Science education must change! This truism need hardly be cited. Students are ill-prepared to meet the needs of the workforce, to participate as informed citizens in a democratic society, or to understand the excitement and intellectual satisfaction of the practice of science, goals of the Next Generation Science Standards (NGSS) (Achieve, 2012). We use narrative to inquire into a co-reflective partnership between a chemistry professor (Richards), a middle grades teacher educator (Kleine), and a science teacher educator (Deneroff) through six years of co-teaching Integrated Physical Science 4010 (PHSC). The collaboration allowed us to explore deeper meanings of students’ explanations for observed phenomena, and together to investigate organization of instruction to mediate students’ understanding of disciplinary practices, core concepts and cross-cutting ideas—the framework for inquiry learning proposed by the NGSS. We made various false starts and met obstacles before settling on argumentation as the practice which seemed to provide the most leverage for transforming students’ ideas about the nature of science. What we learned from our collaborative investigations in PHSC began to spill over into our separate teaching practices. Our experiences reveal evidence that all of our students, undergraduate science majors in chemistry courses and pre- and in-service teachers alike, showed that traditional science education facilitated little understanding of the nature of science or of its unifying, overarching principles. As a result of our reflective practice, we make the immodest claim that in order for pre-service teachers to become science learners themselves, they must transform their ideas about (a) what science is, (b) what learning science means, and (c) who they are as learners.

**Theoretical Framework**

Our students’ notions were acquired over their previous years of schooling as well as their informal participation in cultural activities. Using the language of social practice theory (Lave & Wenger, 1998; Lave 1996), ideas people have about who they are, how they became that way and what they are doing are labeled “identities.” (Wenger 2001). In the community of practice framework, learning can be seen as the transformation of identity from the periphery of a cultural activity to full participation as experts. For the purposes of PHSC 4010, we define traditional science learning as supporting Traditional Science Identity, and the goal of instruction to be the scaffolding of Inquiry Science Identity. (See Deneroff, 2013.) Anything less than transformation of identity will result in traditional science teachers who reproduce traditional science teaching. Without our own consistent interrogation of the meaning of things students said and did within PHSC and in their homework, as well as our recursive explorations of the effects of our “teaching” on the meaning students made of the activities and conversations we held during the course.

**Science talk**

There is a watershed moment in our six years of working together on PHSC: Our opportunity to engage in extended discussions with Beth Warren and Ann Rosebery of TERC. In 2011 they visited our university. Conversations caused us to consider the role of classroom discourse in positioning children as capable or incapable science learners, during what Rosebery and Warren (2008) call Science Talk. Such notions were familiar to Deneroff who had not known how to broach the subject with Richards; one of the obstacles to collaboration was a reluctance to overstep imagined bounds of academic freedom and autonomy. Rosebery and Warren conducted a seminar attended by a number of us working together on a grant to improve middle grades science teaching and learning. Richards immediately understood Ann and Beth’s argument that teachers’ assumptions about children from marginalized groups constructed identities for youth as being either smart or not smart, which transformed her ideas about the purposes of hands-on science activities. Deneroff also felt transformed and empowered by thinking about Science Talk; Richards’ support gave her permission to try out participation structures and discourse practices to foster equity in science classrooms. We three continued to talk and think about the role of talk in science learning, at first not applying these ideas to PHSC, but to our professional development work in local K-12 schools. Our co-teaching became a little more comfortable and spontaneous. As we will discuss below, Richards provided Deneroff with a teachable moment, and she decided on the spur of the moment to try Science Talk in PHSC. This proved a modestly successful experiment that encouraged us to bring more systematic attention to classroom discourse in the next iteration of the course in Fall 2010. Our purpose was twofold: to engage teacher candidates in deep learning about the structures and processes of science, and to provide them with tools for conducting Science Talk (or Social Studies Talk, etc.) in their field placements and eventually in their teaching.

