Productive disciplinary engagement as a recursive process: Initial engagement in a scientific investigation as a resource for deeper engagement in the scientific discipline

Xenia Meyer *

Graduate School of Education, 4646 Tolman Hall, University of California, Berkeley, CA 94709, United States

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Engle and Conant (2002) show how productive disciplinary engagement (PDE) for students can be attained through learning environments structured to support problematizing subject matter, give students authority to address content problems, hold students accountable to others and disciplinary norms, and provide students with resources. This paper considers how one classroom’s involvement in a scientific investigation embodied and extended the PDE framework. In this U.S. based classroom, 5th grade non-native and English language learning students engaged in scientific inquiry and contributed their findings to a greater scientific community. This paper proposes that these students experienced PDE at both initial and deeper levels, where students’ initial PDE in scientific activities served as a resource for PDE at a more discipline-specific level.

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1. Introduction

Engle and Conant (2002) describe how structuring learning environments to promote student problematizing of subject matter, authority to address content problems, and accountability to others responsive to shared disciplinary norms, together with making resources available to students, may foster productive disciplinary engagement (PDE).

As Engle (2011) further elaborates and explains, PDE entails students actively engaging in activities related to a discipline, and being productive, or in other words, make progress – and while PDE refers to the in-the-moment attentiveness to students’ disciplinary activities, the framework for PDE refers to the kind of learning environments that need to be established by educators to foster PDE. The guiding principles of this framework include that educators promote student problematization of subject matter, give students authority to address content problems, hold students accountable to others and to shared classroom and disciplinary norms – and provide students with the necessary resources to continue learning. Though a variety of different pedagogical approaches may foster PDE, this paper considers what PDE may look like in the case of an inquiry-based investigation, where students participate in addressing an actual scientific research question in collaboration with practicing scientists.

The movement toward inquiry-based instruction seeks to reform didactic and lecture-based approaches to science instruction where teachers teach about science rather than engaging students in doing science through involvement in scientific practices (National Research Council (NRC), 2000, 2012). In inquiry-based classrooms, students learn science through the context of participating in scientific activities, where scientific content is embedded into scientific practices,
which are ideally made explicit to students. Though there has been dispute of what, exactly, counts as inquiry (e.g. Berland & Reiser, 2009), the NRC (2000) describes one North American influential vision of what student involvement in classroom-based scientific inquiry would entail. This description includes the restructuring of classroom learning environments to: (a) engage students in scientifically oriented questions, (b) provide opportunities for students to give priority to evidence in responding to questions, (c) encourage students to formulate explanations from evidence, (d) have students connect explanations to scientific knowledge, and (e) encourage students to communicate and justify their findings in a scientific manner (NRC, 2000, p. 29). More recently, the NRC (2012) specified that in addition to participating in inquiry, student involvement in scientific practices entails practices such as students asking their own questions, planning and carrying out investigations, analyzing and interpreting data, and engaging in argument from evidence. Though the implementation of inquiry, or student involvement in scientific practices, remains on a continuum, with more or less emphasis of the various aspects of scientific practice, Berland and Reiser (2009) delineate three essential goals to scientific inquiry: sensemaking, articulating, and persuading. Consistent with the recommendations of the new framework for science learning (NRC, 2012), these goals suggest that a learning environment structured for inquiry would provide students with opportunities to make sense of data, share their findings, and convince others about what they find.

Though engaging classroom-based inquiry may provide learning opportunities for students that more closely models scientific activities, in many cases classroom-based inquiry falls short of modeling the actual work of scientists because of the lack of access to scientists and their guidance in learning about scientific norms (e.g. Chinn & Malhotra, 2002; Schwartz, Lederman, & Crawford, 2004). It is important to note that while classroom-based activities are authentic to the practices of school science (Lave, 1992) and reflect an hybridized culture of pedagogical practices combined with scientific content and practices (Hogan & Corey, 2001), they may not necessarily be representative of what scientists actually do. Invoking students in scientifically authentic investigations (Bencze & Hodson, 1999; Lederman, 1992), in collaboration with practicing scientists, may provide opportunities for school-based inquiry to extend beyond the classroom and connect to a scientific community of practice (Wenger, 2007). In this way, classroom-based inquiry may become more authentic to the actual work of scientists and students may be provided with opportunities to learn more about scientific practices and norms beyond the classroom environment. In this unique learning environment, a hybrid space may be formed between the classroom and context of the scientific activity and the fusion of disciplinary and school-based norms may occur. This sort of learning environment may also provide a stepping-stone for promoting deeper levels of PDE in science, by first engaging students in more surface-level aspects of the discipline.

In the case of involving students in inquiry, a teacher may guide them toward PDE in science. In a learning environment where a teacher engages students in scientifically oriented questions, students may have the opportunity to problematize content and form their own questions about what they are observing. Problematizing may entail not only students making sense of content from their own perspectives, but also making sense of content using scientific terms (Ford, 2008). Students involved in actual scientific investigations may also have access to resources, such as authentic scientific questions and the scientists who ask them. As students are provided with opportunities to formulate explanations from evidence and communicate their findings, they may begin to practice authoring their own ideas. Student authorship with respect to inquiry-based practices also presupposes that students have access to resources, such as data to work with and an audience who is interested in and responsive to their findings. As students give priority to evidence and learn to justify their findings – as well as connect their learning to prior scientific knowledge, they may begin to demonstrate accountability to disciplinary norms. That students are able to do so would involve students having access to data and to scientific knowledge and guidance to learn scientific disciplinary norms, again in this case, a resource. Thus, through PDE in scientific practices, students are also introduced to the scientific discipline.

While the idea of establishing collaborative relationships between science classrooms and practicing scientists is gaining momentum (e.g. Cakmakci et al., 2011; Rennie & Howitt, 2009; van Eijck & Roth, 2009; van Eijck, Hsu, & Roth, 2009), more research is needed to consider the impact of student engagement in actual scientific practices in school settings may be. This paper claims the hybrid context formed by the infusion of scientific practices into a classroom setting, with the teacher both structuring this learning environment and serving as a broker between classroom and scientific practices, provided students with the opportunity to engage in PDE at both initial and deeper levels. This paper further proposes that student PDE in actual scientific practices may itself serve to foster students gaining, or appropriating, disciplinary aspects of scientific problematizing, authority and accountability, in effect creating a positive feedback loop between these principles and fostering PDE at a deeper, in this case scientific, disciplinary level.

