't, it is hard to recognize it as a good choice.

Meta-Affect and Affective Regulation

Finally, we discuss "meta-affect" (DeBellis & Goldin, 2006), meaning awareness and management of the experience of feelings:

> It is what enables people, in the right circumstances, to experience *fear* as *pleasurable* (e.g., in experiencing a terrifying roller coaster ride as fun), or to distinguish vicarious emotional feelings evoked by books or films from their "real life" counterparts. Meta-affect helps guide the experience of *hypothetical* emotions, as these are used for cognitive gain. (DeBellis & Goldin, p. 136, emphases in the original)

Scientists often articulate such meta-affective dispositions, for instance, perceiving confusion as motivating, associating puzzles and uncertainties with pleasure rather than intimidation, and perceiving inconsistencies as simultaneously bothersome and stimulating rather than menacing. Meta-affect, we suggest, is another part of scientists' experience of science. This is evident in Einstein's "deep longing to understand" (Keller, 1983, p. 387) and Rubbia's being "driven . . . not by the success, but by . . . the desire of understanding." Root-Bernstein (2002) described an "aesthetic angst required to motivate the search for a solution" (p. 72).

A recent popular book (Firestein, 2012), in fact, is dedicated to this point, how scientists thrive on "ignorance." "Mucking about in the unknown is an adventure; doing it for a living is something most scientists consider a privilege" (p. 15). Despite the possibility of finding out "that they were pitifully mistaken, fundamentally incorrect" (p. 66), grappling with the unknown generates "the motivation, the excitement, the thing that gets you to the lab early and keeps you there at night" (p. 66). "Success in science, either doing it or understanding it, depends on developing comfort with ignorance" (p. 87).

Again, there are similar accounts from mathematics; for example, Norbert Weiner writes that "one of the chief motives driving [him] to mathematics was the discomfort or even the pain of an unresolved mathematical discord" (Weiner, 1956, pp. 85–86). Likewise, Bertrand Russell remarked: "In all the creative work that I have done, what has come first is a problem, a puzzle involving discomfort" (Hutchinson, 1959, p. 19). As these quotations illustrate, feelings experienced within reasoning are not always positive. Much of what scientists learn involves coming to tolerate and persist through "negative" feelings.

Carlson's (2000) study of mathematicians working on problems produced evidence of this, showing how "each mathematician exhibited mild frustration." "It was during these frustrating moments," Carlson notes, "that they were most frequently observed scanning their knowledge base" (p. 143). Most notably, Carlson recounts, mathematicians had "internal discussions" to manage various cognitive and emotional responses to the problem-solving situation and were unwilling to let go of a problem once they had initiated a solution. They even kept at the problem after the interview had ended. These case studies highlight a kind of meta-affect whereby frustration at "not knowing" is leveraged to stimulate and inspire thinking.

EPISTEMIC AFFECT

These accounts show various ways in which affect pervades scientists' work. The first two we described are familiar in science education: the pleasures scientists experience in studying phenomena and the feelings involved in scholarly interactions. The next two roles of affect may be less familiar: metaphoric empathy with objects of study, such as in identifying with the system and feeling what it is "trying" to do, and affect as part of the experience of questions and ideas, such as in feelings of unease or excitement that signal latent confusions or novel insights. Finally, we discussed scientists' awareness and management of these various feelings as part of their expertise and maturity in the field, their feelings about feelings, or meta-affect, highlighting in particular their learning to experience challenges as pleasurable.

In these various ways, accounts of scientists implicate affect, not only or simply toward science but complexly entangled within it. We first described this affect as "disciplinary," but we decided that the term gave a misleading sense of feelings peculiar to science. We came to refer it as "epistemic" and, subsequently, discovered accounts in philosophy of "epistemic feelings" and "epistemic emotions" (Arango-Muñoz, 2014; Arango-Muñoz & Michaelian, 2014), such as "the feeling of knowing," a "gut" sense of an idea forming, or "the feeling of error," that something might be wrong.

Our purpose here focuses on science and science learning to argue that part of learning to engage in the intellectual practices of science involves learning at the level of affect. Taking up the pursuit means, in part, becoming driven by feelings of puzzlement and curiosity, coming to manage and be motivated by feelings of confusion and frustration, anticipating and seeking the joy of a discovery or a new understanding. To be clear, we are claiming that these feelings inhere in science, but we are not claiming that they are peculiar to science. (By analogy, an exercise physiologist would claim that abdominal muscles are important for dancing, but, of course, those muscles are not specifically for dance.)

We now turn to compare and contrast this view with prior research on affect in science education.