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Science as experience, exploration, and experiments: elementary teachers' notions of 'doing science'

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ABSTRACT

Much of the literature on science teaching suggests that elementary teachers lack relevant prior experiences with science. This study begins to reframe the deficit approach to research in science teaching by privileging the experiences elementary teachers have had with science – both in and out of schools – throughout their lives. Our work uses identity as a lens to examine the complexities of elementary teachers' narrative accounts of their experiences with science over the course of their lives. Our findings identify components of teachers' science-related experiences in order to lay the groundwork for making connections between teachers' personal experiences and professional practice. This work demonstrates that teachers' storied lives are important for educational researchers and teacher educators, as they reveal elements of teaching knowledge that may be productive and resourceful for refining teachers' science practice.

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Current reform efforts in science education acknowledge the important role of children's everyday thinking – developed in, shaped by, and tied to their everyday experiences with the world around them – in meaningful science learning (National Research Council [NRC], 2012). Children inherently draw upon the knowledge gained through everyday experiences with the natural world to reason about scientific phenomena during formal learning experiences (Hammer & van Zee, 2006). Thus, we ask teachers to be responsive to children's everyday thinking because children's ideas contain pieces of knowledge that are productive for science learning.

If we ask teachers to be responsive to children's ideas in science, then it is important for us, as researchers, to view teachers' everyday experiences with the natural world as potential sites of knowledge development that may be productive for science teaching and learning. Although elementary educators are not typically viewed as science experts (Davis & Smithey, 2009), in this work we assume that teachers, like children, naturally construct ideas and thinking about scientific phenomena through their everyday experiences and interactions with the world around them. This scientific thinking, rooted in everyday science experiences, is the same kind of thinking that we want teachers to recognise and take up in their students' thinking as students engage in developing more

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sophisticated scientific understandings. Thus, we contend that the same everyday experiences that inform teachers' disciplinary understandings of science concepts and practices may be productive tools for helping elementary teachers refine their science teaching in ways that are responsive to students' thinking. Helping teachers – and teacher educators – recognise teachers' everyday experiences and thinking as resources for science teaching and learning may lay the foundation for meaningful change in elementary science education that aligns with responsive, inquiry-based practices.

Taken together, we argue that: (1) teachers' everyday experiences with the natural world are productive in that they serve as the basis for teachers' knowledge of science concepts and practices, (2) this disciplinary knowledge rooted in teachers' everyday experiences mirrors what we want teachers to recognise and take up in children's thinking as they engage in science learning in the classroom, and (3) by recognising everyday experiences as sites for their own science learning, teachers may more effectively design meaningful science learning experiences for students.

Before understanding how teachers' everyday experiences may influence their science teaching practice, however, we must first understand teachers' experiences with science throughout their lives, and further, we must identify the kinds of disciplinary knowledge embedded in those experiences. Such is the focus of this paper, in which we (1) investigate the range of ways teachers interact with the world around them in science-focused ways, and (2) identify possible elements of knowledge evident in these experiences that may be productive for teachers to draw upon as they adopt an inquiry-based and responsive approach to teaching science in their classrooms.

Theoretical framework and literature review

To investigate elementary teachers' everyday science experiences, we adopt a theoretical lens that frames learning as ecological (Lee, 2008), occurring across a system of interconnected places and with a range of actors. Using an ecological perspective on learning broadens our understanding beyond formal learning institutions, such as classrooms, to include out-of-school spaces. To understand teachers within such a multi-faceted landscape of learning, we borrow a 'messy' notion of teacher identity that focuses on the ongoing development of a teacher-self in response to her environment, a teacher-self that is 'a polysemic product of experience, a product of practices that constitute this self in response to multiple meanings that need not converge upon a stable, unified identity' (Zembylas, 2003, p. 107).

This perspective on learning and identity is appropriate for our work, as we believe teachers' past experiences – in this case, their everyday experiences with the natural world throughout their lives – may reveal pieces of knowledge that may be productive for teachers to draw upon as they refine their teaching practice. In prior work, (Bernstein 2014) examined teachers' personal reading identities (e.g. personal reading experiences) and explored how their identities were manifested in their reading pedagogy. She concluded that teachers' personal identities, as articulated through their reading life stories, could serve as the foundation for professional practice. We extend this prior work to a different disciplinary context – specifically, we seek to understand elementary teachers' personal science identities. Although we acknowledge that teachers' personal and professional identities are connected and influence what happens in classrooms (Bernstein,

2014, Connelly & Clandinin, 1999; Drake, Spillane, & Hufferd-Ackles, 2001; Madden & Wiebe, 2013), the singular focus *personal* science identities was purposeful. We first want to understand what elementary teachers' everyday experiences with science look like and identify what, if any, pieces of knowledge tied to those experiences may be productive resources for their science teaching practice before we looked for evidence of these knowledge pieces in practice.

In prior work, identity has been used as a lens to explore teachers' personal experiences (e.g. personal identities) and professional practice (e.g. professional identities). For example, Mensah (2012) investigated how preservice teachers view themselves through social markers (i.e. race, class, gender) that influence how they talk about their science teaching identities. Mensah concluded that teachers' personal experiences influence what, how, and why they teach. In addition, Madden and Wiebe (2013) investigated the relationship between teacher identity and practice and found that teachers' personal experiences do influence not only what teachers do in the classroom, but also what students do when learning in science. Much of the prior research on science teacher identity reaches a similar conclusion – teachers' identity can and should be leveraged in teacher learning in order to make explicit its connection to practice (Avraamidou, 2014; Luehmann, 2007; Moore, 2008).

Many scholars conceptualise identity as multi-faceted and dynamic (see Avraamidou, 2014 for review). For example, Gee (2001) describes identity as 'being recognized as a certain kind of person in a given context' (p. 99); it follows that teachers would have multiple identities that stem from their 'core identity' as they engage in different teaching contexts. In a conceptual analysis, Luehmann (2007) applies Gee's notion of identity to explore challenges teachers face when developing a professional identity as a reform-minded science teacher. She considers how teachers' experiences during their teacher preparation programs influence their professional practices and articulates a notion of 'professional identity as being recognized by self or others as a certain kind of teacher' (p. 827). We apply Luehmann's notion of identity to investigate teachers' personal science experiences throughout their lives and what pieces of disciplinary knowledge have been developed through those experiences that could support reform-oriented science teaching.