To theoretically illustrate the recursive process through which student initial PDE led to deeper PDE in this hybrid classroom setting, this paper makes use of a case of student involvement in the Fossil Finders project, an investigation conceptualized by geologists using fossils to research environmental changes during the Devonian period. This case study provides a compelling example of the trajectory of PDE in a classroom of underrepresented, where students’ initial PDE in classroom activities prepared them and became a resource for deeper levels of engagement in the actual practices of geological research. This project was implemented with a 5th grade classroom in an underresourced urban school in the eastern part of the United States, a setting in which innovative approaches to science instruction and PDE may be unlikely to occur (Settlage & Meadows, 2002). The focus classroom served underrepresented and non-native language speakers, many of whom were recent immigrants. The goal of engaging these particular students in scientific activities was to provide them with opportunities to engage in and experience scientific practice. The intention of the curriculum was not to transform these students into scientists, but rather, to illustrate what participating in science could be like. The collaboration between the
classroom and scientists provided a setting to observe how students achieved PDE through involvement in inquiry, and appropriated scientific authority and accountability as they problematized, gained expertise, and made contributions to an actual scientific investigation.

2. Theory and background

To consider how the framework for PDE (Engle & Conant, 2002) may relate to participation in authentic inquiry, I center my focus on the experience of the learner in the instructional setting structured by the teacher and draw on theories of situated learning and identity (Brown, Collins, & Duguid, 1989; Rogoff, 1995) with respect to communities of practice and their disciplinary engagements (Lave & Wenger, 1991; Wenger, 1998). I further draw on Engle’s (2011) conceptions of authority and accountability to address how each lead to and result from PDE, vis-à-vis participation in the authentic activities of science.

At the core of Engle and Conant’s (2002) and Engle’s (2011) description of PDE, lies student engagement. According to the authors, student engagement entails students discussing content with substantive contributions in coordination with one another, remaining on-task and/or reengaging in the topic and remaining on-task for long periods of time, and indicating enthusiasm for what they are learning through emotional displays. This engagement then becomes disciplinary when “there is some contact between what students are doing and the issues and practices of a discipline’s discourse” (Engle & Conant, 2002, p. 402). In the case of traditional classroom-based activities, this discourse may remain limited to school-based discourses. However, classroom participation in scientific investigations may extend the normal classroom context to include aspects of scientific work and thereby scientific discourse (Lemke, 1990; Rosebery, Warren, & Conant, 1992). This particular kind of learning context may be formed as a result of the interaction between students and scientists when working on a collaborative project. Finally, the authors explain the productive nature of disciplinary engagement, or that disciplinary engagement results in intellectual progress over time on the disciplinary issues being engaged in. The four core guiding principles forming the preconditions in which PDE can occur include student problematization of subject matter, authority to address content problems, accountability to others and to shared classroom and disciplinary norms, and access to necessary resources. Of these principles, I focus on the teacher’s positioning of student authority and accountability to both the classroom and scientific disciplines.

Engle (2011) describes student authority as starting by students having intellectual agency, or an active role, in knowledge production that is based on their own ideas. This then progresses along an increasing scale to authorship, contributorship, and students becoming authorities to the extent they are recognized for the knowledge contributions that they make within and potentially beyond the context at hand. Engle and Conant (2002) further explain that accountability entails students having responsibility for accounting for how they have aligned their intellectual work to content and practices of others within their field of study and to related disciplinary norms, “to the extent that these [disciplinary norms] can be embodied in a classroom” (p. 405).

In regular classroom settings or classes other than science, student authority may resemble opportunities to voice opinions and share ideas whereas accountability may entail that students situate these ideas with respect to the positions of others in the field of study. In an inquiry-based learning environment, teachers provide opportunities for students to engage in scientific activities where they problematize content by asking scientific questions, become accountable to others and disciplinary norms by finding evidence for explanations, and make use of intellectual authority and accountability by constructing explanations and linking them to other scientific knowledge. Through being given access to scientifically oriented questions, a responsive audience, and scientific knowledge, students access and build from supportive resources for problematizing and accountability. Further, the infusion of actual scientific work into classroom settings, may serve to introduce scientific disciplinary norms into the classroom, in effect creating a hybrid classroom-scientific space. In this hybrid space, students may first be introduced to scientific concepts with the guidance of classroom norms. Then, using this learning as a resource, extend their learning toward enacting norms more consistent with scientific practice, which may guide them in still deeper participation and engagement in scientific disciplinary activities.

Drawing from the perspective that engagement in the activities of a discipline results in the learning of that discipline (Rogoff, 1995), it is likely that through the initial stages of participation in scientific activities in the classroom, participants become prepared for deeper engagement in those or other scientific activities. With a teacher structuring classroom activities to be more closely related to the activities (such as inquiry), context (such that of an investigation), and culture (such as nature of science) of the scientific discipline (Brown et al., 1989), students are afforded greater opportunities to engage with, participate in, and learn about the scientific discipline more directly (Schwartz et al., 2004). Through this participation, learners may even begin to appropriate and practice aspects, or roles, of that particular discipline (Ford & Forman, 2006; Rogoff, 1995). Ford and Forman (2006) posit that disciplinary resources are formed through participation in activities. “Through participation in a disciplinary or classroom community, people come to learn the various roles that exist in that practice. Subsequently, these roles serve as disciplinary resources” (p. 8). In the case of participating in scientific activities, these resources may include the scientific discourse and practices appropriated by participants (Driver, Asoko, Leach, Mortimer, & Scott, 1994).

While content learning is a form of intellectual progress that may be attributed to participation in an actual investigation and would alone illustrate the productivity in PDE, other forms of disciplinary progress through the adoption of scientific norms and practices may also ensue. These norms and practices include the appropriation of scientific authority and
accountability to the scientific field, both characteristic of identification with and taking on an extended membership within the scientific field (Wenger, 1998) – and may become resources for deeper levels of PDE. This process may be particularly relevant for students from backgrounds that are underrepresented in the sciences, for whom everyday life communities may not regularly make use of scientific language and practices, or share a worldview consistent with that of Western modern science (Aikenhead, 1996). Participation in an authentic science investigation may thus afford opportunities for all these forms of productivity, which embody and reinforce the PDE framework as an iterative process. It is their initial PDE in the classroom context of the Fossil Finders project that students were able to use as a resource for deeper and more discipline-specific PDE in a geological investigation (Fig. 1). The Fossil Finders project involved non-native and English language learning (ELL)\(^1\) students from underrepresented backgrounds in an actual scientific investigation and explicit instruction in NOS (Lederman, 2004) in collaboration with practicing scientists (Crawford, Ross, & Allmon, 2007). These scientists had gathered more data than they were able to process and analyze from various sites and different depths along the stratigraphic columns. The analysis of these data would entail the identification and measurement of these fossils to reconstruct the general populations of these organisms found in different locations and during different time periods. A gain or decline in the populations of various specimens would suggest a change in environmental conditions.

