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Beginning Teachers Immersed into Science: Scientist and Science Teacher Identities

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ABSTRACT: We use identity as a multidimensional lens to explore ways in which beginning teachers saw themselves as scientists and as science teachers during and after 10-week summer apprenticeships at a science lab. Data included four interviews with each teacher, three during the apprenticeship and one after the first year of teaching. Two themes emerged that were used to organize the findings: (a) science as a practice and (b) science as a community of practice. Teachers came to appreciate certain science practices, speech acts, and tools. As scientists, they noticed and engaged in the nonlinearity, messiness, risk taking, evolution over time, and complexity of science (their own and others'), and in both levels of scientific activity, theory and data, and their interplay. Their scientist identity also came to incorporate the delicate dynamics of collaboration, autonomy, and mentoring within a community. However, for several reasons the teachers raised, such practices became elements of their science teacher identities to differing degrees. What they experienced as science teachers was a sense of conflict. At times this conflict took the form of ambivalence,

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a back-and-forth movement between their sense of the practice of science and their sense of what makes school different from the lab. *Sci Ed* **89:**492–516, 2005

INTRODUCTION

Apprenticeships in science research settings and apprenticeship-like learning environments have been receiving increasing attention as a means of helping students construct and appropriate understandings, practices, tools, and language used in scientific activity and avoid developing simplistic and naïve conceptions about the nature of science and the practitioners who do science. A few studies have explored high school students' (Bleicher, 1996; Etkina, Matilsky, & Lawrence, 2003; Richmond & Kurth, 1999; Ritchie & Rigano, 1996) and college students' (Ryder, Leach, & Driver, 1999) involvement in apprenticeships in scientific settings. In these studies, student involvement in doing science varied in duration and type, but in most cases it included a long-term project, outside the school setting, under the guidance of one or several scientists. The settings of engagement in scientific practice were mostly university research laboratories. In these studies, researchers explored characteristics of the practice of science that students noticed, appreciated, and constructed, noting both successes and challenges. Similar to the limited number of studies that explore K-16 students' experiences and understandings in science apprenticeships, there is a limited number of studies (some relatively very recent) that focus on preservice or in-service teachers of K-12 students and their own experiences and understandings in science-setting apprenticeships.

In this research, we learn from teacher candidates involved as "fellows" in a 10-week full-time summer apprenticeship in a science research laboratory. We use the lens of "identity" to explore how these fellows thought of science as a community of practice when they talked as scientists and when they talked as science teachers. We were interested in understanding the degree of fit or misfit between their scientist and science teacher identities by analyzing the thoughts they shared, over the course of their apprenticeship and one-year later after they had completed their first year as new teachers, about their lab experiences and what they would take from them into their own classrooms. In this way, we wanted to investigate whether these new teachers made sense of important scientific practices in different or similar ways depending on where science took place—science in the lab and science in the classroom.

THEORETICAL FRAMEWORK

The present inquiry is informed by three clusters of scholarship. First, there has been limited research that focuses on the value of teachers' or teacher candidates' participation in apprenticeships in science research settings. Second, there is extensive scholarship on the construct of identity that people develop in sociocultural settings. Third, there is ongoing diverse research that focuses on the nature of scientific practice and its characteristics as they relate to the practice of science teaching. For each of these clusters, we outline below the scholarship that shaped the present study.

Apprenticeships

Apprenticeships in science research settings allow teachers to participate in the scientific community and that helps them develop an enriched, more complex, and sophisticated view of the practice of science (Richmond, 1998) that is necessary if they are to help their own students construct such a view. Cunningham and Helms (1998) claim that such an experience is needed to give the teachers "the requisite knowledge—both sociological understandings of science and pedagogical knowledge" (p. 493) in order to succeed in teaching authentic science. Thus, teachers may be more likely to use experiences in the classroom that closely align with those experiences scientists may encounter in doing research. "Being a member of such a scientific community, and learning and participating in its discourse and practices are opportunities to be encouraged so that all students—not just the very few—might develop a richer understanding of and appreciation for the scientific enterprise" (Richmond, 1998, pp. 586–587). Such a classroom culture enables a larger population to experience the nature of scientific practice, thus making our classes more "democratic" (Cunningham & Helms, 1998, p. 486).

Reviewing existing literature, Brown et al. (2002) found mixed outcomes for apprenticeship models in teacher preparation programs in the US. Two studies emphasized positive aspects of apprenticeships—one revealed how apprenticeships helped in enabling teachers to implement worthwhile research experiences in their classrooms (Helmer, 1997), and the other documented the high quality of the teachers' research projects (Spiegel, Collins, & Gilmer, 1995). However, two other studies (with one being a continuation of the other) revealed that teachers do not necessarily develop complex sociological and epistemological understandings of the nature of science by only being engaged in science apprenticeships (Schwartz, Lederman, & Crawford, 2000; Westerlund et al., 2001).

Brown et al.'s own study focused on the apprenticeship science course offered at their institution where preservice teachers work with scientists for 9 h per week, have six seminar meetings with a science educator, and present their research at a research symposium with all the scientists and preservice teachers. The study exposed preservice teachers' conceptions of their involvement in research settings, and the variation in owning their work depending on the level of involvement. As the teachers reflected on how the apprenticeship experience affected their teaching practice, they offered reasons why they would not implement in their classrooms the apprenticeship experiences. Reasons included time limitations, content coverage, end-of-course tests, and their own limited understanding of how to do long-term investigative experiments in classrooms.

The limited research on apprenticeships that teachers undertake in science research settings points toward the need to explore more deeply the meanings teachers, and teacher candidates, develop in such settings, and how the sociocultural science settings they find themselves in come to shape their identities as practitioners of science and practitioners of science teaching.

Identity

The constructs of identity and identity formation are complex. Brickhouse, Lowery, and Schultz (2000) note: "Individual identity is not necessarily either single or stable. A person can be a part of or aspire to many different communities simultaneously" (p. 443). Lemke (2003) also emphasizes the multifaceted and developing (changing) nature of identity. He highlights that identity is constructed by interaction and is shaped by the cross section of self and others. Thus, identities are shaped, or some traits of our identities become foregrounded, depending on what is accepted in a setting. The culture of a particular setting provides cultural components used to construct strategies of action (Swidler, 1986), and shape the particular identities we develop by membership and affiliation to that particular setting. As Swidler articulates, "a culture is not a unified system that pushes action in a consistent direction . . . it is more like a 'toolkit' or repertoire from which actors select differing pieces for constructing lines of action" (p. 277). Furthermore, Swidler emphasizes that people do not build lines of action by choosing one action at a time. These lines of action are influenced by the ways the various actions are organized and linked in a particular culture. These actions depend on the particular worldviews, habits, beliefs, and the symbolic forms in general that people in the culture have to experience and express meaning.

Gee (2000–2001) differentiates between four different types of identity and elaborates on what influences their formation and development, along with particular examples of each identity. These are perspectives on identity that "interrelate in complex and important ways" (p. 101). The *N-identity* is the nature perspective that is determined by nature rather than society, but gains its force as an identity through the work of institutions, discourse, and affinity groups—the very forces that constitute the other perspectives. The *I-identity* is the institutional perspective—a calling or an imposition that is shaped by the authorities of a particular institution. The *D-identity* is the discourse perspective, the power of which is determined by the ways people treat, talk about, and interact with others, which may be further influenced by the particular institutions people are associated with. Last, the *A-identity* is the affinity perspective that is shaped by allegiance to, and participation in, a set of distinctive practices of a particular group. All of Gee's types of identity see identity formation as influenced by a delicate balance between the personal and the social, with the latter incorporating the socio-interactional, the organizational, the sociological, the historical, the semiotic, and the cultural. Thus, such a sociocultural position toward identity is based on an "ecological view of communities" (Lemke, 2001) where languages, belief systems, and specialized discourses and practices of communities that people inhabit shape their identities.

Lemke (2003) also contends that the issue of different timescales is critical in identity formation. Thus, we need to differentiate between short timescales of a certain situated activity and larger timescales that span across recurring similar activities. Furthermore, as he notes, "identities on all scales shape and are shaped by desires and fears rooted in human embodiedness and its subsistence needs, affordances of pleasure, and vulnerabilities to pain. The phenomenological experience of unique selfhood overflows social semiotic categories, both structural and agentive, as we create feeling as well as meaning for ourselves and others across the multiple timescales of our lives" (p. 2).