Though we draw on Luehmann's work, our conceptualisation of teacher identity differs in an important way. Luehmann argued that beginning science teachers' identities often conflict with reform-based science practices, because teachers may not have had experiences with engaging in the practices of science. In our work, we contend that all teachers, from novice to expert, have had meaningful experiences with the natural world throughout their lives, during which teachers may have developed pieces of disciplinary knowledge that closely align with the practices of scientists. We investigate the range of ways teachers interact with the natural world throughout their lives and identify the pieces of knowledge in these experiences that teachers could leverage as they refine their practice. In so doing, we position the relationship between teachers' everyday science experiences and the pieces of knowledge and understanding developed through them as fruitful.

Currently, limited research exists in elementary science education that explores teachers' personal experiences with science (i.e. personal identity) or what pieces of knowledge within these experiences may be productive in refining understanding of their work as a science teacher (i.e. professional identity). Much of the research on science

teacher identity examines self-efficacy and beliefs towards science teaching using methodology that involves administering validated surveys and semi-structured interviews (e.g. Luft & Roehrig, 2007; Morrell & Carroll, 2003). Additional work focuses on affective relationships with the content such as attitudes towards science (e.g. Riegle-Crumb et al., 2015). While this work is important in providing insight into aspects of science teacher identity, it does not reflect the dynamic and multi-faceted nature of science teachers' identity over the course of their lives and across academic and non-academic spaces; rather it measures identity with fixed and stable constructs of self-efficacy, beliefs, and attitudes. Furthermore, much of this prior work is limited to teachers' experiences with science during their teacher preparation programs and thus does not consider how teachers' identity is shaped by their everyday experiences with science throughout their lives.

Our work opens up sites for additional inquiry in three ways. First, researchers recognise the importance of experience in shaping teachers' identity and thereby practice, and they argue that teachers' stories reveal insight into practice (Bernstein, 2014; Connelly & Clandinin, 1999; Flores & Day, 2006; Sfard & Prusak, 2005). We agree and therefore assume that teachers' science life stories can be powerful tools in understanding teachers' personal science identities, however, we need to more fully examine teachers' personal science identities – identifying those pieces of knowledge evident in their narratives – in order to unpack the knowledge that may influence what it means to be a teacher of science.

Second, while we acknowledge the importance of teachers' preservice experiences on their professional identities, we believe that expanding the landscape of teachers' experiences to include their everyday interactions with the world around them may provide a more complete story about the range of disciplinary knowledge teachers use in designing science pedagogy focused on students' thinking.

Third, the ways in which teachers' personal identities are shaped by their scientific experiences have not been thoroughly researched, though some researchers have suggested that teachers' personal science identities may influence how they engage students in disciplinary practices and support learning in science (Eick & Reed, 2002; Luehmann, 2007). Thus, our work provides a foundation from which to further study how teachers' personal science identities shape their science teacher professional identities and thereby practice.

To this end, we investigated teachers' everyday past science experiences in order to explore teachers' knowledge and thinking around science as a discipline. Our findings come from stories told by seven elementary teachers about their everyday experiences in science. We make no claims about the comprehensiveness or representativeness of these teachers' science stories, rather we view these stories as an exploratory starting point to understanding the complex ecology that contributes to shaping teachers' disciplinary knowledge of science.

Study design

Our study was designed to uncover disciplinary knowledge of science present in teachers' retrospective accounts of experiencing science throughout their lives. Specifically, we asked teachers to tell us their personal science stories and examined those stories for evidence of disciplinary knowledge of science that might inform the ways in which they

understand what it means to be a science teacher. This initial work lays the groundwork to study the relationship between teachers' personal science identities and their professional science teaching identities and practice. Because there is no existing foundation of research that has explored elementary teachers' science life stories, our study was exploratory in nature. We sought to be open and expansive in our empirical design, so as to capture a diverse range of elementary teachers' science experiences across their lives. At the same time, we recognise the limitations of our participant sample, which, while representative of our state's elementary teacher population, may not share science experiences with teachers in other regions of the country. In showcasing our participants' science experiences we hope to (1) promote an interest in elementary teachers' science experiences among educational researchers and teacher educators, (2) provide an empirical blueprint for those interested examining similar lines of inquiry, and (3) contribute to a larger effort to recognise teachers' life experiences as relevant to teaching and teacher education.

Participants

The primary investigator recruited seven elementary teachers who actively taught science in their classrooms at the time of this study. We decided to only select participants who were actively teaching science because our methodology of conducting science life story interviews presented opportunities for teachers to tell stories that connected their personal and professional identities. We are ultimately interested in whether we might see these connections between teachers' past science experiences and their current science teaching practices in the stories that they shared. This would require that participants have current science teaching experiences from which to draw upon.

Snowball sampling (Miles & Huberman, 1994) was used as a recruitment technique in which research participants were asked to recommend other potential participants. This technique is sometimes used to access hard to reach populations. We used it specifically because of its effectiveness in gaining access to elementary teachers who actively teach science – a population that prior research has shown is often difficult to access because actively teaching science is not the norm in many elementary school settings (Spillane, Diamond, Walker, Halverson, & Jita, 2001). It is often viewed as a fringe subject – taught only if and when there is 'extra' instructional time (Spillane, 2004). Hence, the primary investigator first contacted a single teacher she knew who actively taught science in her classroom and invited her to participate in this study. Upon agreeing, the researcher then asked this teacher to identify another teacher she knew who also actively taught science in his/her classroom. This process continued until seven elementary teachers agreed to participate.

The seven teacher participants all held K-5 teaching certification in West Virginia (the state in which the study took place). Their schools served both rural and suburban West Virginia communities. Six of the teachers were elementary generalists who taught in self-contained grade-level classrooms, and one was a reading specialist who taught in a pull-out program. Six teachers were female and one was male. Their teaching experience ranged from 1 to 34 years. Much of the literature on teacher identity focuses on preservice teachers or those in their first year of on the job (Avraamidou, 2014). Most of our participants, however, were veteran teachers; all but one had seven or more years of experience. This provided a rich and extensive teaching history from which teachers could draw upon

when recalling experiences with science. Table 1 provides participant demographic information.