For the investigation, scientists shipped cross-sections of rock containing fossil samples to classrooms, where teachers involved students in identifying the fossils they were finding, measuring them, and entering their data into a database, such that the data measured in one classroom could be compared with data measured in other classrooms for analysis by students and the scientists. The curriculum related to the project was theoretically rooted in a constructivist approach and included background preparatory lessons on measurement, fossils, principles of geology (such as superposition), and nature of science using an inquiry-based approach. For the investigation, students made use of their background learning and skills to engage in the actual work of scientists. This project, therefore, involved the bringing together of a scientific project and a classroom setting to create an hybridized learning environment (Hogan & Corey, 2001) that more closely resembled actual scientific practice.

The implementation of the project in an urban classroom serving ELL students from Latino backgrounds provided a unique setting in which to observe how the authentic scientific investigation was structured to provide a learning environment that fostered PDE. It is in these very settings that innovative approaches to science instruction seldom occur (Settlage & Meadows, 2002) though they may serve to benefit students. In addition, in many cases in the United States, ELL students are placed in language remediation programs, where “the possibility of continuing to grow intellectually [is] deferred until such time as they are considered to be able to handle English” (Valdes, 2001, p.14). This project, however, drew on research-based practices to use the context of the scientific investigation to provide students with opportunities to learn scientific content and discourse along with English (Rosebery et al., 1992; Stoddart, Pinal, Latzke, & Canaday, 2000). Given the general lack of science instruction for students at the elementary school level in addition to the absence of innovative instructional approaches reaching children who are non-native speakers and/or are in underresourced schools (Gonzalez, Moll, & Amanti, 2005), the implementation of an innovative curricula involving a scientific research project provided a window into the potential for PDE with students in such settings.

3. Methods

This study used a case study design and a participatory observation approach (Merriam, 1988) in one teacher’s classroom to explore how classroom-based inquiry with links to actual scientific research fostered PDE in science classrooms. The focus teacher of this classroom, Monica (pseudonym), served Latino 5th grade students from economically challenged families (with 84% of the students receiving free or reduced-price lunch). Most of the students in her dual-language class were either first or second generation immigrants, and many regularly spoke Spanish with their families at home. Monica implemented the Fossil Finders instructional unit and its related investigation in collaboration with practicing scientists in her classroom following a summer professional development program, during which she learned about inquiry, geology, and became familiar with the curricula. Monica then transferred these learning experiences into her classroom to supplement her regular classroom instruction.

Video tapes and time-indexed fieldnotes from across the instructional unit provided the primary source of data to capture and illustrate how the learning environment she structured fostered PDE for her students (Jordan & Henderson, 1995). These video data were coded for the implementation of different aspects of inquiry by the teacher or students, student engagement, and scaffolding for language learning. Such an approach provided a basis for characterizing the learning environment structured by the teacher and the instructional approach she used. It also allowed for cataloging student engagement across the instructional unit. Students were also pre-post tested on science content and their views on science to measure learning. Together, these data provide the basis for claims related to how the nature of the hybrid learning environment related to the classroom implementation of an actual investigation provided for a shift from initial to deeper PDE.

The Fossil Finders instructional unit was implemented over the course of 13 instructional days in block periods (30–90 min long) (see Table 1). During this time, Monica prepared her students for participating in the investigation by using

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\(^1\) The term “English language learners” refers to the designation of non-native language speakers of English in the United States while these students are in the process of developing academic English language proficiency.
an inquiry-based approach to provide them with background geological content, such as learning to identify fossils, and instruction about nature of science (NOS). This background instruction formed opportunities for initial PDE that may have served as a resource for later and deeper student PDE in the actual investigation. Instruction in NOS was included to provide students with guidance in understanding the connections between the scientific activities of the investigation and what scientists actually do (Schwartz et al., 2004). The teacher also supplemented the instructional unit with literacy activities, such as an English language arts journaling and a writing project focused on nature of science. In this way, Monica served as an intermediary between school and scientific spaces.

Monica initiated the data collection and analysis portion of the investigation using the fossil samples shipped to her class during a scientist’s visit to the classroom. Because the scientist happened to visit their classroom, students were able to interact with her and ask scientifically oriented questions about fossils while observing their fossil samples. Students also had the opportunity to ask her general questions about practicing geological work and the process of becoming a geologist. This scientist had received pedagogical training and was receptive to student-centered approaches to learning. For example, she provided students opportunities to ask questions but probed them with more questions rather than answers. She thus guided and prompted students to think more deeply about the content in a way that was consistent with inquiry-based approaches. Monica also made use of my presence in the classroom as a resource and asked me to interact with students when they had questions.

4. Findings

This section describes how the context of an actual scientific investigation in a classroom setting created a learning environment that engaged students in both initial and deeper PDE. In this particular learning environment, the hybridizing of both classroom and scientific practices allowed for students to first problematize questions, author of ideas, and practice student accountability along the lines of more classroom-related norms – which then shifted to encompass more scientific norms as students engaged in the investigation. In this section, I will share how teacher structured this learning environment where students were positioned as participants in scientific work and provided opportunities to: (1) problematize content

Table 1
Curriculum implementation and focus across instructional days.

| Instructional day | Focus                  | Activity                                                                 |
|------------------|------------------------|--------------------------------------------------------------------------|
| 1–2              | Background lessons     | Activity about uncovering fossil tracks that modeled aspects of NOS;     |
|                  |                        | specifically, the tentativeness and subjectivity of science              |
| 3                | Background lessons     | Students were provided with fossils for unguided “discovery.” Prompts    |
|                  |                        | asked: What is it? What environmental conditions do you think it lived   |
|                  |                        | under?                                                                  |
| 4–12             | Literacy activities    | Students wrote stories about the NOS activity that modeled the          |
| 5–9              | Background lessons     | Students learned to identify and measure fossils. Students then       |
|                  |                        | learned to gather more detailed data about fossil samples into a data    |
| 10–11            | Investigation          | Scientist visited the classroom; students interacted with her and       |
| 12–13            | Investigation and      | Monica confirmed student data and measurements by working with the      |
|                  | literacy activities    | Other students continued working on their Tricky Tracks stories         |

Modified from Meyer, Capps, Crawford, and Ross (2012).
through the scope of authentic research questions; (2) author their own ideas and contribute them to the class – making use of both classroom and then scientific disciplinary norms when sharing these ideas; (3) show accountability to regular classroom norms – which later extended to those of the scientific discipline; and (4) have access to resources such as actual data, scientists, and time to engage in scientific activities. This section illustrates this teacher’s development of a unique, hybrid learning environment structured to involve her students in an actual scientific investigation and the accompanying trajectory of student PDE.

