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Jing Yang
Indiana University, United States

Gayle Anne Buck
Indiana University, United States

Nichole Nageotte
Cleveland Metroparks Zoo, United States

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The Self-Study Process of a Scientist as She Delineated the Meaning of Scientific Inquiry and Developed a New Professional Identity as a Science Teacher Educator

Jing Yang, Gayle Anne Buck, Nichole Nageotte

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Abstract

With this article, we describe and analyze the experience of a scientist as she delineated the meaning of scientific inquiry and developed a new professional identity as a science teacher educator. Our inquiry adopted a self-study methodology with a variety of data sources, including sixteen-weeks of journal entries, critical friends' meetings and reflections, video and audio-taped lessons and students' artifacts. The self-study process captured her conflict between scientific inquiry in the classroom and her chemistry research. We captured three stages of her understanding of scientific inquiry. The idea of "authentic scientific novice research" finally resolved her conflicts. This study also revealed three factors that influenced the formation of her professional identity (i.e., competing identities, contextual influences, and personal struggles). This finding and resulting conclusions not only report the evolution of personal understanding, but also bring out the discussion of teacher educator development, especially for those transitioning to science education from natural sciences.

Introduction

One of the essential objectives of science education is to help students develop an adequate understanding of scientific inquiry (Lederman, 2007; National Research Council [NRC], 1996). Pre-service teachers (PSTs) are future teachers that will be guiding the students to this understanding. Thus, helping PSTs develop an adequate understanding of scientific inquiry is an important goal for a science teacher preparation program. In our program at a large university in the Midwest of the U.S., a freshman-level science course is designed to allow PSTs to learn about scientific inquiry by experiencing authentic scientific inquiry. Science teacher educators teaching this course are expected to foster a constructivist learning environment for the PSTs and become role models of inquiry teaching. However, teacher educators in this science education program, as with many such programs around the country, come with various educational and practical backgrounds. These may include college science education, K-12 education, industry or university research, informal science settings, etc. Many new teacher educators expressed discomfort or experienced internal conflicts with the course content (e.g., Donohue et al., 2020; Gatzke et al., 2015). Educators with a strong science background may struggle to navigate scientific inquiry themselves since their views of science were dominated by one aspect of science as a body of knowledge (e.g., Donohue et al., 2020).

Self-study has been demonstrated as an excellent methodology for teacher educators to resolve their discomfort or conflicts by bridging research into practice (Hamilton, 1998; LaBoskey, 2004; Pithouse et al., 2009). Often, self-studies are conducted during the early stages of teacher educators' professional careers as they were experiencing anxieties and conflicting feelings. The self-study conducted here focused on the experiences of a doctoral student who was in her third year of a science education program. She considered herself to have a strong science background since she had extensive research experience in chemistry through another Ph.D. program in theoretical and computational chemistry. She graduated with a Ph.D. degree in chemistry in 2019 and continued her study in science education toward a second Ph.D. During the first two years of her study in our science education program, she was exposed to scientific inquiry in a series of graduate courses. As are result of some initial interactions with the science course noted in this study and science method classes, she embraced the notions of scientific inquiry and had developed a relatively adequate understanding of scientific inquiry. However, with her feet in the two professional worlds simultaneously, she often felt the scientific inquiry in the classroom did not sufficiently represent authentic scientific research. She was eager to bridge the gap between the classroom with PSTs and the authentic science world. She experienced a conflict between the scientific inquiry found in the education program and the scientific inquiry in her actual scientific research. This conflict led to this self-study aimed at examining how she understands scientific inquiry in two different contexts (i.e., chemistry lab vs. inquiry classroom). The guiding research questions for this self-study were (1) How does the scientist understand scientific inquiry in the context of teaching PSTs versus doing authentic research? (2) What factors influence the way the scientist teaches scientific inquiry to PSTs? (3) How does a scientist develop a professional identity as a teacher educator?