Understanding how apprenticeships in scientific research settings contribute to teacher candidates' or beginning teachers' identities as practitioners of science and of science teaching is the goal of our study. As we study interns' conceptions, we keep in mind Helms's (1998) conviction that "the self comes not just from what a person does, or his or her affiliations, but also from what a person believes, what a person values, and what a person wants to become" (p. 812).

Scientific Practice

There are multiple ways to frame relevant aspects of scientific practice and communities of science practitioners that educational researchers have developed and studied. These include how scientists use division of labor, communication, support systems, networks, and collaboration (Cunningham & Helms, 1998); deal with ambiguity, uncertainty, and complexity (Roth, 1995); appreciate the theory–data dialectic (Varelas, 1996); appropriate actions of others in the course of ongoing negotiations (Ritchie & Rigano, 1996); juggle the intellectual-thematic and the socio-organizational dimensions of a community of practice (Varelas, Luster, & Wenzel, 1999); and construct arguments that are convincing and compelling (Bowen, 2004). Such issues are, we believe, important parts of a set of standard practices, of speech acts, and of tools and equipment (Denning & Dargan, 1996) that characterize scientific practice. Thus, in this study, we use a multilayered framework of such aspects of a community of practice to explore the interns' conceptions relative to the practice of science and the practice of science teaching as they engaged in summer apprenticeships in science settings.

Furthermore, we take into account the distinction between seemingly different views of science that scholars have articulated. Dewey (1910/1985) distinguished between two meanings of the word science—as “the body of facts” and as “the processes by which something fit to be called knowledge is brought into existence.” He noted: “We define science as a systematized knowledge, but the definition is totally ambiguous. Does it mean the body of facts, the subject-matter? Or does it mean the processes by which something fit to be called knowledge is brought into existence, and order introduced into the flux of experience? That science means both of these things will doubtless be the reply, and rightly” (p. 75). Similarly, Holton (1988) noted the following as a contradiction: “Science seems to depend on clear and prescribed types of concepts in one direction, and on a free license of creativity in the other” (p. 405). He proposed to resolve this contradiction by distinguishing between two separate uses of the same word as noted above: “[there] are two very different activities, both denoted by the same word, ‘science’: the first level of meaning refers to private science, the science-in-the-making . . . the second level of meaning refers to the public science, science-as-an-institution, textbook science, our inherited world of clear concepts and disciplined formulations” (pp. 405–406). As we seek to explore the teacher candidates’ identities as scientists and as science teachers during and after their apprenticeships, we keep in mind these distinctions.

RESEARCH FOCUS

Teachers of science need to have a strong feel for and negotiate both the practice of science and the practice of science teaching. Thus, it is important that we explore and understand how teachers’ identities as practitioners of science and practitioners of science teaching come to be shaped during apprenticeships in science research settings, and how the meanings they develop become parts of their identities as scientists and as science teachers. As Bryan and Abell (1999) remind us, “a preeminent goal of science teacher education should be to help prospective teachers challenge and refine their ideas about teaching and learning science and learn how to learn from experience” (p. 137). If such experience includes participation in science research communities, what ideas become salient to teacher candidates about science and science teaching and contribute to their identities as practitioners of science and practitioners of science teaching?

Thus, we undertook to study the teacher candidates’ or beginning teachers’ own sense of salient elements of the practice of science and the practice of science teaching, along with similarities and differences among candidates and between the two practices. We aimed at identifying the cultural components, experiences, and actors associated with this summer apprenticeship that contributed to the teacher candidates’ identities as practitioners of science and practitioners of science teaching, and how these beginning teachers themselves perceived them and reasoned about them. We also undertook to explore how different types of identity are shaped by various dimensions of these apprenticeships and how they relate to the differentiation of private and public science.

In this way, we wanted to contribute to the limited literature on the ways teacher education majors make sense of relatively long experiences in scientific settings and how these experiences shape their meanings and their feelings about science and science teaching. At this point, it is worth noting how we use the term apprenticeship. The fellows were not apprentices in the sense that they would become permanent members of that practice. However, using the notion of authenticity as defined by “the dynamic manner in which [certain cultural] components come to interact and define the overall system over time” (Rahm et al., 2003, p. 741), the fellows were involved in authentic science settings where they were inducted in, and did science over a sustained period, just like apprentices do (Lave & Wenger, 1991).

CONTEXTUAL BACKGROUND

The Department of Energy and the National Science Foundation have teamed up to support PreService Teacher (PST) fellowships designed to "provide laboratory research opportunities to highly motivated preservice teachers. The program targets a diverse group of preservice teachers preparing to teach K-12 science, mathematics, or technology and provides opportunities for them to do research in a laboratory setting" (Department of Energy, 2002). The three preservice teachers in this study were from a large Ph.D.-granting research university where they had just completed their certification programs. They applied and were selected through a nationwide competition to work as PST fellows on research projects at a major science lab. Fellows were paid a stipend for their summer research, as well as a housing and/or travel allowance.

The fellows were given a list of projects available at the lab when they first arrived, and from this list (in consultation with the Director and staff of the Education Office of the lab) they chose which project they wanted to pursue for the 10 weeks. The students were paired with a research mentor, an employee of the lab studying the topic of interest. Once during the summer the fellows were visited by the Department of Energy program officers to debrief about their progress.

The time spent during their 40-h week was recorded in a weekly log the fellows submitted in order to receive their stipends. Fellows were also provided with a "syllabus" of experiences to take place over the summer. While most of their time was spent conducting research and writing, additional experiences included an orientation to the lab, the PST program and its requirements, attendance at science workshops, activities, and seminars, and weekly lunch meetings with program staff and lab personnel.

METHOD

Participants and Setting

In this study we focus on the three fellows who worked in the lab during one summer. The two women fellows, Elena and Pamela, had just received their bachelors degrees in elementary education, both with endorsements in middle-school mathematics. David had received his master's degree in secondary education with endorsements in English and physics. (All names used are pseudonyms.) All three fellows had completed the mandatory science courses for their education degrees, as well as their science teaching "methods" courses. They were aware of distinctive differences between their experiences in science courses and what they had learned about teaching and learning in their science teaching methods courses. Their science courses were filled with "traditional" elements—"for the science classes that I've had, it was just like read the text, we're having a test" (Elena) or "what I've gone through school is this, is how you do it, this is what you're going to do next, this is what I want out of you, this is what I expect of your paper . . . [school was] regurgitation and that's why I did horrible in physics" (Pamela). In contrast, in their science teaching methods courses, the fellows had explored constructivist principles that foreground the role of learners, their needs, motivations, prior understandings, and interests, along with an emphasis on the complex, nonlinear, dialectical, and collective nature of scientific practice.

The fellows were involved in different projects at the lab. Elena and Pamela worked on ecology projects, whereas David worked on a physics-related project. Elena and Pamela worked closely with each other in research in a prairie on the lab grounds. That research involved species-diversity sampling and documentation. Elena opted to conduct a study of the effectiveness of the bluebird boxes on the lab prairie. She investigated the 29 bluebird boxes on the grounds and determined whether they were being nested, and if so, what birds were making the nests. Her research focused on four specific geographical regions of the campus, and, as well as assessing the placement and design of the boxes, she continuously monitored the housing to follow their use. Her study necessitated frequent walking of the grounds, as well as mastery of information on bird calls, appearances, egg characteristics, and nesting habits. By the conclusion of the project, she had determined that most of the boxes were not being used by bluebirds, and she was able to offer explanations and implications of her findings.

Pamela also chose to work on a prairie project, but a different one—she explored the diversity of butterflies on the lab grounds. She surveyed the butterfly population every afternoon in three different habitats on the grounds: the public, open prairie, the private prairie, and the forested area. She recorded the number of butterflies and the number of species, and developed appropriate means of reporting her data. She concluded that the woodland contained the largest diversity of butterflies, and she was able to draw a link between butterfly diversity and the quality of reconstructed portions of the prairie.

In contrast, David worked on physics projects. Initially David chose to work on an ongoing project to build and test handheld cosmic ray neutron detectors interfaced with a computer and suitable for classroom use. Over time, however, David worked more on a related project redesigning a website for an ongoing neutrino oscillation study, a project designed to "test for neutrino mass via a search for neutrino oscillations" (Booster Neutrino Experiment Website, 2002). David found that this study led to a need to master computer programming. Toward the end of his project David began to study programming languages, such as HTML and writing GCI scripts.