4.1. Problematizing content through authentic research questions

Through the hybrid context of a classroom involved in an authentic investigation, Monica structured a learning environment in which students were first able to engage in their own questions about fossils prior to exploring the research questions framed by scientists. In this learning environment, students clearly asked and explored their own ideas about fossils. Monica then provided students with guidance in situating student understandings into the scope of the research study. In this way, students were able to problematize scientific content on their own terms prior to engaging in the more scientific practices of addressing research questions by making inferences from their observations. This section illustrates how students transitioned from problematizing content in their own ways to using scientific practices to do so.

Monica initially structured the class time such that students were able to work in small collaborative groups instead of providing students with guided instruction. For initial problematizing, students had autonomy to independently observe fossil samples and develop their own ideas about what they were seeing:

“You’re going to look at these fossils that Ms. V actually dug out this summer… you are going to look at them and you’ll take… one specimen… I want you to try to look and see what you identify as a fossil… and I can [come] around if you’re not sure it’s a fossil. You can point it out and [I’ll] let you know if it is or not. Then, you’re going to hypothesize what [they are]. What it is that you’re looking at? Is it vegetation, is it animal? And, if it is, what do you think it might be? …Can you switch them up [with your group members] and look at different ones? Yes.” (October 6, 2008)

Though Monica made herself available to confirm whether students were looking at actual fossils (as opposed to other marks on the rocks), she provided them with opportunities to themselves consider what it was they were seeing.

During this time, she deferred scientific authority to students by not correcting their mistakes, instead letting them correct them on their own with the assistance of disciplinary resources. For example, one student, Raul, shared what he thought was a fossilized fish in a rock. “I think I found a fish… ‘cause it has the fin right there and it looks like it has the eye” (October 6, 2008). Through his explanation, it became evident that Raul thought that the entire rock was a fossilized fish because it was shaped like one. Though records of fossilized fish are nonexistent during the Devonian period, Monica allowed Raul and his classmates to make their own inferences about what they were seeing before providing students with fossil identification guides, which they successfully used to resolve their initial misunderstandings.

Through this process, she allowed her students to bring their own understandings into the science learning process. Though initial student knowledge was not qualified as being scientifically authoritative, let alone close to being correct, students were given the opportunity to have their own ideas – a step toward authoring their own ideas in a scientific way.

Later in the unit, Monica and the visiting scientist, Trina (also a pseudonym), guided students into considering the relevance of what they were studying with respect to scientific questions, both reinforcing the authenticity of student work and its larger purpose. When Monica showed students a representation of the environment in which the fossilized organisms had once lived in, she facilitated students in making the connection that this environment must have been tropical (December 2, 2008). When the visiting scientist came to the classroom a week later, she extended the concepts Monica had reviewed with students and discussed how the fossils students were observing related to questions driving the geological work:

“So, when your fossils were collected, [in] North America, specifically [in the] area where we are, [the environment] was about what the Caribbean Islands are like. So you used to be in a nice Caribbean island here and you could have been laying out on the beach and sunning yourself. Then 380 million years went by and now we’re in snow.” (December 9, 2008)

Here, the scientist indicated that the local environment was at one point very different. She went on to ask students how scientists could learn about the present-day environment by studying the past. She then continued to further explain the purpose of this work:

“Geology is really cool… [we study] oceans, boats, currents, climate change, wind patterns […] because it’s all interrelated… and that’s exactly why geology is related to ocean study, because we have to know why the ocean used to be deeper and grew… the ocean was up on land for a while so we need to know why that happened so that’s a lot of the reason why we have to study everything.”

With the aid of resources, such as the guidance of their teacher and the visiting scientist, the activities students were involved in and the research questions presented to the class were contextualized within the greater scope of geological research.
Along these lines, students demonstrated initially problematizing questions related to science and fossils on a surface level and later, on a deeper level recognizing how this content related to geological research and the scientific discipline. This deepening of disciplinary understandings is reflected in one student’s response to the pre-post question: “What is science?” While this student, Bianca, initially stated “science is like things that would help you find out about the solar system, gravity, you can find out about the moon, the milky way and lots of cool projects,” following her participation in geological activities, her response to the same question stated “science is about observing, making inferences, figuring out experiments [sic], and things that lived millions of years ago (dinosaurs).” Here, she is clearly drawing on deeper disciplinary understandings about how geological research is conducted, including the process of making inferences from observations, which by default include a process of problematizing questions. This process of addressing deeper disciplinary questions is also elaborated in the example of authorship below.

4.2. Student authority: appropriating the scientific activity of authoring ideas

Monica also established a learning environment that promoted PDE by providing students with opportunities to author their own ideas. This is evidenced in how Monica prompted students to make sense of what they were seeing, positioned them as local experts in the pronunciation of dinosaur names, and credited students for their intellectual contributions to the class. Through initial PDE in the investigation, students also began to exhibit scientific disciplinary activities, such as the making and sharing of discipline-appropriate ideas.

During the introductory phases of the investigation, Monica designed an activity apart from the background lessons of the curriculum to allow for students to come up with their own ideas about the fossilized organisms they were observing. This activity invited students to being authoring ideas related to the content and engage in discussions around these ideas (October 7, 2008):

1  Xenia: [To Damian] Me puedes mostrar que tienes? Translation: “Can you show me what you have?”
2
3  Damian: A rock and in that rock I see a backbone...
4  more fossils
5  Xenia: Okay. Where’s the fossil? Can you show me? I’m going to zoom in. Oh yeah, there’s something there.
6 
7  Eva: And the backbone, the backbone, right here [directing eye gaze at rock] [Damian points to part of rock with pencil]
8  
9  Brendan: [from the other side of the table] And we see like this thing… there’s a shell right here [Damian points to smaller part of rock with pencil]
10
11
12  Xenia: Okay. Something there too? What do you think that is?
13
14  Brendan: Like a clam shell?
15  Xenia: Okay. Do you agree? [to Matias]
16  Matias: Yeah!
17  Xenia: Okay… What else did you find?
18  Damian: [From across the table, to Eva] Se ve como… Seashells Translation: “It looks like”
19  Matias: Seashells
20  Brendan: Yeah!
21  Damian: [From across the table] …Piel de un dinosaurio. Translation: “Dinosaur skin. Here, here!”
22  Xenia: Aquí, aquí!