Science life story interview

The primary researcher conducted science life story interviews with each teacher. The interview was adapted from McAdams' life story interview[1] (1996), in which participants were asked to narrate life stories organised around developmentally segmented chapters (e.g. childhood memory, adult memory) and significant moments (e.g. high point, turning point) spanning their life course. The researchers made specific modifications in line with previous research that sought to understand teachers' discipline-related experiences across their lives (Bernstein, 2014; Drake et al., 2001). For instance, rather than being asked to describe their earliest memory, teachers were asked to describe their earliest memory *related to science*. The researcher described what qualified as an earliest science memory as follows:

> Think back now to your childhood, as far back as you can go. Please choose a relatively clear science memory from your earliest years and describe it in some detail. The memory need not seem especially significant in your life today. Rather what makes it significant is that it is the first or one of the first memories you have about science …

Similar wording was used for each of the eight episodes, which included a peak experience, a negative experience, a turning point, an earliest memory, an important childhood scene, an important adolescent scene, an important adult scene, and one other important scene, all related to science. In total, we collected 56 life story episodes from participants.

Data sources and analysis

The science life story interviews were audio-recorded and lasted approximately 90 minutes. Data consisted of interview transcripts ranging between 25 and 35 pages in length. Data analysis progressed in several iterative phases. First, the three investigators made several initial passes with the data before settling on lines of analysis that were both consistent with the initial goals and theoretical frames of the inquiry and were suggested by the data. Once we settled on lines of analysis, we individually delved into

Table 1. Demographic information on teacher participants.

Teacher (pseudonyms)	Gender/race	Grade level	Years of teaching experience	Certification/specialization
Anna	Female/ Caucasian	K	27	K-5 Elementary Education/Generalist
Tara	Female/ Caucasian	1st	26	K-5 Elementary Education/Generalist
Jennifer	Female/ Caucasian	2nd	13	K-5 Elementary Education/Generalist
Maggie	Female/ Caucasian	2nd	9	K-5 Elementary Education/Generalist
Clifton	Male/Caucasian	3rd	1	K-5 Elementary Education/Generalist
Leslie	Female/ Caucasian	5th	34	K-5 Elementary Education/Generalist
Kayla	Female/ Caucasian	K-2	21	K-5 Elementary Education/Specialist (Reading)

a small sample of the data – two to three interviews – to generate an initial list of codes related to that line of analysis. We then shared our codes with one another and discussed the affordances and constraints of each code, considering both how well it represented the data and how well it helped us address our research questions. Upon agreeing on a set of codes, we individually applied those codes to the full corpus of data, then reconvened to compare and compile our individual analyses. Throughout this process, we actively worked to understand and challenge one another's interpretations until we were satisfied that we had examined the data from a range of perspectives that captured the participants' meaning and that would help us to answer our research questions. Our collaborative approach to analysis facilitated a forum in which we 'debated and clarified' (Harry, Sturges, & Klingner, 2005, p. 6), and while we sought consensus, we did not attempt to meet an agreement threshold in our use of codes. Our purpose was to use an analytical approach that reflected the possibility of multiple meanings suggested by the data. Other research teams have also relied on this form of group consensus and openness to multiple interpretations of data (Kvale & Brinkmann, 2009; Sandelowski & Barroso, 2003). We worked in different configurations for different phases of analysis (Table 2). All three researchers worked collectively on generating the initial lines of analysis, pairs of researchers worked on each separate line of analysis, then we reconvened as a whole group to look for themes across our distinct lines of analysis.

We used this iterative and collaborative process for three separate sets of codes along four lines of analysis. We found that embedded in teachers' stories were explicit notions of what it means to 'do science', or engage in scientific practice, as well as what each participant emphasised about those practices. In response, we analyzed the data using content-focused grounded theory (Strauss & Corbin, 1990) to identify emergent categories of teachers' understandings of 'doing science'. Four dimensions of 'doing science' emerged: (1) the *landscape* in which 'doing science' takes place, (2) the *habits of mind* required for 'doing science', (3) the *look* of 'doing science', and (4) *ways of being* in 'doing science'.

Analysis of the fourth dimension, which examined intersections across dimensions, was achieved through second cycle coding (Saldaña, 2015), an approach to qualitative data analysis that synthesises individual codes or sets of codes to more comprehensively capture relationships across data. For this dimension, we employed a set of codes previously developed by other life story researchers interested in identity, described in more detail in 'Looking across the Dimensions' below. We layered this new set of codes

Table 2. Phases of iterative and collaborative data analysis.

Analytic phase		Data under review	Researcher team composition (number of researchers)
Holistic assessment of data to discern appropriate lines of analysis		Three interviews	Individual assessment of lines of analysis (3) Collaborative discussion (3)
Performed three times, for each line of analysis	Development of codes for each line of analysis	Two to three interviews	Individual development of codes (2) Collaborative discussion (2)
	Application of codes to data	All interviews (7)	Individual application of codes (2) Collaborative discussion (2)
Second cycle coding (looking across individual lines of analysis to understand broader themes)		All interviews (7)	Collaborative discussion (3)

on top of our existing codes, and in doing so, uncovered relationships across our entire corpus of data.

Because our sample is not representative of all elementary teachers and our goal was not to generalise beyond our sample, we were not interested in a preponderance of certain codes as they compared to codes less-frequently applied to the data. Our purpose in this research was to begin to understand the wide range of ways in which disciplinary knowledge of science may be manifested across teachers' lives, with a long-range goal of helping teachers recognise diverse sources of scientific reasoning amongst their students. As such, every scientific experience was captured in our analysis, not only those that cohered around common codes. Just as teachers may miss important scientific meaning-making if they fail to recognise the wide range of ways in which students engage with the natural world (Bang & Medin, 2010), as researchers, we sought to capture all types of teachers' science-related experiences.

Next, we present and discuss our findings around each of the four dimensions of 'doing science' that were embedded within teachers' stories. In selecting data to illustrate each dimension, we strove to balance highlighting a diversity of different participant experiences with providing the coherent narrative depth and detail of a single teacher's story. Thus, every participant is included at least once in our data tables, and at least two participants' data are treated in more depth in the discussion of each dimension.

Findings and discussion

Dimension one: landscapes of 'doing science'

We found that teachers described both formal and informal spaces in which experiences with science occur – these spaces compose the *landscapes* of 'doing science'. We also found that individual teachers described multiple landscapes across their science stories (Table 3).