During their fellowship, the beginning teachers or fellows engaged in an array of standard scientific practices: developing a question, collecting and analyzing data, interacting with other scientists, keeping notebooks, attending seminars, workshops, lectures, and other presentations, and writing and presenting a scientific report of their research. Specific guidelines for the written scientific reports were given to the fellows from the Department of Energy literature and representatives with the intent to publish the reports on the DOE website. The lab's Director of the Education Office informally assigned due dates during the summer for the various parts of the reports. Fellows were also given both informal and formal opportunities to present their findings. Fellows attended informal meetings during the summer (such as weekly brown bag lunches) at which they discussed their research, findings, and teaching interests. At the end of the 10-week program, fellows delivered a more formal presentation of their work to the community of interest.

All the fellows found and accepted full-time teaching positions for the academic year following their summer fellowships. In his first year of teaching, David taught middle school science and math at a small, year-round, military academy within a larger urban public school. Elena found herself teaching second grade at a large urban public school. After her first year there, she moved to a different school within the same city. Pamela taught eighth-grade math, algebra, literature, and core enrichment at a suburban school. All fellows taught the prescribed school curricula in their first year of teaching.

Data Collection and Analytical Approaches

The source of data for the present study is a set of four interviews we conducted with each of the three Fellows. The first set of interviews took place in the 3rd week of the fellowship, the second set of interviews in the 7th week, and the third set of interviews immediately after the fellowship was completed. All three sets of interviews took place at the lab to allow for informal observation of the fellows. The fourth set of interviews was conducted with two of the three fellows (Elena and David, as Pamela was not available) and took place one year after the fellowship was completed—in the summer after the fellows had completed their first full-year as new teachers.

The interviews ranged from 60 to 90 min each. The first set of three interviews was conducted jointly by the first two authors and the subsequent ones by only the second author. They were all taped and transcribed. We also took notes. Although we asked each of the Fellows the same set of questions, their responses dictated the type and number of follow-up or probing questions. The semistructured interviews included general questions such as: What's the fellowship experience like for you? What new insights are you getting? What ideas get reinforced? How's this experience preparing you further as a teacher? How close are you getting to practicing science and in what ways?

In all questions fellows were encouraged and probed to relay their answers in terms of specific experiences or events. We allowed our experiences in the first interview to inform our subsequent interviews. Specifically, we expanded our bank of questions for the subsequent interviews to include probes such as: Describe your experience and relationship with your mentor(s). What do you hope to have an opportunity to do before the end of the experience? Did you set and are you realizing any self-selected goals? Describe your journaling. Describe your interaction with your peers.

During the first three interviews, as we were mindful of time, given that we were interviewing the fellows in the lab setting and during their normal day, not necessarily every question was able to be discussed at every sitting. Interviewing the fellows in the lab allowed us to interact with them within the setting of their research and the context of their daily schedules. On occasion we also attended lunch meetings with the fellows and observed them informally in their settings. During the fourth interview we were more unscripted in our approach, initially asking the fellows what they remembered from their fellowship experience and inviting them to talk about their first year of teaching and how their fellowship may have shaped their teaching practices. Their responses were used to guide follow-up questions. Each of the fourth interviews lasted just over an hour.

We conducted the interviews in the way specified above in order to let the fellows draw upon their experience in the lab and the classroom, and bring out their conceptions regarding the practices of science and of science teaching, through a variety of opportunities and prompts. Conversational-style interviews allow for extensive mining of interviewees' perspectives, views, understandings, and interpretations. However, it is also important to keep in mind limitations of interviews that, in fact, apply to all forms of communication. Interview data depend heavily on interviewees' abilities to articulate their views and ideas, and interviewees' interpretations of the purpose of interviews and the questions asked. Furthermore, what is more pronounced in conversational-style interviews rather than other forms of expression of ideas is that interviewees' conceptions are brought out in the context of the interaction between the interviewer and the interviewee. Being cognizant of that, the interviewer (and 2nd author of the study) was very careful not to lead the fellows in any particular views and directions. Nevertheless, as Bakhtin (1981) reminds us: "Language is not a neutral medium that passes freely and easily into the private property of the speaker's intentions; it is populated—overpopulated—with the intentions of others. Expropriating it, forcing it to submit to one's own intentions and accents, is a difficult and complicated process" (p. 294). Thus, this study sheds light only on the fellows' "interview-situated" conceptions and meanings.

Denzin and Lincoln (1994) note that qualitative research and analysis is especially well suited to "seek answers to questions that stress how social experience is created and given meaning" (p. 4). Thus, we employed a qualitative, interpretive approach to explore how the fellowship experience contributed to the preservice teachers' identities as novice scientists and as beginning K-12 teachers of science. Furthermore, the use of grounded theory

(Strauss & Corbin, 1990) allowed themes to emerge from a back-and-forth process between engagement with the data at different levels and discussion among researchers around their interpretations of the data. More specifically, each author first read all interview transcripts identifying main ideas that were perceived present. After discussion among the researchers around main ideas and fellows' ways of thinking about them, the 2nd author developed narratives for each of the three fellows distilling the long transcripts of the several interviews for each fellow into one abridged "story" per fellow. The narratives were read by the 1st author and checked for accuracy. After reading the three narratives, and discussing similarities and differences, the authors started to identify larger themes. Then, each of the two first authors went back to the transcripts and flagged all instances of these themes present in each fellows' talk about both communities—the science community in the Lab and the science classroom community. Subsequently, we organized all instances in an event matrix (Miles & Huberman, 1984) for each fellow. Using an iterative constant comparative method (Glaser & Strauss, 1967), all three authors finally created a unified set of interpretations about each Fellow's thinking.

FINDINGS

As the fellows and soon-to-be teachers engaged in science apprenticeships, they noticed and made their own sense of important standard practices, speech acts, and tools of scientific practice as scientists and as science teachers. Two themes emerged from the data that encompass many of the various aspects of scientific practice identified in the theoretical framework—(a) science as a practice and (b) science as a *community* of practice. As the fellows brought up elements associated with each of these themes, they revealed who they saw themselves being as practitioners of science, and they allowed us to see what, who, and how it was shaping who they were as people doing science, engaged in scientific practice inside a large laboratory. Furthermore, these fellows revealed how they negotiated their scientist identities with their science teacher identities. Some of the salient elements of the practice of science that the fellows experienced and made their own in the lab took different meanings and significance as they revealed who they saw themselves being as teachers of science in the classroom. Their science teacher identities incorporated some important standard practices, speech acts, and tools of scientific practice, but in forms that expose the delicate and difficult tensions they struggled with in the practice of science teaching.

Science as a Practice

Scientist Identity. The nonlinearity, messiness, risk taking, evolution over time, and complexity of science (their own and others') came to be defining elements of who the fellows have been as practitioners of science. In some ways, they anticipated it, they enjoyed it, but it also frustrated them at times. The fellows also engaged in, and appreciated, both levels of scientific activity, theory and data, and the interplay between the two—a critical intellectual element of scientific practice.

Nonlinearity, Messiness, Risk Taking, and Complexity. As the fellows worked in the lab, they came to see that tinkering with ideas and materials happens in a nonlinear way. For Pamela, the novice scientist, research is a lot of "just playing with what we've got" and "finding out what works and what doesn't work." According to Pamela: "It's funny to hear some of these physicists talk because, you know, they're, like, they laugh at themselves saying that they're just still trying to make sense of the basics anyway . . . It's kind of like playing with what you've got and searching." Furthermore, Pamela started conducting a butterfly survey without having a sophisticated grasp of what a "survey" was which she more fully developed along the way.

For David, too, exploration was an important element of who he was as a scientist. "I think what I'll do is just play with this cosmic ray detector to figure that out and to sort of work with that." For David conducting scientific research involves encountering problems and working—often through trial and error—to discover their solution. "People who are looking at the things that are coming out as they run the experiment . . . they're sitting there wrestling with this problem, how do we run an experiment, set it up, and also not know what we're getting while we're running it . . . It's like this tension that they're wrestling with, it's pretty neat."

For both Pamela and David, it was defining cultural components of the practice of science (e.g., not knowing, sharing, wrestling, tensions) that caught their attention and that they decided to adopt in their practice. It was within the cross section between themselves and others, along with the accepted norms in the setting, in which important dimensions of their scientist I- and D-identities were formed. Furthermore, David also showed us how feelings, along with meanings, contribute to the formation of the scientist identity.