In this exchange, Brendan jumped in to talk about what he and Matias were observing in their rock samples (lines 10 and 11) while I was talking to Damian and Eva (lines 1–9). While I turned my attention to Brendan, Damian continued to talk about what he was viewing to Eva (lines 18, 21 and 22). In this way, this exchange is illustrative of students being active learners with the opportunity to author their own ideas about science, which in turn may have served to promote science subject-matter learning. Clearly, this example also illustrates student engagement in learning, with these students discussing content with substantive contributions in coordination with one another and indicating enthusiasm for what they are learning (Engle & Conant, 2002). It is also notable that students made use of their native language, Spanish, when talking about what they were seeing.
As the unit progressed, Monica further positioned her ELL students as local experts that made more substantive contributions to the classroom community by relying on them to pronounce scientific terms. During the second day of instruction in the unit, Monica stated, “the title of this book is called the Peteronodon. I hope I pronounced that right. I had to say it little by little because it’s difficult for Miss M to pronounce all the dinosaur names. But it’s the… how do you say it?” (October 6, 2008). When students, in chorus, responded with a pronunciation, Monica replied, “Oh, you guys are familiar. You’re better than me. Excellent. I’m going to have to call on you to help Miss M out with that.” In this instance, Monica relied on the students to help her pronounce dinosaur names, based on their prior knowledge. In this, not only did Monica validate this disciplinary knowledge that they had developed, but she also positioned herself as a learner within the classroom community.

Monica further attributed authority to specific students by recognizing the substantive quality of student contributions. For example, Monica related a group reading in the class to an inference that Raul had share with her in class the day before (December 10, 2008):

Monica: “There are specific fossils found in different parts of the US … looking for signs of sea that was once here.” And, that was a discovery that Raul made yesterday, that New York State was…

Raul: [Enthusiastically] Underwater!

Monica: At one time, underwater… Here, Raul had his ideas from the day before validated both by his teacher (line 5) and by outside sources, such as the book being read (lines 1 and 2). It is also significant to note that the connection made by Raul, between the type of fossils being found and the environmental conditions under which the fossilized organism once lived, is at the core of the geological investigation.

By drawing on student knowledge and other sources of information, Monica constructed a classroom environment in which she was no longer the single source of knowledge, but rather a learning facilitator. Together, these passages illustrate the learning environment established in Monica’s classroom, where students practiced authorship in having their own ideas be publicly recognized – and Monica’s practice of drawing on her students for knowledge through the context of an authentic investigation, which positioned them as knowledgeable sources and potential contributors to the collective understanding in the classroom and beyond the scientists’ actual investigation.

As students became involved in scientific disciplinary work, they began to reflect authority as related to scientific disciplinary practices. For example, it was not enough to share ideas, without aligning them to other scientific norms, such as providing evidence and explanation, in order to receive credit and become positioned as an author of ideas in the classroom. The following example, which occurred at a later point in the investigation, illustrates this shift in student authority. In this example, one particular student shared an idea and was probed to show justification for her ideas using evidence, demonstrating some of the disciplinary aspects of scientific argumentation. In the following passage, this student defended her ideas in response to Monica’s questions about how the student group had identified and measured a particular fossil (December 12, 2008):

1 Monica: Let’s see, what [fossil] is this one that we were talking about? Over here, right? Hmmm…

2 Renee: Miss, I think it was the brachiopod… the half of the brachiopod, with the symmetrical shape…

3 Monica: Where’s it symmetrical? Do you see it symmetrical? Oh, I see what you’re talking about. Maybe because it goes in like that…

4 Okay, so you think it’s a – we’ve decided it’s a brachiopod

5 Renee: Nine… Ten?

6 Alissa: Yeah. Measure it.

7 Monica: Okay, so who’s going to measure it? Your eyes are better than mine [Renee is already measuring the fossil]

8 Nelia helps Renee readjust the ruler and hold the rock]

9 Renee: Nine… Ten?

10 Monica: Which way?

11 Alissa: Length.

12 Monica: Ten? Dame ver [Translation: “Let me see”]

13 [Renee models how she is measuring the rock]

14 Let me see? Okay, you’re right, you’re right.
When Monica first questioned whether Renee had correctly identified a brachiopod (for which symmetry is a key feature) (lines 5 and 6), Renee used the rock itself as evidence to support her claim by pointing out its symmetry. Monica then transitioned from attributing the (potentially inaccurate) fossil identification to her students to also accepting their conclusions. This is evident in how she changed her train of thought in mid-sentence: “Okay, so you think it’s a – we’ve decided it’s a brachiopod” (lines 8 and 9, emphasis added). Monica later challenged whether the fossil measurement was done correctly (line 17). When Renee modeled how she completed the measurement, Monica readily agreed with the measurement and credited her with being right (line 19). In this scenario, Renee demonstrated authorship of her own ideas but needed to make use of scientific disciplinary practices, such as making use of evidence in constructing her ideas, to ultimately be recognized for her ideas by her teacher in this particular instance.

Without Monica providing her students with opportunities to make sense of what they were seeing, positioning them as local experts, and crediting them for their intellectual contributions to the class, it is uncertain whether students like Renee would have developed deeper understandings and authority related to the fossils they were studying. Further, though the justification of ideas using scientific norms may seem similar to the principle of accountability to disciplinary norms in the PDE framework (Engle, 2011; Engle & Conant, 2002), I argue that there is no other way to share ideas and have authorship for them within a scientific discipline. In the next section, I illustrate the progression toward disciplinary accountability in a broader sense.

4.3. Being scientists means being accountable to the scientific discipline

In the hybrid classroom environment, Monica held her students accountable to the already existing norms of the class while also positioning her students as practicing scientists who were accountable to scientific norms. This included holding students responsible for being able to justify the accuracy of their work, a school-based norm. However, as students began to identify themselves as participants in scientific work who were being scientists, they appropriated scientific habits, thereby demonstrating accountability for their activities using scientific norms, in addition to school norms. In this case, adherence to school-based norms also served as a resource for later adherence to the disciplinary norms of science.

During the first day of the instructional unit, Monica pointed out how scientific practices were similar to those already being employed by the class, specifically emphasizing the importance of accuracy also being part of scientific work:

> It’s important as scientists to always keep accurate records and to date all of your entries, okay? We date everything we do in our class anyway, right? Reading, writing, everything that we do, but specifically as scientists, you need to keep accurate notes and put your date all the time, whenever you do entries. (October 6, 2008)

This statement reflects the beginning of the transition of the classroom into a hybridized space where regularly practiced classroom norms, such as accuracy, are also relevant to scientific work. It is important to note that in this statement, Monica also positioned students as being participants of scientific work and referred to them as “scientists.” In being positioned as scientists, students were effectively being held accountable to scientific norms by their teacher. Their participation in the scientific project also called for them to follow the scientific norms of the project. For instance, students needed to measure their fossil samples in centimeters, not inches (which they were more accustomed to), as the metric system is standard system of measurement in science. Monica further reinforced the concepts of accuracy needed in scientific work – and the potential for human error during data collection – by instructing all students in the group to measure the same fossil samples and resolve any disagreements.