We were struck by the inclusion of both formal and informal environments that teachers described as places where their science meaning-making took place. Past research has suggested that students and teachers typically conceive of science as happening in formal contexts such as laboratories, separated from the 'real world' (Christidou, 2011). Similarly, our teachers discussed 'doing science' in formal contexts, such as classrooms and professional development (PD) sessions, in 57% of the life story episodes. Interestingly, however, 43% of the life story episodes happened in informal learning environments, such as backyards or garages. Among the seven teachers, six describe both formal and informal landscapes of 'doing science' across their science life stories.

In order to illustrate the multi-faceted and dynamic nature of identity present in these stories, we highlight two teachers' stories: Maggie's and Leslie's. While both teachers' stories contain diverse landscapes of 'doing science', Leslie's science story displays a greater range of diversity because her episodes span both informal and formal contexts, while Maggie's episodes take place in only formal contexts.

At the time of this study, Maggie had recently moved from teaching middle school math/science to teaching 2nd grade (all subjects). Throughout her science life story, Maggie only described 'doing science' within classroom contexts, either as a student or as a teacher. For example, Maggie described her experience in 8th-grade science class:

Table 3. Informal and formal landscapes of 'doing science'.

	# of Teachers	# of Episodes	Excerpt illustrating landscape (each from a different teacher's story)
Formal landscapes			
In classroom (as student)	7	24	When I was in middle school we were learning about weather and the teacher specifically asked me what an anemometer was. So when I gave my answer, he made fun of me and so did everybody else. (Jennifer, Nadir Experience)
In professional development	2	5	I signed up and took the summer workshop, which really kind of renewed my interest in science and being able to teach children science concepts … (Tara, Important Adult Scene)
In classroom (as teacher)	1	3	We put on our scientists' coats at school, you know, in second grade, we were scientists. And so we had science journals and notebooks, and we did data; we did investigations. (Maggie, One Other Important Scene)
Informal landscapes			
In home	6	8	My father actually had a … severe stroke … where he lost the ability to talk and to walk. I spent a summer working with him and did a lot of research about stroke victims. So being able to help my father at their dining room table and actually see him gain that back and know that I was able to help him. (Tara, Peak Experience)
In medical context	3	7	I took allergy shots when I was a kid … that particular Saturday morning I got my shot … I had these terrible stomach cramps … It was an anaphylactic reaction … I went back to the allergist … and he checked the bottle … He said 'it was my mistake it was a new bottle and I had mixed it ten times too strong'. (Kayla, Important Adolescent Scene)
In nature	4	6	We were always told to go outside and we would play with worms. We would find worms under bricks and we would play with them. And I was always amazed when you pulled them apart both ends would keep on moving. (Anna, Peak Experience)
In extracurricular activity	2	3	I joined cub scouts … my dad always worked, but I remember I got to do the pine wood derby with him. … I got to use my hands, so it was cool and I got to build something. (Clifton, Important Childhood Scene)

> I had this amazing science teacher … the one thing I remember the most in his class was making an ecosystem in a two-liter pop bottle. And having plant life in there and some kind of animal life in there with the soil and all the parts. That's … the earliest thing I can remember of science, that's sad that it's 8th grade. (Earliest Memory)

Maggie also described the 2nd-grade classroom where she currently taught as a place where she felt responsibility for (and struggled with) providing her students experiences in 'doing science':

> I moved from teaching 7th and 8th grade math and science to 2nd grade and having to figure out how I'm going to still make sure that my kids get science when everybody else is so worried about reading and math. And it is a difficult thing … they also need those science experiences. You need to make sure that they have an understanding of the world around them … I needed to figure out how to incorporate [science experiences] into these young children's lives. How do I make sure they leave me with a love for science? That was not an easy thing for me to do … (Turning Point)

Each of Maggie's eight episodes takes place in formal landscapes such as these. Leslie's episodes, on the other hand, take place in both informal and formal contexts. At the time of this study, Leslie taught in a 5th-grade classroom. Throughout her science life story, Leslie mostly described 'doing science' within informal landscapes, yet she also described formal

landscapes of 'doing science' within PD experiences. For example, Leslie described nature as a place in which she experienced 'doing science':

> We would go into the woods and go on paths or go on areas that had not been explored … to see how it changed over the summer and to see the different flowers that bloomed. Even though I haven't become a person that's interested in the life sciences as much as I am the physical sciences now, that was the point in time where science was a part of nature, but I wasn't looking at it as science. It was a part of me and a part of my close relationship with my cousin. (Peak Experience)

Later in her science life story, Leslie described 'doing science,' at home with her father and brother as they built a model:

> I can remember [my father] working with my brother with an erector set. I remember going over to help and wanting to watch and getting it to work … I would just sit there and he would let me hand them, I didn't get to do it, I remember that. I could hand them the different screws or the different size pieces … I would say that was the first thing, because I was watching and experiencing some, but more sitting back and watching as something could be built and made to work. (Earliest Memory)

Leslie also described 'doing science' within the informal landscape of a medical context recounting how doctors had to work together in addressing her mother's disability:

> My mother was handicapped and had to have five different surgeries … the first one was when I was in 1st grade and her last one she had done was when I was a senior in high school. I think I saw that side of how it wasn't just one doctor … it was a whole team. Nobody knew everything. As a young child it scared me, because I wanted one person there to say this is how it's going to be and everything's going to be all right. I think as a senior in high school I was thankful there was the team of people … that was needed because nobody could know everything. (Important Childhood Scene)

Although her science life story was characterised by informal landscapes for 'doing science,' formal landscapes were also evident in Leslie's story. For example, she described how a PD opportunity got her started in science teaching:

> I became involved with a project called the NEED Project. It stands for the National Energy Education Development Project. I got the materials and they were so fabulous on energy education, but they were not just science. They were language and they were math and they were social studies. There were skits. There were songs. You had the fine arts pulled in. It was such an integrated program, along with science experiments. And, boy, I just took that and went with it. (Other Important Scene)

With the exception of Maggie, the teachers described both formal and informal environments where their science meaning-making took place. In other words, most described 'doing science' both in and beyond classrooms and laboratories. And while Maggie did not, her story still highlighted everyday experiences with science (e.g. building an ecosystem in a bottle; asking questions about the world). We think this has important implications for supporting a shift towards reform-based science teaching practice which requires teachers to be responsive to students' everyday thinking around scientific phenomena they have encountered in their everyday lives both in and out of the science classroom. As is evident in their stories, these teachers already possess disciplinary knowledge supporting the notion that science is learned through everyday experiences in everyday formal and informal contexts. As teacher educators, we need to

find ways to access and build from the full range of science-related life experiences teachers have had in order to support teachers in using their disciplinary knowledge of 'doing science' across a diverse range of landscapes to inform their science teaching practice.