**PHSC: A Community of Practice Coping with Contradictions**

**The problematic history of PHSC**

 The course PHSC 4010 was posited in the late 1990’s in response to an unfunded mandate from the state department of education that middle grades teacher candidates complete three upper level courses in two different content concentration areas. After much consultation between Arts & Sciences and Middle Grades program faculty, it was decided in the new millenium that all Middle Grades teacher candidates would take one new, specially-created, upper level content course in each discipline: geography, physical science, mathematics education and English linguistics. In part this was due to the philosophical commitments of Middle Grades faculty, who felt that all candidates should have enough solid content grounding to be able to create interdisciplinary curriculum units during their internships and induction years. Moreover, in the last ten years, enrollment in the Middle Grades cohorts has varied between 12 and 27. In most years candidates pursuing certification in middle school science numbered fewer than five so a stand-alone course for such low enrollment would not be practical. Therefore, in order for the newly created courses to be viable, inclusion of the entire cohort would be necessary.

 The chemistry faculty balked at teaching an upper level course to students who had little or no preparation for that level of material. Planning conversations between chemistry and education faculty danced around the tension between content and pedagogical content knowledge (PCK). In 2000 they settled on a designation of the course as Physical Science (PHSC) versus chemistry and/or physics with an offering for undergraduates (PHSC 4010) and graduate students (PHSC 5010). For the first several years the course was kicked around between chemistry instructors who designed and executed it as a traditional science course with engaging laboratory activities. The Middle Grades program supported a course release for Kleine, later Deneroff, who replaced her in 2008, to co-teach. Kleine continued to take an active role in the course planning and assessment. She contributed a deep knowledge of history and philosophy of science and continued to follow to the course design and participate in some of the debriefing and planning sessions. During the early days of PHSC, she was able to occasionally inject a pedagogical lens, seen as superfluous by the chemists; there were also guest content lectures from geology and astronomy faculty who filled in disciplinary gaps to prepare science candidates for the state content licensing examinations. Kleine introduced PCK through a field test of an online module with videos designed for professional development of science teachers. The teacher candidates, also taking their first courses in learning theories concurrent with PHSC, struggled to make sense of these videos and especially the concept of “content storyline,” which was emphasized in the modules.

Students, especially those who did not intend to teach science, bitterly complained about the course, which included physical science content appropriate for high school, as boring and too hard. Efforts by science faculty to provide engaging and fun activities did not appear to affect students’ attitudes. Those with a science background thought it insultingly easy. Overall, few embraced the instructors’ expectation that they motivate themselves to learn material outside of their area of interest. Many railed against an ambiguity and uncertainty that did not seem to faze the instructors, and were compliant only when the path to success was clear and padded with praise.

While it was apparent there were tensions it was more than a little murky as to how to go about addressing the turbulence. After we had spent a great deal of time in later years uncovering and reflecting on our students’ understanding of the nature of science, we determined that the challenges posed by the concept of content storyline were symptomatic of our students’ profound bewilderment about science--its purpose, power, and processes. Our reflections about the class, although seemingly circuitous and regressive, eventually provided us a line of sight for understanding the root of their distress.

**The Utility of Understanding PHSC as a Community of Practice**

Deneroff brought to PHSC a social practice theory perspective, which committed her to the position that students came to the course having a shared, socially-constructed paradigm of what occurs (and should occur) in science classes, which Wenger calls a shared repertoire of practice. Students’ ideas about science are social practices rather than cognition, and a product of Traditional Science Identities developed through participation in 14 years of schooling as well as watching cultural icons such as Ms. Frizzle and Bill Nye on television. This Traditional Identity in turn mediated students’ perceptions of the content of PHSC. She doubted that these successful college students would easily adopt an Inquiry Science Identity, since the already-developed Traditional Identity mediated further learning (Deneroff, 2008). Deneroff, developing a close relationship with Richards, the instructor of record, introduced a “science autobiography” exercise on the first night of class in 2009 to tease out and make public the Identities which students brought to science learning.