Theoretical Framework and Relevant Literature

The self-study is grounded in three areas of literature: (1) scientific inquiry, (2) transformative learning, and (3) professional identity development. The gap between scientific inquiry in the classroom and the real science world creates conflicting feelings for the first author to teach scientific inquiry in a teacher education program. These feelings serve as a disorienting dilemma that sparks her self-study and transformative learning. As transformative learning occurs, a new professional identity emerges.

Scientific Inquiry

Scientific inquiry is one of the essential reformed-based notions of teaching and learning to influence students' decisions about personal and societal problems (Lederman, 2007; Lederman et al., 2013). Inquiry is an act of human endeavor to understand the materials world, both individually and collectively; from this process, people interact and try to make sense of the information they collected and therefore develop new knowledge to describe the materials world (NRC, 2000; Osborne, 2014). Because of the characteristics of scientific enterprise, including the conventions and ethics involved in the development, acceptance, and utility of scientific knowledge (Schwartz et al., 2014), we could distinguish scientific inquiry from inquiry in general. According to National Research Council (1996), authentic scientific inquiry describes the activities scientists conduct in everyday practice. Harwood et al. (2002) point out "this could be paraphrased as 'scientific inquiry is what scientists say it is'"(p. 1).

Scientific inquiry may refer to the activity that scientists conduct in everyday practice (Schwartz et al., 2004; Roth, 1995), or skills of scientific inquiry, knowledge about scientific inquiry, or pedagogical approach of teaching science content in science classrooms (Schwartz et al., 2004). Although scientific inquiry is understood differently, there exist a consensus among the many divergent groups of scientists (Osborne, 2014). Summarizing discussions of scholars from two distinct groups (i.e., philosophers and psychologists), Osborne (2014) suggests a three-phase model as a general model to represent scientific activities. These are (1) investigating, such as making observations, defining questions, collecting data, (2) developing explanations and solutions, such as formulating hypotheses, propose solution, building theory and models, (3) evaluating evidence which involves drawing connection with previous research, communicating at different levels. These three phases are not linear, as new evidence may be considered to add/modify existing explanations (NRC, 2000).

As inquiry is a natural way that scientist understand the material world, it is natural to engage students in scientific inquiry in the classroom to promote science learning (Osborne, 2014). Students' practice in an inquiry-based science classroom mirrors authentic scientific practice in many forms. For example, students define questions, plan and conduct investigations, gather evidence and propose explanations, and communicate and negotiate with each other (NRC, 2000). However, scientific inquiry in the classroom does not fully represent the real world of science (Schwartz et. al., 2014) because of the differences pointed out by Osborne (2014). For example, the goal of science is to generate new knowledge of the material world, while the goal of science teaching is to help students understand a body of existing knowledge, how such knowledge is derived, and learn skills for scientific practice. This leads to the question of why scientific inquiry is still desired in teaching. By examining each scientific practice, Osborne (2014) summarizes benefits of engaging students in inquiry. For example, questions raised by students help to activate their prior knowledge and promote active learning; a lot of empirical research demonstrates that engaging students in constructing explanation and argumentation lead to greater learning outcomes (Osborne, 2014).

Science educators with strong science backgrounds may struggle to delineate the meaning of scientific inquiry. For example, a new science teacher educator with biology experience expressed discomfort and anxiety when teaching scientific inquiry in a science teacher education program (Donohue et al. 2020). In this study, the gap between scientific inquiry in the classroom and the authentic world of science evoked conflicting feelings for the first author to teach scientific inquiry, even though she received adequate training and support from her Ph.D. program. The self-study reported here allows the first author to systematically investigate her personal journal and produce knowledge that informs both self and other science educators with similar backgrounds and experiences regarding teaching scientific inquiry.