Dimension two: habits of mind for 'Doing science'

In 70% of the episodes across the life story interviews, we found that teachers described specific characteristics one should have when engaging in science – this is what we mean by the *habits of mind* for 'doing science' (Table 4).

Prior research indicates that teachers think about 'doing science' as following specific procedures (i.e. the scientific method) (e.g. Windschitl, Thompson, & Braaten, 2008). In our participants' stories, however, there was a diverse array of habits of mind that do not conform to a specific procedural approach. Additionally, like the *landscapes* dimension, teachers' habits of mind for 'doing science' varied both within and across their stories. Table 4 demonstrates variation across teachers by providing brief excerpts, one from each teacher's story, illustrating each of the habits of mind we saw across their stories. To illustrate this variation, we highlight different habits of mind within two teachers' science life stories – Maggie and Kayla.

Maggie described three different habits of mind across her eight science stories: collaborating, questioning, and being active in pursuit of understanding. For example, in one episode, she described her students collaborating to learn about simple machines:

Table 4. Habits of mind for 'doing science'.

Habits of mind	# of Teachers	# of Episodes	Excerpt illustrating habit of mind (each from a different teacher's story)
Visualize	2	4	I mean there are definitely facts and things … but science is something you have to see. … it's very abstract. So in order to fully understand, I think they [kids] have to see it in action. (Jennifer, Important Adult Scene)
Question	5	5	You can do the experiment and then say all right what happened? Why do you think this happened? The big thing was questioning … (Clifton, Important Adult Scene)
Collaborate	6	12	So their project was to use simple machines and make a simple machine work. They could do it in pairs, in groups and this one group of boys, and I will never forget when their machine worked … they were so excited. (Maggie, Peak Experience)
Be curious	4	6	We were always told to go outside … we would find worms under bricks and we would play with them. We'd make mud cakes and mud pies. It was interesting to see how it dried on our clothes and you could just brush it right off. I've always been curious, and I think that's why I realized how children were curious. (Anna, Peak Experience)
Engage senses	4	7	Bringing things into the classroom … bringing in some bones, so the kids could actually hold them and touch them and figure out where in their body that is. Kayla, One Other Important Scene)
Seek answers/ knowledge	5	15	So I had to just start doing a lot of my own research and reading to find out because I knew that [my son's tantrums] weren't normal as they [the doctors] kept telling me. So I did a lot of research and have found out a lot of things … (Tara, Turning Point)
Active in pursuit	7	20	I think that's what opened my eyes, when I actually did it, instead of just watching others do it. That was me watching and knowing what should happen and what you should do, but now let's actually try, you can do it! (Leslie, Earliest Memory Episode)

> I was teaching a 7th grade science class … I had a number of special education students in my class who had difficulty with reading, writing, and those kinds of things. So their project was to use simple machines and make a simple machine work. They could do it in pairs, in groups, and this one group of boys, and I will never forget when their machine worked … they were so excited. They have always stood out in my mind. That moment, that class, those boys, they just couldn't believe it. They were like, "We did it! We made it work!" (Peak Experience)

In another episode, Maggie described the habit of asking questions in 'doing science':

> You need to make sure that they have an understanding of the world around them. I feel that getting the kids to question and ask questions and to figure out how to answer them without going to Google is a great way to do that. (Turning Point)

In addition, Maggie emphasised being active in the pursuit when 'doing science', as she often clearly articulated experiential and hands-on learning as important in her students' science learning experiences. Here, she explained:

> I want my students to have experiences that they will remember, and I want them to do hands-on things. Science is the perfect subject for that. I mean they have to do to remember. They're not going to just read a book and say got it. So they need those experiences. (Peak Experience)

Similar to Maggie, Kayla's stories reflected habits of mind that involved questioning and being active in pursuit of understanding. Her stories also described two additional habits of mind not reflected in Maggie's stories – engaging senses and seeking answers/knowledge. For example, in one episode, Kayla described engaging different senses as her students learned about the human skeletal system:

> I can remember in fifth grade bringing in some bones that my husband had helped me borrow when we were studying the skeleton, and you know really getting into the body systems … so the kids could actually hold them and touch them and figure out where in their body that is. (Turning Point)

In addition, Kayla emphasised seeking answers/knowledge when 'doing science', as she articulated helping her students find more information about unfamiliar content found in their reading books as important in her students' integrated science learning experiences. Here, she explained:

> I want to try to encourage that spark of interest for students even in the guided reading lessons. If we have a book that talks about a particular animal and maybe it's not something we have here, I'll pull out the iPad and we'll do a quick search so we can look at a picture or read a quick description. (Earliest Memory)

These excerpts from Maggie and Kayla's stories illustrate that they possessed pieces of disciplinary knowledge demonstrating a range of habits of mind for 'doing science', which is consistent with what we saw across our other teachers' stories (see Table 4). Clearly, our teachers possess multiple ways of thinking about the habits of mind required for 'doing science'. Again, we think this has important implications for supporting a shift towards reform-based practice, which requires teachers to nurture these very same habits of mind for 'doing science' in their students (Duschl, Schweingruber, & Shouse, 2007). Again, as teacher educators, we need to find ways to access and build from the full range of science-related habits of mind embedded in teachers' science stories in order

to support teachers in using this disciplinary knowledge of the habits of mind required for 'doing science' to inform their science teaching practice.

Dimension three: looks of 'doing science'

In 66% of the episodes, we found that teachers described science as taking certain forms – this is what we mean by the *looks* of 'doing science'. Among our participants, we found eight distinct ways in which they described the action of participating in a scientific endeavor (see Table 5).