When students began to identify and measure fossil samples on day 10 of the unit, Monica then reinforced the importance of checking each others’ work by remeasuring the same fossils several times. As Monica explained, this was to “reduce human error” because “scientists make mistakes” (December 9th, 2008). Having already positioned students as scientists, she here pointed to the potential of even scientists, who focus on being accurate, to make mistakes.

At the end of the investigation on day 12, Monica herself reviewed student work and measurements for accuracy. As she sat down with a student group, she described: “we’re going to go through you data and check if it’s correct so that we can put it into the computer today” (December 12, 2008). Though accuracy may also be construed as a regular school-based norm, in the context of this activity, where the data students entered would be used by a number of other classrooms, it became a practice that was relevant to other communities beyond the classroom. Monica further explained, “We’re doing double-checking. We might be off so that’s what scientists do, they double check.” In response to her teacher’s positioning them as scientists, students did, in fact, begin to identify with being participants in scientific work and adhering to scientific norms. For example, Brendan likened himself to a scientist because he “h[a]d a notebook like a scientist” and took notes in it (December 15, 2008). Raul further provided a rationale for describing himself and the rest of the class as scientists as they were “basically doing the same thing” as scientists.

As students further engaged in the investigation they began to also demonstrate accountability to the scientific discipline in a different sense. By participating in scientific activities using scientific disciplinary norms, students enacted accountability to the scientific discipline. This was evidenced by the fact students engaged in activities of the scientific discipline, meaning they had justified the activities and behaviors they were involved in along the lines of scientific disciplinary practices. This included practicing scientifically minded activities, such as making observations, comparing pieces of data, and categorizing findings – consistent with scientific practices. In the following brief example at a later point
in the investigation, a student group discussed a particular fossil specimen as they worked to find, identify, and measure fossils found in their sample bags (December 10, 2008):

1. Matías: Hey, [it's] another clam inside out!
2. Isabel: Then measure it. [assertively]
3. Bianca: What is it? Let me see. [Matías shows Bianca]
4. Yeah, it's a clam. It's kind of a round one. It's fragmentation.
5. Ms. Monica said we all measure it…
6. [measures using ruler] The length is… 20 mm

In this example, Matías exhibited enthusiasm and engagement in what he was finding (line 1). By saying that he was finding “another” clam that is inside out, he is comparing the specimen he found in his sample with others he had already seen. By connecting this particular piece of data to other similar data samples he had already observed, he is showing evidence of the disciplinary practice of comparison in science. Isabel then responded with a prompt for him to stay on task and to complete the other aspects of data collection (line 2), thereby demonstrating an hybrid accountability to completing the classroom task at hand and to the larger project, which depended on the data this and other groups would analyze. Bianca then responded with interest in the specimen that Matías had found and confirmed that his identification of it was accurate (lines 3 and 4), demonstrating the appropriation of a scientific attitude in addition to content-matter learning. She further commented on the other characteristics of the fossil, such as its shape and intactness (with fragmentation indicating that the specimen was broken) and thereby demonstrated scientific observation skills (line 4). Finally, the group constructed another piece of evidence for the investigation when Bianca measured the fossil that Matías found and shared this piece of data with the group (line 6).

In this brief interaction, it is clear that student activities and interaction were guided by classroom and scientific disciplinary norms, and through their actions, students showed accountability to these norms. In other words, students justified their enacted behaviors (and not just ideas) along the lines of scientific disciplinary practices, such as double-checking measurements.

While Monica initially held students accountable to classroom norms, she also likened them to scientific practices such as paying attention to details in note-taking and confirming student results. Consequently, students began to practice an hybrid accountability to both classroom and scientific norms, where they adhered to classroom norms, such as completing the assigned classroom tasks, while demonstrating accountability to their data and findings as well as other disciplinary norms, such as making use of evidence in sharing their explanations. In this way, student accountability progressed from an accountability to classroom norms toward an accountability that encompassed scientific norms.

4.4. Having resources and tools: data, scientists, time and initial PDE

Participating in an authentic investigation through an inquiry-based approach provided students with the context for engaging in actual scientific activities with the use of actual samples and access to practicing scientists. With access to actual scientific questions, students were able to engage in and problematize scientific content. Further, the context of an actual scientific investigation provided students with access to an interested audience of scientists as well as other classrooms participating in the investigation – positioning student findings as having real bearing beyond the scope of their own classroom. Thus, the investigation served as a resource for fostering accountability to a greater number of other people than students are usually held accountable to. In addition, students made actual contributions to science by entering their data into a database to be used by their class, other classes, and the scientists leading the study. Thus the investigation also was a resource for supporting students’ authority as contributors.

Science learning for students was first contextualized through background instruction and made use of actual data, both served as resources for PDE in the context of this project. When students were first viewing fossils, they were surprised by the fact that they were entrusted with actual fossil samples and asked “is this real?” (October 7, 2008). This shows that students were aware that most schoolwork simulates rather than truly enacts disciplinary activities. Students then used equipment, such as calipers, magnifying lenses, rulers, and identification charts to learn how to make their observations and measurements of practice fossils. This knowledge was then used to engage in observing, measuring, and cataloging newly unearthed fossil samples that were part of the investigation. In this way, students were then able to draw on prior learning that had resulted from their initial PDE during the scope of the actual investigation. Students also began to observe other features about the fossils in the investigation, such as coloration and weather they were fragmented. These data would later provide grounds to make inferences about the past environment, such as the geological events around which the fossils must have been formed. In this way, background learning about scientific content served as a resource for students to become more deeply involved in PDE.

Students were also provided with the resource of direct access to a practicing member of the scientific community. Though the project initially provided students with access to scientists through an online portal, this scientist’s visit to the classroom provided students opportunities to interact in person. The scientist was available to answer student questions about what they were viewing and reinforce and validate the disciplinary aspects of science, such as norms and practices that
the teacher had introduced to students. The strengthening of these disciplinary norms and practices then helped foster stronger accountability to the discipline. It also may have fostered problematizing that was even more well-connected to the discipline of geology.