Likewise, Elena's time at the lab helped her see how mistakes are made all the time, they get corrected, and the work moves on. "There's a lot of, like, factors we have to think about . . . that you don't think about, like, the first time you're doing everything and you're like, 'I wish I would have known this sooner so I could have done it . . . how could you miss that?'" When Elena went to the field with Pamela to catch butterflies, "We're like, this is easy. The net is, like, this big. We're going to be able to catch a bunch of butterflies . . . [but soon we realized] Oh my goodness, we're like, couldn't catch anything, couldn't find anything, ran them all out of the prairie [with the big net]." For Elena the nonlinearity of scientific practice involved going back and forth—while she was preparing her final report and showing it to her research mentor, she noticed "there is some data that is missing, like certain measurements that I had already taken, but I need to go back out there and take it again." Elena's scientist D-identity that was being developing in the context of interactions with her mentor accepted making mistakes as an unavoidable part of doing science that needs to be attended to.

For Elena, taking risks was a characteristic of her developing scientist A-identity. She was working with her research mentor, Pamela, and others, in the midst of the lab prairie, but as a lifelong city dweller, nature was fearsome for her. At the beginning of her research, Elena admitted "[I'm] still getting over my fear of nature here." She "slowly approached things," exercising caution in her unfamiliar surroundings, and frequently was terrified of what she was doing. She later noted: "We saw a dead snake. I'm like, 'ooh, I want to touch it.' Before, I'd be like, 'oh my gosh,' you know, I'd hurry up before it comes back alive or something." Elena's much longer experiences in the city had shaped her fears that she was trying to suppress, or overcome, as she was living the short-term lab experience. Her developing scientist identity was shaped by the differing timescales of her experiences.

For David sticking with a topic long enough and experiencing the inevitable failures was part of developing understandings. When speaking of working with Pro Script, a programming language, David recounted "I failed completely. I mean I learned a lot of it, but I kept trying." His failure, frustration, floundering, and flexibility allowed him to eventually master the task. Elena also indicated that as her time in the field increased, her understanding of the habits and characteristics of the birds increased dramatically—"I actually know birds now. I mean the different types, some of them, I'm getting the hang of it." Pamela knew how complex scientific work was—"we really just had to decide everything, you know, how, where, what, why . . . I had to decide what I'm looking for, how I'm looking for it, where I go, how we go, you know, the different materials that we use . . . I think that in order to do a project like this, you have to do everything." A very strong sense of self as an agency came through in defining her identity. Furthermore, she echoed the sense that a state of messiness exists before sense making comes around in the practice of science—"[I had to] just jump into it and learn . . . I have all these things in my head about all these different butterflies and asking all these questions but to have, you know, a research question [is difficult and takes time]." For Pamela, the scientist, her practice involves coordination between a wild collection of ideas and a structured question.

Theory–Data Dialectic. A different coordination became a critical element of the fellows' scientist identity, namely the dialectic or interplay between theory and data. The fellows saw the data level as a critical part of scientific activity. For David, it was important to "make sure you are precise in the way you collect [data], and there's a lot riding on it, and it doesn't happen in a second, you know, and there is a lot of time that is spent problem solving, and thinking about things." And, in his mind, instrumentation affects the quality of data—"the tool you're using to measure, how accurate is that?" Likewise, as Elena talked about Pamela's project, she noted: "You don't go straight ahead, which we did and we probably shouldn't have, you're supposed to go walk on the side so that [the butterflies] don't think anything, and, like, the clothes you wear when you go, you're supposed to try to blend in, I mean we're out there with our pink T-shirts or something and we, like, stuck out." For Pamela, the scientist, the data level, the routines associated with data collection, and the data's variability were salient—"that grass gets higher everyday, so, I mean, each [day] is kind of, like, you have to peek a little bit more . . . but that's part of the data collecting . . . you could collect data forever and you will get something different every time."

However, along with the emphasis on the data level, all the fellows, as scientists, talked about the theoretical level and explanatory frameworks that were an important part of their and others' practice of science. David noticed what the other scientists in the lab were doing—"here's the problem . . . the different experiments found radiation at one point and measured it at another and it was different. They're trying to account for why that is." For David, the scientist, a theory is a model, framework, and the outcome of "imagining." It is a salient element of his scientist identity, his scientist D-identity that was promoted by the interactions he had with other practitioners as he was immersed in the culture of science. Elena also showed how she had constructed the dialectic of theory and data as part of her scientist identity—at several occasions she talked about how the knowledge and understandings she had developed about birds allowed her to collect more and different data all the time—"I mean now I hear everything [because I know what to hear]."

Elena's sense of the interplay between theory and data was also exemplified in her struggle to differentiate between results and conclusions as she was writing up her research report. "Results and conclusions . . . what's the difference? Why don't you just call it 'the end'? But, then, I found out the difference is [inaudible] basically state what you have in your table, and what you've found, not what you make of what you found because that's in your conclusions, and that's, like, really hard for me to, I really had a struggle with my results . . . it's like, in my results I'm, like [inaudible], and this is why this and why that, and I kept on going on what should have been in the conclusions." Part of Elena's struggle was that she wanted to explain her data and offer her theoretical constructs that would allow her to make sense of her empirical results as she was writing up her results, as opposed to waiting to put these data–theory connections in the conclusions. A cultural component of the practice of science, namely the existence of two separate sections (results and conclusions) in a scientific report, enabled her as a scientist to grapple with the theory–data dialectic, an important element of scientific practice. This opportunity arose as her scientist I-identity was being formed.

Science Teacher Identity. As teachers of science, the fellows recognized the messiness, complexity, and uncertainty of science-in-the-making, but hesitated, debated, wondered, and worried about the extent to which they could and should be enacting them in their classrooms. They differentiated the practice of science teaching from the practice of science referring to teacher's ethical and moral obligation to students, student prior knowledge and understandings, time constraints, need for closure, and student interest. When it came to science teaching, the fellows also privileged data collection and analysis over developing theories or explanations. They justified their preference based on student and their own interest, their own flexibility with content knowledge, available curricular materials, and the difficulty of constructing a conceptual framework.

Dilemmas: Messiness vs. Order and Structure. As noted above, the fellows' science teacher identities incorporated elements of science-in-the making. Elena, the science teacher, condemned "book science" and contrasted it to "what happens in science," advocating that "you have to try over, that's why [students] always have to test over. You have to see that science isn't always going to happen the way that it says in the book." She thought that "it's okay if [students] make mistakes in their science experiments," and she appreciated that variability was inherent in scientific explorations and did not imply incorrectness—"and if, I mean, [students] may have done the same thing but maybe we just have two different outcomes, it doesn't mean that you're actually wrong." And Pamela echoed the idea of complexity and nonlinearity in the practice of science teaching—"I don't think there is a right [answer] necessarily, I mean you're probably going to be searching, hopefully you're going and get a certain answer and then you would just reinforce the importance of numerous trials, you know, and say 'well, maybe we should try it again.'"

However, despite her recognition of the learning possibilities that stem from erring, Elena noted the tension she felt as a teacher to encourage the "correct" answer—"it's just like, I mean, it's so hard because as a teacher you feel like I have to teach them this so they definitely have to get the end results correct." And many times, Elena wanted her students to get to one particular place, although she acknowledged that it may be impossible—"my lesson plan was all neatly planned out that [students] are going to do this, they're going to do that, and you know, kids don't always go the way you want them to." Elena also recognized the need for students to confront their mistakes but questioned her ability to allow failure in the classroom—"it's better for them to do it actually, like, learn their lesson but when it comes down to it, I don't know, like I'm the type of person like, 'oh, don't forget this' and I'll ruin it [for them], you know." Although as a scientist she believed in jumping in and playing around with ideas, questions, and techniques, as a teacher she was more cautious because "kids' lives are at stake . . . I'm scared, like, I don't want to screw up these kids." Elena associated a moral responsibility to her teacher duty to enact more of science-as-an-institution in her classroom. And she further associated this moral duty with her sense of her teacher responsibility to help students understand and construct meaning—"when they told me, 'Oh look Ms. T. it's floating!' I'm like wait a minute that's not the one that's supposed to float, you know, how am I going to break it down for them to understand?" As she recounted some of her teaching approaches, she noted: "I think [my] experiments are more like straightforward. I don't think I set up most of my experiments where, 'well, you didn't get this, well, what do you think you did wrong?' I don't think I discussed a lot of it with [my students]." In some ways, Elena's science teacher identity is multifaceted as she tried to coordinate her own meanings and feelings of practicing "messy" science with her constructed responsibilities as a teacher of science that are associated with both her science teacher N-identity as a nurturing person who wants to prevent others from failure, and her institutional science teacher identity as she needs to make sure students learn what they are supposed to.