Prior research indicates that teachers usually conceive of doing science as learning facts, vocabulary, and basic concepts, typically from a science textbook (e.g. Huffman, Thomas, & Lawrenz, 2008). Similarly, we found five teachers described learning scientific terms and facts as one of the looks for 'doing science'. In one episode, for example, Leslie described her success in learning science from a book, as she was able to recall scientific terms and facts on a test:

> I would have been one of those ones in early elementary that was one of the book readers that could understand anything in the book and take a test and get an A on it, but if you set things down in front of me, I was afraid I wouldn't be able to do it. (Earliest Memory Episode)

Table 5. Look of 'doing science'.

Look	# of Teachers	# of Episodes	Excerpt illustrating look (each from a different teacher's story)
Conduct an investigation	7	22	We put lima beans in a baggie with a wet cotton ball and … they were starting to sprout in the window, but it was too cold and then they ended up molding. I guess that experiment didn't turn out the way that we had planned it. (Anna, One Other Important Scene)
Observe phenomenon	6	12	We would lay in the backyard and watch the clouds. And we would decide what they look like, you know, this one looked like a rabbit … you really thought about how big the world was and how cool it was. (Jennifer, Earliest Memory)
Build a model	4	5	I remember drawing a lot in grade school. They would have us like draw the heart and label it, draw the digestive system and label it. (Kayla, One Other Important Scene)
Seek answers/ knowledge	4	17	My grandpa had a big chestnut tree in the backyard and we would always go out and gather chestnuts. Every now and then we would get a worm, and then it was like, 'Why is that in there?' and so, I think it helps me want to know why, why do things work? Why is it like that? How does it work? (Jennifer, Important Childhood Scene)
Explore the natural world	4	5	I had a cousin that would spend every summer at my grandmother's house and we would go out for the entire day … we would just go into the woods and to areas that hadn't been explored … that still was that point in time [for me] where science was a part of nature, but I wasn't looking at it as science. (Leslie, Peak Experience)
Learn scientific terms or facts	5	6	I would have been one of those in early elementary that was one of the book readers. [I was one] that could understand anything in the [science] book and take a test and get an A on it, but if you set things down in front of me I was afraid I wouldn't be able to do it. (Leslie, Earliest Memory)
Connect to everyday life	3	4	I can remember looking at the periodic table and thinking I don't understand what this has to relate to me as a teacher. I had a hard time making any kind of connection. (Tara, Nadir Experience)
Integrate disciplines	2	2	Going from teaching a science class … to teaching every subject and figuring out how to get science into these young children's lives … I've been able to integrate almost every subject. I'm not so good with social studies, but I can do math, reading, writing, and science all together and my kids are still doing science. (Maggie, Turning Point)

Other teachers also described the importance of learning scientific terms and facts, however, they also explained the importance of going beyond the textbook in order to fully understand a scientific phenomenon. For example, in one episode, a 2nd-grade teacher, Jennifer, emphasised the look of 'doing science' as being more about experience:

> I don't think you can teach science from a book. I think it is way more experience than it is from a book. There are definitely facts and things that students need to understand, but science is something you have to see. (Important Adult Episode)

We find it interesting that our teachers' notions of what 'doing science' looks like in their life stories extends what prior research indicates about teachers' notions of what 'doing science' looks like in their classrooms. Teachers often clearly articulated the experiential and hands-on nature of science, such as conducting investigations, observing phenomena, exploring the natural world, and using authoritative knowledge. For example, a first-year teacher, Clifton, who taught 3rd grade at the time of this study, described 'doing science' as an investigation when he discussed designing and testing a Pinewood Derby car with his father:

> We were allowed to have so much weight on it, so my dad gave me the weights and he was like, "Where do you want to put it?" I thought why don't we put it on top because it will be weighed down on it. … it really didn't do much, so I thought well maybe if I put it in the front it will help it go down the track faster. (Important Childhood Scene)

Another way Clifton described the look of 'doing science' involved observing phenomenon. For example, he described observing seed germination in kindergarten:

> We took a lima bean and put it in a plastic bag and filled it with water and then watched it, the seeds sprout out from the bean. Everyday the first thing we got to do when we were doing it was … grab our books and then draw a picture of what the lima bean looked like. (Important Childhood Scene)

Another look of 'doing science' within Clifton's science life story involved building a model for the 8th-grade science fair:

> … we learned about the Rube Goldberg machines where you set up basically kind of like a domino effect to get something to happen. So I built an elaborate way of cracking an egg. It was just like this huge thing and I had like a golf ball going into the hole and the flag raising up and a whole bunch of things just to crack an egg. I thought that was the coolest thing! (Other Important Scene)

In sum, all teachers articulated ways 'doing science' beyond learning scientific terms and facts. Thus, our findings indicate teachers have multiple ways of conceptualising what 'doing science' looks like. Again, we think this has important implications for supporting a shift towards reform-based practice, because teachers already possess pieces of disciplinary knowledge that support the notion that 'doing science' takes different forms, from hands-on investigations to reading scientific texts.

Looking across the dimensions: teachers' ways of being in 'doing science'

Our first three analytical dimensions focus on teachers' disciplinary knowledge of science – specifically the knowledge of landscapes, habits of mind, and looks of 'doing science'. This fourth dimension is different in that it focuses on the social context in which

those three types of disciplinary knowledge were developed and manifested. We found in teachers' stories that they described interacting with people in different ways while 'doing science' – this is what we mean by the *ways of being* in 'doing science'.

To better understand how our participants' science experiences were co-constructed with others, we employed a set of codes frequently used to analyze life story interview data that showcases participants' interactions with others across their life stories. McAdams suggests that Bakan's themes of agency and communion (1966), 'are the two central superordinate thematic clusterings in life narratives … articulating important life goals, strivings, needs, and desires' (McAdams, 2001, p. 1). By applying the broad analytical themes of agency and communion, we could contextualise teachers' disciplinary knowledge of science within a social ecology of how they orient themselves in the world: their *ways of being* in 'doing science'.

According to Bakan, 'agency manifests itself in self-protection, self-assertion, and self-expansion; communion manifests itself in the sense of being at one with other organisms … in contact, openness, and union' (1966, pp. 14–15). For example, in our data, we saw agency manifested in teachers' discovery of new scientific interests or individual academic achievement, such as Clifton's excitement about his Rube Goldberg machine. For communion codes, we saw a lot of discussion of teaching and learning, as well as union with the natural world, such as Leslie's description of walking in the woods with her cousin. We used sub-codes of agency and communion, developed by McAdams (2001). Table 6 provides an overview of the ways teachers were communal or agentive in their science stories. It is important to note that this analysis the teachers' life stories did not reflect a singular way of being in science. All of our teachers' stories conveyed both agentive and communal ways of being, as evidenced in Table 6.