The instructional approach used to involve students in an authentic investigation also provided students with time to explore scientific content on their own timeline. Students were able to engage in the investigation in large blocks of time (90 min), over the duration of three months. With time as a resource, students may have had the opportunity to initially explore and engage in scientific content and processes more extensively — providing better preparation for deeper PDE later. Together, these resources were formed by an initially structured learning environment that supported PDE and cumulatively the resources grew during PDE to support the other three principles even more strongly, which led to deeper PDE (review Fig. 1 again).

5. Discussion

Findings illustrate how one teacher structured a learning environment to engage her students in actual scientific activities, which included both initial and deeper levels of student problematization of subject matter, authority to address content problems, and accountability to others along the lines of shared classroom and disciplinary norms, as well as the use of learning as a resource for deeper engagement. This paper suggests that though this tiered approach may be related to the hybrid instructional context of a classroom engaged in an actual scientific investigation, the resultant PDE demonstrated by students also demonstrated first more classroom-like and then more scientifically oriented PDE. This section considers the trajectory of PDE for the students in Monica’s classroom and its potentially recursive nature. It further considers how an hybrid learning environment, one of a science classroom infused with the activities of and actual scientific investigation, may have resulted in a learning environment where initial PDE served as a resource for deeper PDE, where disciplinary aspects of scientific research were appropriated by students.

5.1. Initial to deeper levels of productive disciplinary engagement

Through the context of an actual scientific investigation in a classroom setting, students exhibited PDE at both initial and deeper levels. Student engagement in this classroom first consisted of student fossil observations and developed to collaborative work in groups to find, identify, measure, and explain any fossils that were found in their assigned bag of rock samples (see Fig. 1). Each group’s particular bag of rocks was labeled with the site location and the depth at which rocks were gathered. Using this information, students would then be able to trace how the fossil samples they found compared with those of their classmates and other classrooms in the database. As students groups became more involved in the project, they enthusiastically identified the fossil samples and deliberated the accuracy of their findings (Meyer, 2010).

Student involvement in disciplinary work first involved being guided through a structured activity about nature of science and developed into participation in actual scientific inquiry — where students addressed research questions, analyzed data samples, and synthesized data to make inferences, as well as communicated their questions to scientists, furthering their understandings about science and the scientific discipline (Meyer, 2010). For example, student disciplinary work ranged from making inferences about what they saw (i.e. “looks like the inside of a shell, so it’s a clam”) to asking the scientist disciplinary questions about her work (i.e. “do you study with other scientists?”) (Meyer, 2010).

Students were productive in making disciplinary progress through participation in the project. This productivity included learning about and then practicing the disciplinary activities of the authentic investigation. For example, students learned how to measure using centimeters and then used this knowledge to measure fossils. Students also reflected on science as a discipline following their involvement in the project. Certain students who thought science was “doing work from a book” at the outset of their participation in the project later reported that science was about “making observations and inferences” (Meyer, 2010). Additionally, while students began the unit with minimal understandings about fossils, students showed they had learned scientific content and practices by arguing their cases for particular fossils they had identified at the end of the unit. Though student arguments may not have modeled the full potential scope of argumentation in inquiry (Berland & Reiser, 2009), that these students were beginning to appropriate scientific ways of discussing content (Rosebery et al., 1992) itself demonstrates productivity in learning scientific practices.

Shifts in identity and membership in the scientific community may have encouraged students to take on scientific disciplinary activities and norms beyond their regularly expected classroom norms (Yackel & Cobb, 1996) — including those of authority and accountability. For example, while regular classroom activities and norms such as sharing ideas and being right about answers may have encouraged students to initially engage in the project, I argue that later student engagement in the project began to be shaped and driven by deeper understandings about the scientific discipline. Deeper disciplinary engagement included making sense of data by using evidence rather than just having and sharing ideas with respect to authority, and verifying the accuracy of data for the greater purposes of the project rather than working to complete specific classroom tasks with respect to accountability. In this way, the appropriation of disciplinary norms and a certain degree of membership through initial PDE may potentially form resources to come full circle and promote PDE at a deeper level more akin to the focus discipline — in this case, science.
5.2. An hybrid learning environment toward recursive PDE?

Clearly, the unique learning environment of a classroom involved in an actual scientific investigation in collaboration with practicing scientists supported the guiding principles for fostering PDE. The complementary relationship between participation in inquiry and PDE was evidenced by student engagement in actual scientific activities and in their intellectual progress made related to disciplinary content. While efforts to introduce scientists to students (Rennie & Howitt, 2009) and students to the actual work of scientists (van Eijck & Roth, 2009; van Eijck et al., 2009) are not new, most do not entail sustained classroom engagement in actual scientific activities. In addition, the inquiry-based instructional approach combined with explicit instruction in nature of science served to make scientific culture and activities accessible to participating students (Meyer & Crawford, 2011; Meyer et al., in review). That the infusion of authentic scientific investigation into classroom-based science instruction is possible at the elementary school level shows promise for bolstering classroom science inquiry with even more accurate representations of the scientific discipline (Chinn & Malhotra, 2002; NRC, 2000, 2012; Schwartz et al., 2004). Importantly, this approach shows particular promise for engaging underrepresented students who are non-native speakers into scientific disciplinary activities and practices.

However, teacher professional development and preparation to successfully implement this kind of inquiry must be considered (Crawford, 2000). It is unlikely that Monica would have been able to deliver this inquiry-based instructional unit without rigorous content-matter preparation and instruction in strategies for implementing inquiry. Through learning content first-hand through participating in the same investigation during the professional development program, she was able to draw from her own learning experiences and structure similar learning opportunities for her student. She was then able to replicate and adapt this instruction for her students, making admissions when content was beyond her knowledge and framed these moments as collaborative learning opportunities. Though Monica was a novice to implementing inquiry in the classroom, her teaching embodied the essence of scientific inquiry (Crawford, 2000).

Further consideration is also needed around: motivating students to participate in authentic disciplinary activities, and fostering student identity and the appropriation of disciplinary norms as a reflexive part of PDE with respect to science. The reason these issues are important is that the activities and norms of science may serve to challenge students’ cultural and everyday ways of knowing (Aikenhead, 1996). The opportunity to be involved in inquiry and actual scientific work, in this case geology, proved to be motivating to this group of underrepresented students. Students were astounded to have access to actual fossil samples and to have the task of being able to be the first one to document any fossil specimens that they themselves had found. Further, students were also proud to be involved in something that had actual bearing beyond the classroom context and related to a larger learning community (Engle, 2006) – that of other classrooms and practicing scientists who would continue to work with the data gathered and findings generated by the students. I draw on the authenticity of this context to suggest that student engagement in these activities and access to scientific community members cast them as legitimate peripheral participants (Lave & Wenger, 1991) in geology. As such, students appropriated aspects of scientific culture and practices, such as accuracy and attention and other norms for scientific discourse, such as providing evidence to support ideas (Lemke, 1990; Rosebery et al., 1992). Accordingly, scientific data submitted to the database by classrooms was, in fact, assessed to be accurate by the scientists (Smrecak, Ross, Capps, & Crawford, 2011).