Richards, a traditionally trained PhD chemist and Director of the university’s science education center, at the time was puzzling over how to select appropriate hands-on activities for the course, and for the teachers in the professional development she was implementing as part of her duties. Richards was herself undergoing transformation as a teacher. In retrospect, she sees a struggle to figure out “how to let go of too much information. I was classically trained. Give me some problems, and then pass onto the next chapter.”

 **What does it mean to be a person who learns science?** For Deneroff, the struggles took a different form. She disagreed with the assignment of traditional problem sets with little explanation, and felt that hands-on activities were not going to transform identities because they were interpreted by students as doing rather than learning. In fact, one evening, Deneroff was watching a group perform a task; we asked them to unpack the evidence that supported successive historical models of the structure of the atom by cutting up expository text and transforming it into a table to match the propositions with data they had collected in the laboratory. The students’ conversation was entirely procedural, what to put where, and no discussion of what the text or data might mean. “Do you see this as learning or about getting it done?” Deneroff asked, with a tone of voice that must have conveyed her genuine interest in the answer rather than an implicit criticism, since the students seemed to respond openly. “We either have time to learn or to get it done. Since it’s going to be graded, we have to get it done.” Deneroff became curious and began asking her students in other classes whether they saw assigned tasks as learning opportunities or activities to get done. They universally responded that they focused on getting it done. “Wow.” she said to Richards. We were not getting through to them. We thought were assigning rich tasks that would produce critical thinking, and they were just doing things. Even this assignment designed to engage students as thinkers was perceived as traditional memorization of facts.

 The evidence for atomic theory task was itself the result of a test all but five of 22 students had failed. The test occurred after Richards’ lecture on atomic theory, and the students had finished the following data collection activities:

1. Viewing the emission spectra of gases through diffraction gratings;
2. Taking a “light tour” of the town wearing diffraction grating glasses and comparing incandescent and “neon” lights;
3. Conducting flame tests of various metals;
4. Looking at chemical glow sticks of the type used by children at Halloween, with diffraction gratings.
5. Running an interactive Phet simulation (University of Colorado, n.d.) of hydrogen atoms being bombarded by light and emitting photons as they returned from higher to lower energy levels.

The students read two chapters on this topic from Bill Bryson’s (2004) *A Short History of Almost Everything.* While the students were able to answer factual questions from Bryson’s narrative, they were unable to reconstruct how their own data supported models of the atom. They did not see their data as real science, nor did they connect it with theories developed by real scientists in the distant past. It appeared the practices of science remained outside their Traditional Science Identities, making them incomprehensible.

For a couple of years running, we asked the teacher candidates to read Eleanor Duckworth’s essay (2006) “The Virtues of Not Knowing.” The first time through we were surprised when it evoked a great deal of emotion; several began talking about, as children, having been “shut down” by adults, especially teachers, before having a chance to explore their own ideas. The unimaginative, rote practices of schooling inflicted invisible wounds. Still, however much these successful college students mourned the loss of creativity and joy of learning in their own histories, unless they developed tools to engage in the life of the mind themselves, it was unlikely they would be able to recognize intellectual curiosity and foster the development of reasoning in the youth they will teach.

Issues of identity surfaced in the analysis of the science autobiographies, which were transformed from narratives to a timeline posted on the wall. In 2011, Deneroff wondered aloud why many thought dissecting a frog in seventh grade was science. There followed an awkward silence. Finally Deneroff asked, “Do you think it’s science because you did it in science class?” The class giggled a bit and shuffled their feet, agreeing, Yes, that was it. students consistently found this a nonsensical question with an obvious answer. “It’s science because we did it in science class.” We argue science education is embodied and socially situated, that is, that it occurs in the persons of the teacher and the students through the social practice of science teaching (Deneroff, 2013; Bryan and Atwater, 2002). Changing the “outcomes” of science learning requires understanding ourselves as teachers, and our students’ understanding of what it means to learn science. We tell the story of coming to understand post-secondary science teaching over the course of six years of co-teaching an upper level physical science course for pre-service middle grades teachers.