These codes were useful not only insofar as they provided context for teachers' disciplinary knowledge of science, they also reflected differing conceptions of scientific work. The frequent images of a scientist as lab-bound, isolated, or asocial (Finson, 2002) are at odds with the collaborative, in situ approach of many reform-based science standards and curricula. Thus, teachers' agency and communion orientations help us see ways in which their ideas of 'doing science' may be consistent or incompatible with inquiry-based curricula.

After coding teachers' episodes within their science life stories for ways of being, we layered these codes on top of our other 'doing science' codes evident in each episode. This allowed us to see the relationship between social context and disciplinary knowledge of science within each episode. Further, by using agency and communion as a lens through which to view the other three dimensions, we could more holistically understand teachers' ways of 'doing science'. This analytical layering of multiple coding themes helped us capture the ecological complexity of our participants' lives.

Here, we highlight the results of our analytical layering for one teacher, Jennifer, to accentuate the characteristics of both agentive and communal ways of being and how they related to each of the other dimensions.

We found that Jennifer focused primarily on relationships with others (communion) as her way of being in science, and the landscapes in which she did this were balanced between formal and informal spaces. For example, in one episode, she talked about exploring nature with her grandfather:

Table 6. Communal and individualistic ways of being in 'doing science'.

	# of Teachers	# of Episodes	Excerpt illustrating way of being (each from a different teacher's story)
Communal ways of being			
Dialogue	7	13	We talked about the wind and how the wind blows things and we counted how many puffs it took to blow certain objects across the table. (Anna, Peak Experience)
Caring/help	7	22	I try to make sure that I involve all of my students in the classroom just because I was that kid who didn't want to sit down and pay attention. Even though I don't like to do stuff out of the book with science, I still do it just because I know there's some kids that want to learn that way. I need to make sure I'm doing it multiple ways so that all my students have at least one point in the class to want to pay attention. (Clifton, Turning Point)
Love/friendship	4	7	I got married and moved to North Carolina. I ended up getting a group of friends that trained for the county … but because of that I signed up and took the summer [science teaching] workshop with the friend that taught it. (Tara, Important Adult Scene)
Unity/togetherness	5	10	I was probably 8 and all my cousins would go to my grandparents' house and we would lay in the backyard and watch the clouds. And it was just laying there with everybody, we would all line up and we would all lay down there and we would just watch forever. (Jennifer, Earliest Memory)
Agentive ways of being			
Achievement/ responsibility	7	22	I really felt incompetent, like I hadn't learned enough, didn't have enough practice with all the things they were teaching us – starting catheters, taking blood, starting IVs. I really felt not ready. (Kayla, Turning Point)
Empowerment	4	10	[The students'] project was to use simple machines and make a simple machine work. I will never forget when their machine worked … they were so excited … That moment, that class, those boys … They were like, we did it! We made it work! And so I felt like I really had a huge impact on them and their life at that time. (Maggie, Peak Experience)
Status/victory	6	11	I became involved in 1994 with a project called the NEED Project. It stands for the National Energy Education Development Project. I ended up going to the state and to the national teachers' training and getting trained there and then I got asked to help run some small workshops with them in the state. This summer I'm running the whole elementary part of it. (Leslie, One Other Important Scene)
Self-mastery	3	5	I remember going to this first meeting and they put us in groups and I got put with the chemistry and physics college professors. And I remember going back to my room that night in the hotel and calling my husband and crying and saying I don't fit in here. I don't know this stuff … I didn't have enough of the background … But I learned not to be afraid to say I don't know or why does that work like that and they would be very patient with me and help teach me. (Leslie, Turning Point)

> … My grandpa had a big chestnut tree in the backyard and we would always go out and gather chestnuts. And we would sit down and crack them open, look at them, and it was just neat to kind of, I mean, always being inquisitive about things. Just wondering why is it like that? You know, what's it doing? But, of course, like my grandpa was one of my favorite people, so he just always, we always did neat stuff together … Every now and then we would get a worm. You know, and then it was like, 'Why is that in there?' and so, I think it helps me want to know why, why do things work? Why is it like that? How does it work? (Earliest Memory)

We found that Jennifer's life story reflected all seven *habits of mind* for 'doing science' but showed a greater preponderance of 'doing science' as seeking answers and knowledge.

Once again, we saw communal ways of being in her episodes reflecting this habit of mind. Not only did she tell stories of her relationship with her grandfather, she discussed other important people throughout her science life story. For example, she often talked about experiences she had with her son in seeking answers and knowledge about the natural world:

> I think maybe last year at the beach when I was with Donovan and his first time seeing the beach. I don't remember my first time seeing the beach, but he was so enthralled and just wanted to know everything about it. Wanted to know why do the tides take over further down the beach? Why does it, you know, why is all the stuff on the bottom? (Turning Point)

We suspect that Jennifer's story contains a diverse array of landscapes and habits of mind of 'doing science' because she opened herself up to multiple perspectives of scientific understanding: the perspectives of the other characters with whom she found communion in her science life story. Interestingly, however, Jennifer had a narrow look of 'doing science' as she primarily described this look as conducting an investigation and observing the phenomenon. We found this puzzling, as we might have expected her communal ways of being to have a greater range of what 'doing science' looks like because both her landscapes and her habits of mind were quite diverse. Why did Jennifer open herself to a range of people, spaces, and habits for doing science, while simultaneously supporting a more narrow look for doing science across those people, spaces, and habits?

While we only offer excerpts from Jennifer's life story as an illustration of our layered analysis, we found that all seven teachers described both agentive and communal *ways of being* in 'doing science' across their science life stories. Interestingly, we saw a preponderance of agency codes for the 'nadir' episode of their science life stories involving formal classroom spaces; specifically, participants articulated a lack of *individual achievement* in these episodes. For example, Leslie described a move to middle school science that left her disoriented and turned off from science:

> I can remember that sixth grade science teacher and all we did was, we were lectured to and we were given quizzes and worksheets and you defined words. And I didn't enjoy it. It was the first time I didn't enjoy learning. I had been so successful up through 5th grade, and I remember being so frustrated, especially when we got to the simple machines and I got a C and to me that was a crisis. But, I really struggled with that, because I had been a straight A student and was again after that point in time. But, I really struggled with it and it really turned me away from science. (Nadir Experience)

All but one participant told a classroom-based story relating to a lack of achievement for their lowest science moment. This suggests that we further explore how a lack of communion contributes to teachers' understanding of achievement.