It is noteworthy however, to also consider how the Latino students in this class began to engage in scientific activities. As described above, Monica first provided her students with opportunities for exploration with the fossils. Though this may be likened to “hands-on-learning,” which is oftentimes questioned as an instructional approach (NRC, 2000), Monica used this instructional strategy to allow her students to construct their own ideas about what they were seeing. Students began to distinguish science from being about “learning from a book” to “making observations and inferences” about what they were seeing. Providing students with opportunities to develop their own ideas was instrumental to eventually positioning students as authors in science. In most cases, students learn already known content but do not have the opportunity to participate in knowledge construction. Though Ford (2008) posits that students solely constructing knowledge, without learning to critiquing the value of these ideas, may not be fully realizing scientific disciplinary practices, student authority is a first step in this process. As students learn to construct scientifically appropriate ideas by being given opportunities to author them, they may further learn to evaluate the merit of these ideas. Students first learning to hold themselves accountable to disciplinary norms is a step toward later holding others accountable through critiques of others’ ideas (Engle, 2011).

Student engagement in scientific disciplinary work was promoted by the teacher who interestingly likened some key scientific practices to standard classroom practices that the students had already adopted. Monica then positioned her students as scientists and demonstrated how they could effectively become participants of the scientific discipline by extending what they already did in the classroom (Cakmakci et al., 2011). This included maintaining accurate records, as well as identifying and resolving uncertainty in their work (Kirch, 2010), both important aspects of authentic scientific practice. The scientist’s classroom visit added another layer of authenticity to the project and dispelled student misconceptions about scientists (they were no longer only males in white lab-coats mixing chemicals). Students being positioned as scientists by their teacher, interacting with a scientist, and participating in actual scientific activities may have led them to begin to see themselves as scientists (Holland, Lachicotte, Skinner, & Cain, 1998). These factors, combined, may have promoted student engagement in scientific activities and their appropriation of scientific disciplinary practices, skills, and attitudes. Considering PDE in light of authentic disciplinary practices thus needs to consider student identity with respect to the focus discipline.
In most cases, the appropriation of scientific norms reinforced the framework for PDE. For instance, students problematized content by asking and addressing their own questions that were also within the scope of the geological investigation. They further made use of resources – such as time, actual data samples, and the availability of a scientist – to ask other scientifically oriented questions and consider possible explanations. However, in the scope of the authentic investigation, when students began to appropriate scientific disciplinary norms for having and sharing ideas, the authoring of ideas may have began to also resemble accountability to the scientific discipline. Following initial PDE, students began to provide evidence when sharing their ideas – showing accountability to the scientific disciplinary norm of providing evidence for explanations. While the general practice of sharing ideas (whether right or wrong) may have initially engaged students in PDE, the sharing of ideas following disciplinary norms, such as providing evidence to support their ideas, resulted from this participation. Though this may seem to intersect with ideas of about accountability, it highlights the recursive nature of participation in activities and learning about what counts as sharing ideas per disciplinary norms.

Accountability on the other hand, seemed to be identified by the enacted activities of students adhering to disciplinary norms in addition to students providing verbal justification for their ideas. Beyond showing accountability for their data and findings, students demonstrated accountability to scientific norms by actively engaging in scientifically appropriate activities – or activities that were appropriate to addressing the question at hand. This suggests that in deeper PDE, accountability may also be evidenced in the practicing of a discipline (i.e. "scientists keep a journal about their data and findings, so that is why I also keep a journal"). For example, once students were accustomed to having and sharing ideas, they began to have and share ideas that were more consistent with scientific disciplinary practices – and once students learned to justify what they were involved in thinking about with respect to the scientific discipline, accountability consisted of adhering to more closely to disciplinary norms.

This reinforces notions of varying levels of PDE as related to the degree of participation within a particular discipline (Engle, 2011). It is hard to imagine students having the opportunity to appropriate scientific disciplinary norms without first having some initial PDE in scientific activities. In this way, PDE seems to form a precursor to further disciplinary learning in science. Student appropriation of scientific disciplinary norms and PDE, therefore, do not remain mutually exclusive processes. Rather, the transition from initial to deeper (and perhaps still deeper) levels of PDE may be a recursive and ongoing process (see Fig. 2).

As illustrated above, as students engaged in scientific disciplinary activities and began to exhibit adhering to scientific norms, they also continued to show PDE in the activities they were involved in – only deeper and more discipline-specific. Students showing authority in line with scientific disciplinary norms seemed to have more confidence in the ideas they put forth. Further, students showing accountability to scientific activities seemed to understand the tasks they were involved in with respect to the greater purposes of the project. With reshaped notions about science and greater identification with the scientific discipline through PDE, it is possible to envision that students involved in these and similar scientific investigations will engage in scientific disciplinary activities in the future – and continue to make productive intellectual gains.

However, these findings stem from research in one teacher’s classroom, who was implementing an investigation with a particular group of students for the first time.

Research comparing these findings with those of other classrooms involved in authentic scientific research projects and with teachers having differing degrees and types of experience with both classroom and scientific inquiry would be invaluable in helping us understand how to adapt these ideas to differing instructional contexts. Future research could also usefully explore whether these findings have broader implications for how to structure learning environments to achieve deeper levels of PDE in other different disciplinary areas of learning (Ford & Forman, 2006), both within and beyond the scope of science.

6. Conclusion

While the framework for PDE (Engle & Conant, 2002) aligns with the tenets of scientific inquiry (NRC, 2000), the case of a classroom involved in an actual scientific investigation provides an illustration of both initial and deeper levels of PDE in the context of scientific disciplinary activities – structured by a teacher new to inquiry and for students who were non-native language speakers. With their teacher serving as a cultural broker between classroom and scientific practices, student engagement in the disciplinary tasks of science was clearly productive, with intellectual gains being made beyond just
content learning. Through participation in an authentic investigation, these students demonstrated learning science content and appropriating scientific disciplinary norms, identities, and attitudes, which provided them with a discipline-specific structure for guiding deeper participation in the geological investigation. Deeper PDE resulted from initial engagement in a learning environment structured for PDE. It also entails that more discipline-specific norms can only be appropriated through initial PDE. Further research is needed to examine the relationship between the framework for PDE and the process through which participants begin to appropriate the norms and practices of a particular discipline.

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