Over time we became increasingly systematic attempts to respond to the needs of the students and the standards of our disciplines. In Fall 2013, we videotaped and transcribed class discussions, collected students’ work, interviewed students. From 2010 on, we met on a weekly basis to debrief the previous night’s class, and to plan next steps toward our learning goals, recording the planning meetings and transcribing them. One of us wrote various reflective pieces which became blog posts, and which we shared with students, modeling our process. We believe our analysis of this data supported our continued development as science educators, allowing us to examine our own assumptions about science teaching. We offer our insights to the greater community, in the hope that they will contribute to the research conversations about science teacher education, and university science teaching more broadly.

**Our Instructional Goals**

PHSC is offered to partially fulfill the state licensing requirement for middle grades science concentrations, and also to contribute to the intellectual depth of all middle grades teacher candidates who intend to teach language arts, social studies or mathematics. Our goals included having middle grades teacher candidates become adept at and enjoy engaging with crosscutting concepts and appreciation of the power of theory--to have science reasoning as a foundational tool of teaching.

**Physical science.** The content of PHSC is geared to prepare candidates for the state licensure examination in middle grades science. Topics include the standard middle school science fare: Newton’s laws, atomic theory, kinetic molecular theory, the periodic table, chemical reactions, energy, plate tectonics, and astronomy. Trying to teach a heterogeneous class a grab bag of ideas such as this flies in the face of almost everything we know about good science teaching (National Science Teachers Association, 2003). As we continued to examine our own practice year by year, we began to experiment with concentrating on only three or four topics, threading them together by an emphasis on supporting our students’ abilities to understand the role of evidence in supporting theories.

**Nature of science (NOS).** Most of the course content per se was at the level of what should have been high school or even middle school science. If our students’ level of knowledge about canonical science was distressingly low, their understanding of the processes of science was, in essence, nonexistent, as our probes of their ideas about science revealed. They expressed annoyance that our classroom discourse did not reward them for knowing right answers. As one student wrote accusingly on a course evaluation, “She knew that I knew the right answer and still did not call on me.”

**Reflective teaching**

 In our middle grades teacher preparation program, the ideas of reflective inquiry defined by John Dewey (1933) are foundational, and we attempt to model as well as demand that students develop increasing skill with the intellectual process of connecting experience and theory. Darling-Hammond (2009) has consistently argued that opportunity for teachers to reflect in communities is essential to high quality teaching. In our own college there has been a concerted effort to develop faculty professional learning communities. However, as Nelson and Sadler (2013) note, a great deal has been written about pre-service teachers’ development of reflective practice but relatively less about how teacher educators reflect on their own practice and make instructional decisions about scaffolding reflective teaching for teacher candidates.

**Professional learning communities**

 Similarly, there has been a growth in the literature on learning communities within higher education. Many universities, including our own, have promoted cohorts of students who develop relationships with faculty across disciplines with the goal of deep learning (Tinto, 2003). We did indeed intend our PHSC course to resemble a learning community, although there were serious constraints arising from competing curricular demands.

**Vygotskian learning theory**

 We understand learning to arise through social interaction, occurring relationally before it occurs within the individual (Vygotsky, 1968). Vygotsky constructed the zone of proximal development as the fertile space in which the learner deepens understanding through interaction with an expert, doing with assistance what he or she is unable to do unaided. The concept of scaffolding is usually attributed to Vygotsky, although it is often used in ways that are inconsistent with Vygotskian principles. We find Walquí and vanLier’s (2010) discussion of Vygotskian scaffolding provides a powerful theoretical framework for the types of learning conversations we fostered in class. Our classroom practices over the last four years began more and more to assume the form of flexible, responsive exchanges which supported students’ expression of the kinds of scientific ideas which we asked them to consider.