David, too, held different ideas about the practice of science as a science teacher as opposed to as a scientist, but he brought up other reasons for his differentiations. At the beginning, David thought that floundering may be appropriate only after some basic understandings have been developed via "book knowledge you know, getting ideas, learning in the traditional way." But, after his first year of teaching, David portrayed a different image, as his science teacher identity was evolving: "I'm trying to have [students] do a lot of hands-on stuff, a lot of playing, fun, like we use magnets, and we sprinkle filings on them, and giving them time to explore, and play around before I get into more structured stuff." David described a lesson from his class where, in a sense, he played around with allowing the students to play around. However, David struggled with the dilemma of messiness versus structure, and the constraints of time and his need to bring closure to topics made him "feel like I really cheated [students] on content last year, you know. This year I'm going to, really, I think I'm really going to structure, think about having it more content-driven . . . because a lot of time I don't feel like I'm getting closure. I think it's, a lot of neat things are happening, but I think that it's kind of scattered." But, at the same time, David almost prided himself on accommodating floundering. "So if a student said I want to explore this thing with the water, I said 'all right try it out and see what happens' [and that felt good!]" David struggled to negotiate his scientist view of messiness and nonlinearity with his science teacher view of need for balance between science-in-the-making and science-as-an-institution. As he closed up his fourth interview though, he came down to science teaching as a practice, thus portraying a multifaceted science teacher identity—"You know, I'm trying out all kinds of things [in my classroom], and you know, I'll make discoveries."

Furthermore, for David student interest and motivation was considered critical for enacting the messy, complex science-in-the-making in his classroom—"I just think about students from what they're like and how much, you know, you just, how interested you need to be in doing like a scientific project." And Pamela, the science teacher echoed this concern: "I want [students] to learn the same way I learned all these things, I want them to find it, the hard part is that I have to make it interesting and give them a reason to want to find out."

Data Wins over Theory. Student interest, along with his own, also played a critical role in David's view about the theory–data dialectic in the classroom. During his apprenticeship at the lab, David, the science teacher, had the theory level of scientific activity very much foregrounded. Answering why, figuring out what's going on, and using imagination were elements that David associated with the theoretical level, was excited about, and thought would be "great" for his students. "You try, and think of why that happened, and try to revise what initial ideas were about . . . and if you're doing that with students that's great, I mean it's just fun using your imagination, you get to actually, 'wow am I right? No I'm not, but that's cool,' and try and figure what's going on."

But after his first year of teaching, data collection and analysis had front stage in his mind. "The idea of data is huge in my mind. Collecting data . . . kids need to be doing science not reading textbook science, it's just exciting you know so I bought into all that . . . and I think of these words [I kept hearing at the lab] 'look at your data' . . . I really want the kids to go through . . . experimenting . . . in science it's more about do you have any hard evidence, like hard experimental, observational evidence for something, and . . . we've got to get good data." And he explicitly acknowledged that he has not "gotten really into theory a whole lot with [my students] . . . I don't know, kids like measuring paper clips, you know, okay, so there are like these big concepts that seem to just, like, mean a lot to me, that I use . . . when I talk to the kids." Thus, in his practice of teaching science, David wanted to help his students construct an appreciation and understanding of both levels of scientific activity, but he had not reached that point yet. He, as the teacher, had elements of the theory level in his mind and his language, but his students were not necessarily interested in or taken by this—at least as seen by David's eyes. His emphasis on the data level in his practice of science teaching seemed to be associated with a scientist D-identity as he was participating in the talk of his colleagues in the Lab, and a science teacher I-identity as he was paying attention to what generally students in schools were interested in.

But it was not only his students' preference for the data level that led to this imbalance of attention and construction of both levels of scientific activity; David's own immature flexibility with scientific content knowledge also contributed. "I might just leave it out there, and be like hum 'isn't that interesting. I wonder why that happens.' I mean I'm not even sure . . . You know, because my science is not really, really that deep, but I'm like really into it, you know."

Furthermore, when David started teaching, he noted that some of the curricular materials available to him and his students—an important cultural component of the practice of science teaching and school science—were heavy on data collection and analysis—"I looked at them, and there's a lot of process in there. Here's an experiment, they read about an experimental situation, and there will be a data table." Another element of his science teacher I-identity was pulling David closer to data rather than theory. David came to realize that theory, although important, was difficult and challenging for his class. As David and his students did experiments throughout the year, David would encourage them to "pick a variable, and mess with it." But David saw that students had difficulty with this since they did not have a larger framework to think about that particular topic or concept they were empirically exploring. As he noted: "But the kids don't see the system with the variables, you know, it's just something that I've come to understand, but I don't think I appreciate how difficult it is for people to get."

In contrast to David, who as a science teacher considered the theory level of scientific activity but still privileged the data level for his teaching practice, Elena and Pamela almost exclusively thought only about the data level. Elena referred to students doing hands-on activities, collecting data, and building things. She rationalized the increased attention to the data level using what she knew about kids—they cannot sit for long periods of time and they get bored easily. "Kids don't like to just sit there. Anything they can do with their hands, they're fine . . . They weren't bored. They weren't tired. I mean . . . it's part of getting involved and actually seeing it and being able to touch it." Referring to a unit on magnets, Elena noted: "And they loved it, they loved having science class, they loved doing those experiments . . . So I gave them a bunch of just, like, little things, and then I even had them see if they could pull some object through aluminum foil, pull it through cloth, if the magnet would pick it up or not. So I mean it was pretty exciting to see them like actually do that, you know, I mean they were just like, 'Oh!' and even though I mean it's something simple for us to see that of course magnet sticks to anything that's metal, you know, they were just like, 'Oh look Ms. T. it sticks, it sticks!' and they were just very excited to see something like that." Her students' interest in the data level was shaping Elena's D-identity as a science teacher relatively to the theory–data dialectic. For Pamela, though, it was her own interest and excitement with data that made her construct this level as a salient element of her science teaching practice—"the observation, that still amazes me . . . I think that I would allow my students to do that more."

Science as a Community of Practice

Scientist Identity. Fellows noticed that the community of scientists that they have been a part of is a community marked by much collective activity but also balanced with great freedom for individuals. Fellows reflected on how they navigated the autonomy they had, as well as their place within the community. For them it was an exciting, enjoyable, but sometimes uncomfortable experience. As they learned the ropes in the world of science, they depended at times on the guidance of their mentors. Thus, as the fellows interacted with people and routines in the lab, their scientist identity came to incorporate the delicate dynamics of the community of science where collaboration, autonomy, and mentoring play out in ways that allow participants to work together and newcomers to be inducted into the practice and offer their own contributions. The fellows constructed the social nature of scientific activity in two different ways—in terms of scientists working in groups, thus forming a community of practitioners, but also in terms of the community shaping the work of practitioners who work together or alone (Latour & Woolgar, 1979).

A Community That Shares, Determines, and Validates. Pamela, the scientist, like David, noticed early on that the lab "is a community and I had no idea." They both noted an important cultural component of the practice of science that they were living; that at lunchtime the lab cafeteria was bustling with conversations among researchers from different projects, all eager to share their knowledge and expertise. Both a common place to meet and a structure that brings scientists together in the lab, the cafeteria stuck out in David's mind—"everybody eats lunch there and there's always talks going on . . . and it brought people together . . . it's pretty cool." And Pamela, like Elena, talked explicitly about her project and the community of scientists—"throughout the lab people are so helpful, nobody's hoarding information. It's just, everyone's willing to share and they're begging to share. It's just really neat how everybody works together." The concept of a community that shares information, ideas, and expertise seemed to be a part of the fellows' developing scientist I-identity filled with meanings and feelings.

Furthermore, Pamela and Elena, the scientists, felt that it was important they could work together and their collaboration was not only a source of meanings, but also feelings for them—"to have Elena here, I mean to have someone to be like bouncing ideas off and, you know, to make fun of me when I, like, you know, catch these stupid butterflies, you know, even if we're sitting in the computer lab and like, 'oh my gosh listen to this,' you know, it helps a lot." In contrast, David's peers were working quite a distance from the location where his work took place. Often, he worked in isolation, craving the interaction he was able to enjoy on rare occasions. "I'm not around a lot of people in my situation. So I feel like I'm missing out on a lot of the talk that they do and building the sort of connection with the group."