Transformative Learning

Transformative learning refers to how one transforms one's ill-structured frame of reference to a more inclusive, differentiating, permeable, critically reflective, and integrative one (Mezirow, 2003; Taylor, 2017). The frame of reference are sets of assumptions and expectations, such as habits of mind, mindsets, and meaning perspectives (Mezirow, 2003; Taylor, 2017). Learning occurs with the revision of one's frame of reference as a result of rational discourse and critical reflection. Discourse refers to dialogue assessing our point of view of a frame of reference about a specific topic; forming a perspective through a discourse is both interpersonal and intrapersonal (Mezirow, 2003). It is intrapersonal since forming a new perspective involves reflecting upon one's assumptions; it is interpersonal since others' feedback is needed to critique one's frame of reference. Critical reflection is an important aspect of Mezirow's transformative learning theory. Mezirow's transformative learning theory is heavily influenced by Habermas's (1971) notions of instrumental, communicative, and emancipatory learning. These learning forms correspond to the kind of reflection one engaged in. According to Mezirow (1991), reflections take three forms: (1) content describes a problem, (2) process solves a problem and (3) premise(s) deal with the presuppositions underlying our knowledge. Kreber (2004) points out we should encourage process and premise reflection for improving teaching. Christie et al. (2015) point out that integration between transformative learning and practice-based research results in a more informed practice. Self-study aims at improving teaching practice and producing knowledge that informs both self and others regarding teaching and teacher education (Feldman, 2003; Hamilton et al., 2008; LaBoskey, 2004). The spiral research process in self-study resonates with transformative learning processes. This self-study is sparked by the first author's conflicted feeling about scientific inquiry in two contexts, and her transformative learning begins with this disorienting dilemma.

Teachers' Professional Identity

Identity describes how one is recognized as a "kind of person" in a given context either by others or self (Gee, 2000). Identity is a relational phenomenon that involves interpreting oneself in an intersubjective field (Gee, 2000; Beijaard et al., 2004). Gee (2000) proposed four perspectives to view identity: nature-identity, institution-identity, discourse-identity, and affinity-identity. In this study, we do not expect the first authors' nature-identity to change throughout this study since it is determined by her nature and has been modified by the surrounding environment in her childhood. The source of institution-identity was the position one takes in society. In the case of the first author, being an instructor of the course of Introduction to Scientific inquiry is her position. She attempted to fulfill the duties and expectations for this position. The third perspective, discourse-identity, is a personal trait but cannot stand alone without the interaction with others. The discursive interaction in this study mainly happened between the first author and the PSTs in her class. The last perspective is the affinity-identity, with the source being a set of distinctive practices of an affinity group.

The concept of professional identity refers to one's identity in the context in which one works (Wenger, 1999). Summarizing literature in the area of teachers' professional identity formation, Beijaard et al. (2004) describe teachers' professional identity formation as an ongoing dynamical process in which teachers balance between professional self-image and multiple roles they take as teachers. Professional identity not only gives emphasis on the personal side, but also recognizes the influence of one's surroundings and other's expectations (Reynolds, 1996; Beijaard et al., 2004). Researches on developing teachers' professional identity have been extensively conducted with pre- and in-service teachers (Beijaard et al., 2004; Avraamidou, 2014). As summarized by Beijaard et al. (2004), the formation of teachers' professional identities may take different developmental paths (Antonek et. al., 1997). Many knowledge sources, such as teaching, subject matter, and lay theories, contribute to professional identity formation. Teacher's lay theories add uniqueness to one's professional identity. Sugrue

(1997) emphasized the importance of letting teachers be aware of their theories. Teachers often struggle to develop professional identity since they need to constantly interpret and reinterpret varying and competing perspectives, expectations, and roles.

Professional identity has been used as a lens to understand how teacher educators improve their teaching practice during their career transition phases through self-studies. Teacher educators reported discomfort and conflict due to the content of the course. For example, Donohue et al. (2020) conducted a collaborative self-study to understand how a new science teacher educator with strong science background delineates the meaning of scientific inquiry and examines her professional identity. Starting with discomfort and anxious feelings to teach scientific inquiry, Donohue experienced a merging of her identity as a teacher educator and a science teacher. Gatzke et al. (2015) investigated her identity conflicts as an environmental educator teaching scientific inquiry. Through her self-study, Gatzke has built connections between environmental education and science education and realized her multiple identities do not have to be exclusive. In addition to the content of the course, contextual change also affects teacher educators' professional identity. For example, Akerson et al. (2014), a professor of science education with expertise in nature of science, encountered challenges and tensions as an elementary teacher of nature of science during her sabbatical leave. Akerson and coauthors show that the development of professional identity was influenced by contextual challenges and personal struggles. It progresses as one interprets and reinterprets others' perceptions, external factors, and resolve conflicting professions. Allen et al. (2016) explored a doctoral student changing his role from a K-12 classroom teacher to teacher educators for science method class. Allen's instructional decisions were dominated by his institution-identity, accompanied by the development of his affinity-identity. Using a self-study methodology, Ritter (2007) studied the challenges he experienced as he moved from classroom teaching to a teacher education program. His existing classroom teacher identity serves as a source of expertise and resistance. The formation of a new identity is an ongoing and complex process to modify his existing classroom teacher identity to accommodate his new role as a teacher educator.