**Methodological Considerations**

**The Context**

 Our public liberal arts college of approximately 6,000 undergraduates is located in the rural Southeast. Cohorts of 20-25 students enter the Middle Grades program as juniors, and enroll in 18 credit-hours of coursework. In addition, students complete field practicum in schools two full days per week. Most are white females, as is common in traditional teacher education programs (Feistritzer, 2011).

**Data collection and analysis**

We have collected a considerable amount of data over three years: photographs and originals of various posters and inscriptions produced by individuals, student groups and the whole class; notes written on the classroom interactive whiteboard by instructors, and whole group-generated inscriptions produced by students over the course of Science Talks; blog posts on the nature of science; laboratory reports by students; and journal responses to various prompts including items taken from the Views of the Nature of Science (VNOS) instrument (Abd-El-Khalick, Lederman, Bell, & Schwartz, 2001). In all, several hundred pieces of student work have been preserved. We took photographs and videos of students conducting investigations, especially of whole class collaborative projects such as analyzing data. We have analyzed this data previously, and found that Science Talks have been modestly successful in increasing our students’ understanding of science (Deneroff et al., 2013). Four videos of Science Talks were recorded in 2013, which were transcribed and analyzed.

**Narrative Inquiry**

For the purposes of this paper, we mainly rely on notes, emails and blog entries between the authors, and the transcript of an audio recorded meeting which occurred late in January 2014, after the close of the semester. At this meeting we were joined by a third teacher educator who had been instrumental in the early years of the design of this course. The rationale for this methodology is the clear emergence of the Science Talks (see below) as the organizing principle of our course as we continued to inquire into the meaning of events as they unfolded. We use narrative inquiry—a story of our students’ growth as scientific thinkers and our growth as instructors. As qualitative researchers, we argue the goals of qualitative and narrative inquiry are not generalizability and reliability, rather they are apparency, verisimilitude and transferability (Connelly & Clandinin, 1990).

**What it Might Mean**

Our professional conversations about science teaching and teacher education became for each the high point of the week. As Kleine wrote later, interrupting the tedious reading of students’ papers that hijacked a restful Saturday, “I LOVE it...There must be other benefits to higher ed to make the tradeoff worth it. Seeing this suggests it is the collegiality.” Students requested traditional lectures, a textbook, note-taking and examinations and quizzes, even though they grumbled that such classes were boring, and as far as we could tell, learned very little.

**Science Talk**

We began collecting data on PHSC four years ago (2010), as we first tentatively instituted the discourse practice of Science Talk (Rosebery & Warren, 2008). Consistent with research on science learning, we designed our course to provide an environment where learning content occurs through scientific argumentation and discussion (Osborne & Duschl, 2002). We attempted first to tease out the understanding of argumentation and science concepts with which students come to our class, and secondly to find ways to introduce college students to the proposition that scientific “facts” are actually previously settled arguments. Science Talks (Rosebery & Warren, 2008; Warren & Rosebery, 2011) were the vehicle for introducing pre-service teacher candidates to argument within the science classroom, an experience that all told us was new for them. In the participation structure (Erickson, 1982) we developed, students puzzled out explanations for phenomena by talking with each other rather than being told facts by “the professors.” In 2012, we explicitly introduced students to the concept and experience of learning through argument; we informed the class we would be conducting “explanatory inquiry” (Andriessen, 2006, p. 9) as they engaged in public Science Talks, and explained just what this might entail. During this process in 2012, we noticed especially productive conversations when we asked students to use the interactive whiteboard to publicly create inscriptions (Latour, 1987), that is, non-text diagrams and sketches of concepts under consideration as thinking tools. Focusing on the production of inscriptions (See also Lenoir, 1998), more commonly called representations, allowed students to build a consensus explanation for the scientific model we were considering, as well as to introduce them to the practices of authentic science. In 2013, we were able to video record and transcribe Science Talks as well as teacher candidates conducting investigations.