For David, the scientist, the research community does not only share knowledge and expertise, but it also determines and approves projects. "First somebody comes up with an idea. They want to do an experiment. Then they go and they present a letter of interest which is presented to the community. 'Now here at the lab this is what we're thinking about doing. Does anybody want to do it to see if it's something that has appeal to other scientists?' It just moves along and this process takes a couple years. They build a collaboration . . . Everything is open to debate like how they did the experiment, how they analyze the experiment." And Elena saw the projects already shaped in the scientific community she joined as enabling her contributions—"I probably would never really have focused on birds if, like, the topic wasn't, you know, there for me to do my research on. I probably wouldn't have had the nerve to actually go up to a bird box and actually look in it or see eggs." The community's determining and enabling role became part of her scientist A-identity.

Furthermore, Elena had also constructed the validating role of the community experts as part of her A-identity. The larger community of practice would need to put its stamp of approval on Elena's work. She worried about her research report, an essential cultural artifact of the practice of science: "I want to get the data right. I'm scared someone's going to be like this is not right, this is not true." She eventually saw the approved paper as a means to raise her status of teacher. At the end, Elena exuded pride for her paper. She was over the minimum page limit, she had included many pictures and tables, and "you know, actually seeing it going to be posted on the Internet is kind of cool." She had written papers for college courses, "but it's, like, it's for the Department of Energy. To me that's something big."

Individual Freedom and Control. At the same time fellows highlighted collectivity, they also foregrounded individual "freedom" and their own contributions and responsibilities that they wanted to share with the community as part of their scientist A-identity. David characterized his fellowship as "[having] all this freedom to do what I wanted." For Elena, the scientist, "[the research] was kind of like a free thing. I get to roam wherever I want . . . I had to actually go out there, and do it, and find ways of how I was going to do it, and talk to different people, and get different ideas. I don't think I've actually [ever] had the chance to go out there on my own, and like just try things, and like not have someone look over your shoulder." For her, this freedom was needed for intellectual stimulation—"I wouldn't also have someone thinking for me because once that happens, I start to become lazy . . . I mean, I would go and do it because they said to do it but then I don't think after that I would let my brain think, like, 'oh yeah, maybe I should do this' or go like a step further." Pamela was excited to have control over her project. "It started out as butterfly survey on a piece of paper and now I mean I'm making it into, there's more butterflies in this area than another you know and why that is or why it isn't. To make a question of my own and to actually find numerical data to, like, explain, it is very neat." Her science experience produced feelings that helped her construct her image as a scientist—both good feelings and feelings of frustration as she tried to balance freedom with help from others. "It has been difficult being, having so much freedom with what I'm doing."

But the scientists' freedom was constructed in the midst of the community's characteristics and, specifically, the sharing that was going on. David thought of the final research presentation as "[giving] me an opportunity to just share, and get in front of people and show off a little bit, and I had fun doing it . . . you want to share your knowledge, you know, you want to talk, and making a venue for that." Elena further highlighted the complex interplay between the community's expertise and her own effort—"just hearing information all the times about the different things that are around here, and then finding ways, and you know going, you know, to do things on your own, and it's like your experience that you actually getting to share with somebody else."

Mentoring. Furthermore, within this community of science practitioners who share, collaborate on, and negotiate projects, understandings, and participation, the fellows constructed how experts play both a facilitating, scaffolding role and an authoritative, appropriating role. For the fellows, their mentors mediated the delicate balance between, on the one hand, collectivity and collaboration, and, on the other hand, individual choice and accomplishment, thus playing an important role in developing their scientist D-identities.

David loved talking science with his mentor. "He and I will sit and talk about physics and when he has time, he's very willing to sit down and explain things and talk to me. . . And so we just sat down and talked . . . It's really great . . . it's cool." And it was through his mentor's help that David developed an important understanding: "You know [my mentor] would constantly talk about math as the language of science . . . I started to get it . . . it's a very neat thing to understand how they're using math." But when David's mentor went away for a long period of time, David came to realize the delicate balance between using others' help and doing things on his own—"I didn't anticipate it like taking that much time for me to just get materials, get a space, get, start talking with people." Like David, Pamela, the scientist, saw her mentor as playing an extremely important role in teaching her the skills needed for her research. "[My mentor] is teaching me to just observe and to watch and notice." This enabled Pamela to notice how butterflies can be distinguished by their observable characteristics. "You know, by looking at this I can tell that this is a morning cloak partly because it's in the woods or because it's this . . . And then now I know what it looks like and I could point it out in a field."

For both Elena and Pamela, their mentors balanced the help they were offering with the fellows' choices and initiatives. Elena noted: "He's more, like, 'try it out first, if you can't get it, just ask me and I'll help you out.'" And Pamela pointed out: "He was good. He just kind of, he let me kind of just do what I wanted to do and what I felt comfortable doing . . . I don't like a lot of structure, I want my own freedom to, kind of, learn on my own and do things and, you know, but I still want him to be there in case I need him. He'll call me every once in awhile just to make sure I'm ok and that's what I like." When discussing research ideas with him, Pamela highlighted that "he'd be like 'oh that's great.' Then he would kind of sway me a little bit, like facilitate, in that . . . fix my question a little bit." For both Elena and Pamela, there is an evolution in the relationship with their mentors. At the beginning, their mentors worked closely with them, showing them the grounds, helping them perfect their techniques, and guiding the direction of their projects, but slowly they decreased their reliance on him and increased their reliance on each other. In the context of this evolution, Pamela also brought up the validating, appropriating role that she had constructed for her mentor. Her mentor's approval was needed to reassure her that her thinking and data collection were satisfactory. "He took me out two more times just to make sure that I was doing the right, I just wanted to make sure that I was, you know, to just kind of check me, reassure myself."

Science Teacher Identity. When talking about the classroom community, the fellows wanted it to resemble the science community in some ways—students working with each other, some freedom for students to pursue their own interests and questions, emphasis on questioning, critiquing, and debating, and mentoring and modeling for students. However, at the same time, they noted differences between the two communities that centered on the amount of time available, diverse students' interests and motivation to be involved, their own sense of what helping others implies, and their own struggle to enact a balance between autonomy and authority. Notions of collectivity in the sense of large multidimensional projects, where participants share the tasks and responsibilities, and are part of a larger community that shapes and validates their work, were not part of the fellows' science teacher identities.

Negotiating Meanings of Collectivity. David's evolution of his science teacher identity, during and after his apprenticeship, is the richest among the three. Between the beginning of his apprenticeship and the end of his first year of teaching, we see him, as a science teacher, negotiating important elements of science as a community of practice. Early on during the apprenticeship, David tried to translate his experience at the lab to his future classroom—"I've been thinking about how I can create a sort of mini-lab in my classroom, put people in teams, kind of making it actual, very real because it really is like that, they work in groups." But, as time went by, David, the science teacher started doubting—"school is totally different than what goes on here. That maybe it's not the best idea to try and duplicate." When asked to elaborate, David acknowledged that the time required to complete research at the lab was not compatible with the time allotted in school settings. David's science project was five years in progress, and he saw the scientists immersed in "this culture where everybody's dealing with [the ideas] all the time." He debated not only if he could succeed in reproducing that culture in his classes, but also if doing so would be worthwhile—"I think that when I was excited about that idea, I still kind of am, I think the whole idea that you have a big project . . . you have a big question like here's this experiment . . . then to do that involves like a million other problems you get into . . . You have a whole group of people working on them . . . So I think it would be neat to maybe set up a major project like that but I think it would be very hard to do, you know, in a classroom . . . I've been thinking about, how do you get students to want to do a project? . . . Maybe when they start asking their own questions and there's some ownership of what they're doing, they might be interested in it . . . but I think it's really challenging . . . I don't know how I would draw, I think it would be a challenge to draw all students into that so that they're all sort of assigned an aspect of the overall you know project or problem that they're studying."

By the end of the apprenticeship, David had begun to identify elements of the community of practice that might be worthwhile to reproduce in his classroom—"the way [the researchers] all communicate, there's meetings always happening, and they do this very traditional, you know, put up the transparency, and race through all this very technical stuff, and people question it, criticize it, challenge it, and it's a constant thing that goes on there. And I just started thinking about that as something maybe that will go on, I want to have go on in my class." Thus, we see David getting to a different place—seeing the collaborative nature of scientific practice from implying a complex, multidimensional project where each student or group pursues a particular part to implying certain behaviors and actions (questioning, critiquing, and challenging) that may be possible in a variety of projects. Such actions are tied to particular cultural components of the practice of science (i.e., meetings).