In sum, these findings reveal a relationship between teachers' ways of being and their disciplinary knowledge of 'doing science'. This is not surprising as prior research has shown that aspects of social context are certainly related to knowledge development and use (e.g. Lee, 2008). What is interesting to us, however, is how different ways of being within stories with similar landscapes, habits, and looks illustrate differing notions of 'doing science' that are more or less aligned to reform-based ways of teaching in science. For example, two teachers had episodes in their science life story that were quite similar in landscape (a classroom), habit of mind (being active in pursuit), and look (conducting an investigation) of 'doing science', yet differed in their way of being (e.g. one

episode was agentive focused on the teacher's individual learning while the other was communal focused on learning with others). If we were to ignore the social, relational aspect of these episodes, we might characterise each as the same. Yet by considering the teachers' way of being embedded in these episodes, we may come to a different characterisation – both involve being active in the pursuit of understanding science concepts by conducting investigations in a formal context, yet one teachers' notion involves co-constructing scientific understanding, while the other does not. This distinction is important because reform efforts in science education emphasise fostering communities of science learners where individual knowledge is shared and understanding is co-constructed (Duschl et al., 2007). Again, as teacher educators, we should find ways to access and build from these different ways of being embedded in teachers' science life stories in order to support teachers in using their different ways of being in 'doing science' to inform their current science teaching practice.

Implications

Teachers, like children, inherently reason about and make sense of the world around them as they experience scientific phenomena throughout their lives. We know little about the pieces of knowledge in teachers' experiences with science throughout their lives that may be productive for teachers to draw upon in refining their science teaching practice. If we want teachers to make students' thinking central in their practice, then, as a field, we need to first understand the disciplinary knowledge of science that is embedded in teachers' everyday experiences and personal identities so we can support teachers in using this knowledge to inform their current science teaching practice. This work is a step in that direction as it provides insight into the pieces of disciplinary knowledge of science that stem from teachers' life experiences with science that can be leveraged in teacher learning contexts. Our findings suggest that each of these seven elementary teachers have a range of disciplinary knowledge of science that they draw on when telling their science stories. These findings reveal that elementary teachers do in fact possess disciplinary knowledge tied to their everyday experiences with the world around them that can be leveraged in developing their reform-based science teaching practices towards designing meaningful science learning experiences for their students. This disciplinary knowledge found in our elementary teachers' science life stories supports the notion that: (1) science is learned through everyday experiences in both formal and informal contexts, (2) teachers possess pieces of disciplinary knowledge demonstrating a range of habits of mind for 'doing science', (3) teachers have multiple ways of conceptualising what 'doing science' looks like, and (4) a relationship exists between teachers' ways of being and their disciplinary knowledge of 'doing science'. What if we could design PD for these teachers that uses this knowledge as a starting point for constructing a stronger professional identity aligned with reform-based practices of science teaching?

Prior work argues that PD 'should be structured in a way that addresses each teacher's individual needs and identity' (Madden & Wiebe, 2013, p. 2590), yet 'teachers may not see connections between their identity and teaching, or subject matter and students; thus, it becomes important that [teacher] educators make these connections, both the advantages and disadvantages, possible and explicit' (Mensah, 2012, p. 16). We agree, and we see the potential of future design-based research (DBRC, 2003) in which this exploratory study

serves as the basis for teacher PD that addresses these needs. For example, in this work, we used an adapted life story interview methodology (McAdams, 1996) to gain access into teachers' science experiences by giving teachers an opportunity to explain and describe these experiences. We think this tool could be used in teacher PD in a number of ways and a number of formats (e.g. online teacher learning communities, science life story teacher discussion groups, etc.). Teachers could tell their science life story in eight episodes as we had teachers do for this study, and their episodes could become objects of inquiry in PD contexts where teacher learners (1) discuss these episodes together, (2) identify the different pieces of disciplinary knowledge of science as well as the social, relational aspects that are present in their episodes, and (3) consider how these experiences with science over the course of their lives connect to their current science teaching practices and professional identities as science teachers. In this way, teachers' stories become resources for their own learning as they shape their science teaching practice in ways that are responsive to students' thinking and reasoning as called for by reform in science education (e.g. Luna, Selmer, & Rye, 2016; Davis & Smithey, 2009; Duschl et al., 2007; Windschitl, Thompson, Braaten, & Stroupe, 2012). Teachers' science life stories can do so both by highlighting what was powerful in their own science learning and by helping teachers understand how their past experiences shaped their current teaching practice both in ways that are consistent or incompatible with practices that support meaningful learning in science. We imagine that teachers would gain the same insight into their notions of 'doing science' that we gained from this research in PD contexts that use science life stories as objects of inquiry.

As such, we feel this exploratory study contributes to our understanding of teacher knowledge, and more specifically, to our understanding of the disciplinary knowledge of science embedded in teachers' everyday science experiences. By focusing on the storied lives of teachers, our work demonstrates that within their everyday experiences with science throughout their lives, teachers develop pieces of knowledge that we think are productive towards informing their science teaching practice in important ways. We learned that teachers' past experiences with science reveal diverse, complex, and dynamic disciplinary knowledge across landscapes, habits of mind, looks, and ways of being in 'doing science'. What this work does not tell us, however, is whether and how this knowledge shapes what teachers do in their science classrooms. This is a direction of future work. Finally, we hope that this exploratory study leads to further research and application that not only gives us theoretical insight into teachers' disciplinary knowledge, experiences, and personal identities in science, but also, as we stated earlier, (1) promotes an interest in elementary teachers' science experiences among educational researchers and teacher educators, (2) provides an empirical blueprint for those interested examining similar lines of inquiry, and (3) contributes to a larger effort to recognise teachers' life experiences as relevant to teaching and teacher education.

Note

1. For more information about the Life Story Interview, see The Foley Center for the Study of Lives website, where the instrument and related information is publically available: http://www.sesp.northwestern.edu/foley/instruments/interview/.

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