Method

Methodological Approach

As the scientist and new science teacher educator was seeking to improve her own understanding and practice by juxtaposing her own scientific research experience with PST learning through inquiry, we adopted a self-study approach (Hamilton, 1998; LaBoskey, 2004; Buck et al., 2016). Self-study of Teacher Education Practices (S-STEP) is a self-initiated and systematic investigation on oneself aiming at improving teaching practice and bridging research into practice (LaBoskey, 2004; Loughran, 2004). Although self-study privileges self in the research design and produces knowledge from personal experience, its outcome informs both self and others regarding teaching and teacher education (Feldman, 2003; Hamilton et al., 2008). Through a systematic literature review, Vanassche & Kelchtermans (2015) identified four major themes that S-STEP researchers addressed, including (1) improvement of one's particular pedagogical strategies, (2) resolving the tension between one's beliefs and practices, (3) contributing to socially just learning environment through self-study, and (4) "articulating a philosophy of practice or exploring broader theoretical-pedagogical interests" (p. 513).

Researchers have conducted self-study focus on individual's practice (e.g., Akerson et al., 2014; Donohue et al. 2020; Gatzke et al., 2015; Ritter, 2007), or parallel self-studies of different educators with a similar problem of interest (e.g., Bullock & Ritter, 2011; Gallagher et al. 2011). The interactive nature of self-study methodology allows for constructing and reconstructing science educator's professional identity (LaBoskey, 2004). By doing so, the self-study framework enabled the first author to reflect on her understanding about scientific inquiry, and therefore inform teaching practices in ways that she believed to result in better students' learning. Although this study focuses on the inquiry of the first author's understanding of scientific inquiry, all three authors were involved in providing support, helping with data analysis, and interpret results from different perspectives. The collaborative nature of self-study, together with a variety of data sources (i.e., two of the essential elements of self-study (LaBoskey, 2004)), ensured the trustworthiness of this study.

Context and Participants

The study was contextualized in a sixteen-week science course for PSTs at a public university in the USA. The goal of the course was to help PSTs to develop an adequate understanding of science and scientific enterprise, experience science inquiry through the theme of environmental activities through which PSTs develop and refined their skills to conduct labs, construct scientific explanations, and make relevant life decisions based on evaluating evidence. The majority of students who enroll in this class are majoring in education, such as early childhood education and elementary education. They usually enroll in this class as freshmen or sophomores.

The first author was the primary participant who was hired to teach two sessions. Secondary participants included one science education professor and one science education graduate student. They acted as the first author's critical friends throughout this study (Schuck & Russell, 2005). The second author was the course coordinator for the course. They both took part in five reflective meetings in which they posed critical and provocative questions to challenge the first author's thinking, provided feedback to her reflection, helped her to identify assumptions and interpret her practice, and made suggestions to narrow down her focus (LaBoskey, 2004). Critical friendship also helped to enhance the construction of the validity and reliability of this study (Loughran & Northfield, 1998).