During his first year of teaching, it was mostly in the context of the science fair project—a particular cultural component of the practice of science teaching—that David tried to enact with his students some of the elements of science as a community of practice. Teaching in a year-long school, he avoided the constraints of time by starting the science fair project in the summer session when he had more autonomy than usual to focus extra time on science. His rich description of how his class did the project exemplified his vision of science practice within a community. First, he started the unit by having the students browse through texts and find a topic "that they thought looked neat." They chose magnetism. David taught the students a few basics about magnetism, followed by his guiding them through a process of exploration, observation, and then more structured observation and experimentation, and finally engaging them in asking and answering new questions about magnetism. David explained that while he began by raising the questions himself, eventually the students were asking questions about magnets—thus, moving from reliance on him as mentor to reliance on a collective dialogue about the science. He noted too that some of his students embraced the freedom to pursue their own science in a similar way to that he had experienced in the science community at the lab. "Then some of them . . . [would say] 'Well I want to try this. Can you see the magnetic field in water? You know, if I put the magnet in water, maybe put some paperclips in there.'"

As David, the science teacher, revisited his idea of a science community where members work on different aspects of the same topic, he noted: "Well like I'm eager to have like this, my idea of lab it's like a community of scientists, and I'm eager to have that in my room where lots of different people are exploring things about some kind of topic. And there's a lot of talking about what's going on. I'd love to have that, kids who are just like 'Oh, Mr. K., I want to do, you know, check this out.' 'All right go on, do it.' Now I don't know if I'm going to pull that one off right away, but that's [my goal]." And David went on to consider a way to accomplish this: "maybe I could have like two days a week where we do like, maybe one free exploration day a week, you know after a while, like, it's nice, I have a new group of sixth graders, maybe like after a year I'll have that as a goal, and maybe we can do that. So in that sense yeah, but my other, my apprehension is I don't want to be like so focused on getting these kids to be scientists, but more just to think scientifically." David's science teacher identity was definitely evolving as he crisscrossed between the practice of science and the practice of science teaching, thus allowing his scientist and science teacher I-identities to intermingle.

Teacher's and Students' Individual Contributions. In contrast to David's ways of problematizing what science as a community of practice would mean relative to his practice of science teaching, Elena's conceptions of science teaching during her fellowship portrayed an approach very much centered on the teacher and the students' individual contributions. Elena, the science teacher, did not foreground the collective dimension of doing science. For Elena, the science teacher was the relative expert who would mediate many of the elements of the students' experience. "I want them to know a whole load of information and it's just like, don't give them the wrong information though . . . I mean, what's going to happen when you don't know the answer?" But, at the same time, she acknowledged that she needed to leave room for the individual student preferences and styles of learning—"it's sometimes hard as a teacher because you go with your learning style usually to teach and not all kids are like that." Elena, the science teacher, only once abdicated her central role in the classroom—"have [the students] lead the class and say 'well, I wonder about this' and maybe we can do it . . . don't tell the child what the end result should be, let them do it on their own, let them figure it out." Only once she, also, referred to the collective nature of work she may lead in her classroom—"I first of all would say well let's discuss what we did. What did group A do? Maybe they did something different from group B, the methods that they used, just different things that they could have done to get a different turnout."

After a year of teaching, Elena's science teacher identity showed signs of evolution. She worried about the central role that she had been taking in her students' learning—"I was not letting them learn on their own or not doing for themselves, so I try to, like, stop that . . . 'Am I babying them too much?'. . . I think I might have babied them a little bit more." She acknowledged the limited opportunities she offered her students to think on their own and she felt good that her students loved science because of the amount of interaction among themselves—"I mean they loved it. They wanted to do it all the time, and I'm not just saying this, you know, to say it, but they did. They loved doing it because that was their time to break, and talk with their partner, and you know, it was a lot more interaction than just sitting at the desk and let's figure out the problem." But, at the same time, Elena thought of the reason that had contributed to her being the major player in the classroom—"time, I mean seeing that science was the last thing that we did do for the day . . . So I mean I think time was a big factor I didn't spend enough time on teaching [science]." Elena's science teacher I-identity came out one more time.

For Pamela, the science teacher, certain elements of the science community were important to bring to the classroom. Like David, Pamela wanted her students "to ask questions, you know, and the questions that I'm asking, about everything, are things that I hope these kids are going to ask because they're normal things. I mean 'where do butterflies go at night?'" And, for Pamela, projects were the cultural tool of the practice of science teaching that would allow her to give her students freedom to form a community of learners and shape the kind of learning that the class and its individual students pursue—"give [students] projects . . . I'm going to say 'We're going to talk about atoms today. What would you like to know about them?' This is how I'm going to do it . . . I want them to learn the same way I learned all these things." But, at the same time, she struggled to balance structure and authority, on the one hand, with flexibility and autonomy for her students, on the other. Her way of dealing with this was intervening at appropriate moments when students make interesting observations—"If we are just outside for anything and someone goes 'oh look that's a bird,' and I'd be like that's a bluebird and if you didn't know we'd find out [more about it]." Another way for Pamela, the science teacher, was to immerse her students into science—"really science is everywhere, you know, whether I'm at home in my backyard there's butterflies or here there's butterflies . . . [by taking my students outside more] then [they] could realize that science is always around you and that you are always going to truly be a scientist if you think about it, you know, you're always wondering and always asking why or what it's doing."

DISCUSSION AND IMPLICATIONS

This study sheds light on apprenticeships of teacher candidates in scientific settings and the ways they contribute to the shaping of teacher candidates' identities as scientists and as science teachers. Our findings suggest that as beginning teachers themselves engage in scientific research and live for an extended (albeit short relative to scientists' life spans) period of time in environments where scientists work, they come to appreciate important standard practices, speech acts, and tools of scientific activity that become salient elements of their scientist identities. Many of these practices map closely to those Roth (1995) outlined as important characteristics of authentic science—experiencing ill-defined problems, experiencing uncertainties and ambiguities, learning that is predicated on and driven by the learner's current knowledge state, experiencing themselves as part of communities of inquiry, and drawing on others' expertise. As the fellows plowed through uncertainty and false starts, as they went back and forth between their questions, their methods, and their data, as they floundered through the many worthwhile topics to study, they eventually found their way through the messiness to well-polished products, their final reports. And as they negotiated autonomy with sharing and validation by the existing community, they also appreciated that data were understood in the context of the scientific "stories," models, theories that they, and other scientists, have built to understand their work (Driver et al., 1994; Lemke, 1990; O'Hear, 1989; Varelas, 1996). Thus, this study reveals findings that are different from those of Schwartz, Lederman, and Crawford (2000) who claim that teachers doing science is insufficient for adequately developing complex understandings of the rich nature of science. At times the fellows in our study expressed their understandings in simple words; nevertheless, their thinking points toward an appreciation of important elements of science as a practice and as a community of practice.

However, for several reasons that the Fellows raised, such elements become part of their science teacher identities to differing degrees. What they experience as science teachers is a sense of conflict that they may or may not be aware of. At times this conflict takes the form of ambivalence, a back-and-forth movement between their sense of the practice of science and their sense of what makes school settings different from a lab setting.

Using Dewey's and Holton's distinctions between the two meanings of science, the findings of the study can be partially captured by Figure 1. The larger double arrow symbolizes the back-and-forth movement between these two meanings of science. At each end of the arrow, elements most salient to that particular meaning are noted as brought out by the fellows. The findings of this study show that the fellows' scientist identities incorporated both meanings. As scientists, the fellows recognized, appreciated, and adopted both public and private science, while they highlighted mostly Dewey's processes and Holton's private science. Thus, in the figure, the *Scientist* "oval" includes both sides of the continuum. However, as science teachers, the fellows leaned more toward Dewey's body of facts and Holton's public science as they were thinking about their science classroom communities. To capture this, the *Science Teacher* oval overlaps mostly with one of the sides, namely

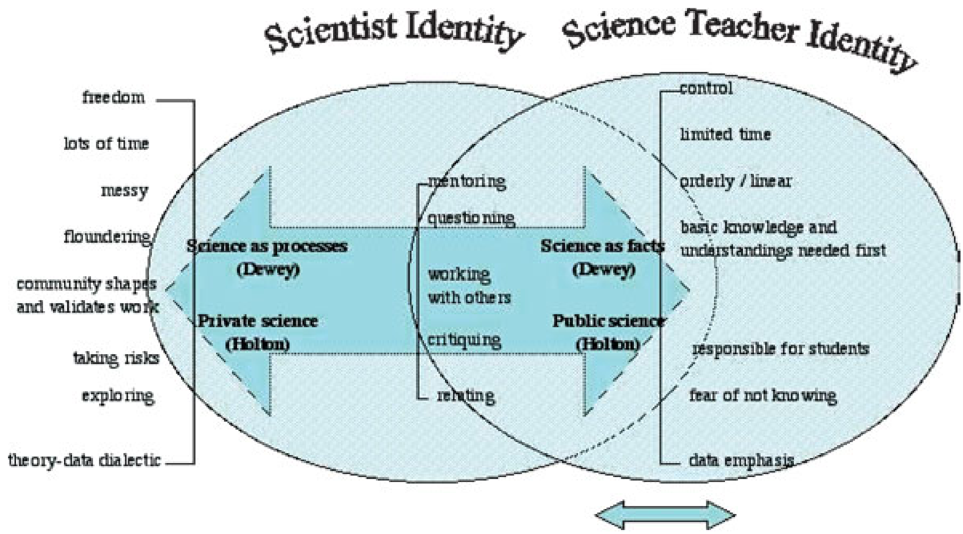

Figure 1. Salient elements of fellows' scientist and science teacher identities.