The following conversation on a different topic, Newton’s Laws, perhaps distills the excitement and rewards for the “professors.”

DENEROFF So one of the things we NEVER did is, we NEVER discussed acceleration.in the class. So that, and there’s an earlier, in the September 24th class where we discussed, we had them build Newton’s cars. Where, so, we never discussed, we only collected data about how far the car traveled and how far the canister traveled. But we never collected data about acceleration. We, talked about F = ma.

RICHARDS We talked about ma = ma

DENEROFF We talked about ma of the car equals ma of the canister that was ejected, but, we never discussed why the distance should have anything to do with acceleration.

RICHARDS So that’s not necessarily true…That didn’t come out right...We did have a little bit of discussion about what acceleration was.

DENEROFF So a definition. Discussion of what acceleration was, what constant velocity, speed, and direction, and that sort of thing. And that was IT. But if you look at the data that they collected, nobody collected any distance-time data.

KLEINE Right. Okay…So are you suggesting though like.. .hey’re jumping ahead to concepts like dissecting frogs, that they think should be part of a science class. In physics, of course, if you’re doing Newton’s Laws you’re going to have, you know, acceleration in there

KLEINE They’re jumping ahead to presuming that will be in there because

RICHARDS It’s in there.

KLEINE Those are the words we heard before!

DENEROFF Right. That’s what I think is going on.

We had been looking through transcripts of Science Talks. Deneroff wanted to review instructional decisions from early in the semester. It was becoming obvious to all that managing Science Talk required the instructors to closely attend to the students’ talk while making sure that we had clearly defined the learning goals for ourselves. Perhaps mapping out the content in greater detail beforehand would have been helpful, so that we could have pressed students to consider what acceleration might mean. During the September 24 Science Talk students were discussing that the product of mass and acceleration (*ma*) of two objects must be equal, one student, April (pseudonym) called out, “Oh, we should have measured the weight of the car!” Looking back, we understand April’s self-assessment to have validated the learning potential of instruction that required students to use observations to support claims. When we reviewed the transcripts and notes from November and December, we noticed that students had begun to spontaneously break out un-facilitated conversations about the meaning of evidence, and to feel accountable for questioning and adding to statements of their colleagues.

 When Deneroff debriefed the cohort the following year, when they were seniors and had taken a great deal more learning theory coursework, the teacher candidates reflected that they had, in fact, found Science Talk useful in their own teaching. “*Now* we get it,” someone said. “Not then. We hated it.” Watching the eye rolling and uncomfortable shifting in their chairs during video recorded sessions, we would have to agree. Students made suggestions about how it could have been less “annoying.” “Explain it to us in advance.” (We did.)

The project which we embarked upon was simply too different from traditional science schooling, and students Identities as Traditional Learners prevented them from making sense of what seemed to them nonsense. The notion that they, ignorant of science could talk together and generate new knowledge, was completely implausible. It took another semester of building Inquiry Identity through other coursework for the teacher candidates to refashion identities that allowed them to process such ideas.

**Implications for the Conceptual Change Model of Learning**

 In the literature on preparing future science teachers there is a great deal of emphasis on strategies, technological innovation and students’ conceptual change (Bryan and Atwater, 2002), but little about the process of being a reflective university instructor. Science Talks allowed us to assess students’ knowledge in an in-depth way. We often came to the conclusion that successful college students are adept at answering low-level, recall questions without understanding concepts. In fact, based on our experiences with Science Talk, we wonder whether the conceptual change theory that underpins almost all research in science teaching, applies at all to our students. We propose that our students display very little evidence of knowing science at a conceptual level. Analyzing the results of our science autobiography and our observations and transcripts of students talk in our class (Deneroff et al., year), we see that their ideas about science are primitive, and that their mental models of the nature of science actually inhibit learning science. We argue that some form of intensive and extensive discourse-based instruction such as Science Talk is required in order for future science teachers to develop conceptual understanding of science consistent with the Next Generation Science Standards.

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