Holton's public science and Dewey's science as a body of facts. However, when talking about classroom communities, the fellows did not simply dismiss all aspects of private science. On several occasions they considered putting private and public science together, incorporating to varying degrees in their classrooms those elements of science that are between the two ends of the science continuum. They struggled, though, to enact in their classrooms the delicate dance between the two meanings of science, and they brought up several obstacles that pushed them closer to public rather than private science. The location of the *Science Teacher* oval relative to the science continuum should not be seen as static. Rather, as the data of the study indicate, depending on the nature of the issues that need to be attended in classrooms, the *Science Teacher* oval can shift closer or further away from private science.

Furthermore, this study helps us see the fellows' scientist and science teacher identities as an interplay of the four types of identity that Gee (2000–2001) proposed, with the I-identity and the D-identity being particularly strong. The fellows' I-identities were shaped by the lab and the school, and the positions they hold in these institutions, that influenced the scientific practices, tools, and cultural components that they chose to portray as scientists and as science teachers. Particular events in these institutions, accepted norms, expectations for accomplishments, goals, and outcomes, led the fellows to fall into different parts of the continuum between public and private science as scientists as opposed to as science teachers. But it was not only the institution that shaped their identities. These were D-identities too—the fellows constructed their identities through discourse with other scientists, their students, and themselves, influenced by not only accepted practices ("authorities") within the institutions, but also by the conversations, the ways with words, and the understandings as well as the feelings that these interactions brought up for them about their practices of science and of science teaching. In a less pronounced way, the fellows also revealed A-identities as they referred to not only larger institutional practices and specific discourse practices, but just affiliation with groups that did similar science research. Their N-identities were overshadowed by the others as the fellows sparsely referred to their own personal characteristics, strengths, fears, desires, and weaknesses that shaped who they are as scientists and as science teachers.

At the intersection of all these I-, D-, A-, and N-identities, the fellows seemed to be immersed in contradictions. At times, they shared that their own school experiences with science in K-16 were nothing like the experience they had at the lab. They did not have meaningful and enjoyable experiences during their school years, but they loved their experiences at the lab. As learners and practitioners of science at the lab, they thought "messiness" was not only OK but helpful in their understanding. What was important for them was the interaction with not only their mentors, but with a larger community of peers, along with their own actions, struggles, decisions, triumphs, and failures. They played a critical role in the range of activities, communication practices, and relationships that constituted their participation in that community. They were important as the practitioners, the doers, the learners. Their conceptions of private science were foregrounded along with an emphasis on their role as learners.

But, as teachers of science, they had the tendency to want to make things clear for the students, more linear, with closure, and structure. They were highlighting more their one-to-one interactions with their students, and their responsibilities for helping and leading the students. They had to mediate, structure, organize, and shape everything in their classrooms. They, again, were important, but now as the mentors, the coaches, the teachers. Their conceptions of public science were foregrounded along with an emphasis on their role as teachers. And, after their first year of teaching, they kept oscillating between giving their students more autonomy versus giving them a more structured learning experience. The fellows' conceptions of themselves as scientists and as science teachers both foregrounded their own roles in each of the communities they were referring to (i.e., lab science and school science). Both who they felt they were in each of these communities (of course, always in relation to others) and what they felt was right/acceptable, true, and beneficial for each of these communities shaped how they talked about them.

Looking at their two identities, the beginning teachers were living interesting contradictions, a roller coaster of meanings and feelings, alternating emphases and roles. Such contradictions are not inherently problematic. In fact, contradictions may well lead to evolution and growth, if these teachers engage in dialectical logic (Hegel, 1969) examining these opposites and resolving the conflict. Such opportunities may allow and encourage teachers to explicitly address, discuss, and debate the validity, value, and implications of such opposites. Furthermore, some of the reasons the fellows brought up to make sense of the differences they were considering between science in the lab and science in the classroom affect important concepts that define authentic science, such as sustained involvement and ownership (Rahm et al., 2003). Worrying that there is only limited amount of time they could devote to school science, and worrying about whether certain projects would catch their students' interests, teachers' sense of being able to provide authentic science experiences to their students may be compromised. Thus, we may perceive the contradictions and tensions that the fellows were expressing as resting on fertile grounds characterized by a commitment to authentic science and to students' meaningful experiences—grounds that would further nurture resolution of tensions and growth.

Furthermore, the concept of hybridity may be useful in understanding these beginning teachers' identities. Hybridity has been used in literacy research to capture the complexity and diversity of ways that people use to make sense of oral and written texts. Hybridity theory examines how being "in-between" (Bhabha, 1994, p. 1) can be enabling and constraining for one's literacy development. Hybridity challenges unity and helps us see how seemingly different and opposing views may be held together, actually working together to allow individuals to function in different settings. Moje and her colleagues (2004) write that "the notion of hybridity can apply . . . even to a person's identity enactments and sense of self" (p. 42). Thus, using the concept of hybridity, we may see the differences in the beginning teachers' scientist and science teacher identities as opportunities for them to build bridges between experiences and cultural practices at the lab and in the classroom, to make it through and navigate different practices (the practice of science and the practice of science teaching), and to even allow them eventually to challenge and reshape parts of both practices.

Theorizing further on the differences that the fellows' scientist and science teacher identities showed, we also need to consider the timescales of the fellows' engagement in the practices of science and of science teaching. During the summer apprenticeships, the beginning teachers were in the midst of performing science, but they were not in the classroom. They evolved in the ways of doing science and in the ways of thinking about it. They developed a particular sense of the complexity of scientific practice as they engaged in a certain progressive relationship with it. It was when breakdowns occurred that they became aware of particular aspects of scientific standard practices, speech acts, and tools. As they struggled to overcome barriers of all different types in order to shape up and pursue their projects in the midst of the structure of the existing community, characteristics of scientific practice became visible to them as the tacitness of such characteristics that exists among experts (Polanyi, 1966) was dismantled. By not being in the classroom at that time, they did not have opportunities to engage in reflection in action (Schön, 1983) as it relates to the practice of science teaching. And when they were teaching, their apprenticeships were over and they were not engaged in doing science. More opportunities to address and resolve conflicts may be available if the timescales of engagement in the two practices coincided in some ways.

In closing, we find identity as a powerful, rich, and multidimensional lens that allows us to explore ways in which beginning teachers see themselves as scientists and as science teachers when they are involved in extensive apprenticeships in scientific settings. Furthermore, this study lets us see that immersion into scientific communities and practices is a complex and potentially useful tool for shaping beginning teachers' identities as scientists and as science teachers. The study exposed and problematized discrepancies in terms of salient elements of these two fellows' identities. These discrepancies can help teacher educators be more aware of parts of teacher identities that they want to or should discuss, elaborate, and focus on.

Furthermore, this study leads us to ask the question about how conscious of these discrepancies the beginning teachers were themselves, and whether and how they rationalized these discrepancies in their minds. Extending this line of research to explore such issues may shed light on the interplay of Gee's N-, I-, D-, and A-identities, and the factors that shape them. Furthermore, extending this line of research to explore beginning teachers' developing identities as science teachers as they continue teaching for several years may shed more light on the ways that the school as an institution (I-identity) and teachers' discourse practices with one another (D-identity) in the midst of their own personal characteristics (N-identity) shape the dimensions of science as a practice and science as a community of practice that teachers bring into their classrooms.

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