During the period this study was conducted, the first author enrolled in two graduate-level courses in science education. This was her third year in the science education doctoral program. She served as a materialist for this course during her first year in the program and taught one section as the primary instructor. In addition, she had experience working with PSTs in science pedagogical method and field experience courses. She previously completed a bachelor's degree in chemistry. She was admitted to the chemistry Ph.D. program four years before adding the second major, science education, to her study. Prior to entering the doctoral program in science education, she participated several research projects in the field of theoretical and computational chemistry. During the semester she was teaching this course, she was working on a chemistry research project to study the self-assembly of organic molecules on the graphene surface. This was a collaborative project that included two experimental and two theoretical groups; she was responsible for computer simulations of small organic molecules on surfaces.

Data Collection

According to LaBoskey (2004), most self-studies are qualitative in nature and data collection methods of a self-study must be appropriate for the research questions. To increase the validity of our study, Feldman's (2003) suggestions to make the construction of the research representation public was adopted. First, a detailed description of the data sources with the justification for data source inclusion were provided. Second, the analysis procedure was described. Third, in addition to triangulate multiple sources of data, multiple ways to represent the self-study and a justification of the selected process was provided. Forth, evidence of value changes in our ways of being teacher educators (Feldman, 2003) is included. Primary data sources included the first author's journal entries and transcriptions of the critical friends meeting. Secondary data sources include videotaped instruction and students' work.

Journal Entries

The gap between authentic scientific research and scientific inquiry in the classroom motivated the first author to initiate this self-study. The first author wanted to explore how she understood scientific inquiry in different contexts by maintaining a reflective journal. Journal entries included a pre- and post-class reflections for each lesson to capture the first author's understanding of scientific inquiry regarding the content of a specific lesson and the origin of her understanding, how it was affected by the instructor/student interactions and resulting actions. Also included in the journal entries were post-critical friend meeting reflection.

Critical Friend Meetings

Data sources also included five audio-recorded critical friend meetings which occurred throughout the self-study process. The length of critical friends meeting ranged from 20 to 45 minutes. The first author's understanding of scientific inquiry was challenged by two critical friends (one professor in science education and one graduate student focusing on informal and environmental education).

Videotaped/Audiotaped Instructions

The first author was assigned to teach two sessions of Introduction to Scientific Inquiry. The class meets twice a week that comprised 30 lessons. Each lesson lasted for about two hours. Since the purpose of collecting videotaped/audiotaped instructions was to examine the first author's understanding of scientific inquiry was reflected in her teaching practice, clips showing students engaging in small group activities were not included. Video data were collected when the first author was giving whole-class instruction. Audio data was collected when the first author was on one-to-one interaction with students (e.g., the first author having one-to-one conversation with each student about their final inquiry project; the first author listening to each student's final presentation in a poster form). A total of ~80 h video/audio data of classroom activity was included in this study.

Student Work

Student work, such as their lab reports, group discussion notes, and the poster of their final inquiry projects were produced as part of the curriculum to assess students' understanding of scientific inquiry. For this study, the first author used students' works to reflect her thoughts about scientific inquiry.

Data Analysis

The data was examined through the lens of transformative learning, acknowledging that an expectation of how the prime participant's frame of reference was challenged by her assumptions and disorienting dilemma, and how the assumptions and dilemma lead to the consequence transformation. Also guiding the data analysis was the lens of professional identity formation. Evidence of the development of the first author's institution identity as a teacher educator coming from the authentic science world was sought. Multiple data sources were analyzed using an open coding process. Thoughts the first author expressed that reflected her understanding of scientific inquiry and associated emotions were examined, and then conceptual labels to these thoughts were assigned. Next, these labels were grouped to find patterns in the reflection. The first author constructed the initial coding and shared these with co-researchers to help ensure validity and reliability (see Table 1). Detailed descriptions of analyzing each data source are as follows:

Journal Entries and Transcripts of Critical Friends Meeting

To explore how the first author understood scientific inquiry as it influenced her pedagogical approach to teach scientific inquiry and her professional identity, journal entries and transcripts of critical friend meetings were analyzed for patterns in her reflection. Attention was given to the influences of her prior and ongoing authentic scientific research experience, her rationales to make a connection between authentic scientific research and scientific inquiry in classroom, her emotions such as personal struggles and conflicts, and contextual challenges. During the course time, the first author maintained analytical memos and reflections on her journal entries before each critical friend meeting, which served as the first pass of data analysis. Memos represented the dialogue between researchers and the research data, assisting the formation of a conceptual framework (Charmaz, 2008). Based on the analytical memos, the first author used thematic analysis (Glesne, 2006) to assign conceptual labels to similar thoughts/ideas when data collection was complete. Grouping conceptual labels to form a set of categories and sub-categories was guided by Beijaard et al.'s (2004) framework. The initial coding was shared with the co-researchers to help verify categories and sub-categories (Table 1) to address the unique challenges of how the first author developed professional identity as a teacher educator.

Videotaped/Audiotaped Instructions

Videotaped/audiotaped instructions were analyzed after data collection was complete. As videotapes/audiotapes were viewed, attention was given to instructional moments when the first author was attempting to connect scientific inquiry to the authentic scientific practice. These instructional moments were documented to identify hidden assumptions. As new ideas emerged, new categories were integrated to the coding framework generated from journal entries and transcripts of critical friends meeting. The videotapes/audiotapes were also used to verify categories and sub-categories identified from the journal and critical friend meeting transcripts.

Student Work

Student work was analyzed to determine how they articulated the first author's instruction. The feedback given on this work by the first author and her reflections on whether she agreed that work met her expectations was also explored (see Table 1).

Table 1. Coding Book for Journal Entries and Critical Friends Meeting

Code	Number of instances	Examples
Competing identities	**27**	
Chemist vs. teacher educator	21	01/16/18 I care about the 10th myth because I see myself as a scientist, I feel uncomfortable when others say negatively about scientists. 03/29/18 I think it was because on my way to be a chemist, knowledge like process skills is tacit.
Science learner vs. teacher educator	6	01/11/18 I feel using authentic example from the content area help to develop deep understanding of scientific inquiry and nature of science
Contextual influence	**36**	
Program support	15	01/23/18 I have shared these two slides with other instructors, they agree that's tricky but they generally agree with me. 03/08/18 They are college students they must know plant needs water to grow. They don't need to do a study to figure it out
Student-influence	21	01/11/18 I shared my own example as listed in the pre-reflection, but my students' reaction pushed me back. 04/10/18 After discussed about their research design, I have a better picture about what science knowledge they can learn from their projects
Personal Struggles	**69**	
Value & Belief	27	01/09/18 I was not satisfied with the decontextualized approach to introduce nature of science. Scientific knowledge is missing. 03/27/18 Without reliable sources, I cannot convivence myself they are doing science seriously (or meaningful/serious science).
Emotion	25	01/18/18 I was very happy that my students from both sessions have identify all the inquiry process skills from the journal as a whole class.

Code	Number of instances	Examples
Content	13	04/10/18 I feel bad about not knowing it a head, but it's really challenging for me to twist their research question 01/16/18 Doing science require similar practice, but this is not science. What defines science? 02/01/18 I could not explain some science concepts out of my field
Authority	4	01/30/18 I feel I lose control of their assignment. I told my students "you should be more knowledgeable than me after your inquiry project". 04/26/18 I felt I was losing authority, they do not need me anymore.

Results

In the results section, we switch to the use of "I" to provide the narrative that emerged from our collaborative exploration, acknowledging the self-initiated nature of self-study. In the following sections, we first describe the stages the first author went through in order to understand scientific inquiry in the classroom in a narrative form. Next, we describe influences on the development of her identity as a teacher educator arises from data analysis.

Scientific Inquiry

My understanding of scientific inquiry went through several stages as a result of the systematic investigation during this study. Starting from delineating the definition of scientific inquiry, I expanded my frame of reference to include the nature of science and scientific inquiry. My understanding of the nature of science and scientific inquiry guided my practice in the classroom, which informed my pedagogical decisions. This highlights the value of self-study to inform oneself regarding an improvement in teaching (Hamilton, 1998; LaBoskey, 2004; Buck et al., 2016).

Stage one: "It is nature of science make general inquiry scientific."

Although I feel there was a gap between authentic scientific research and scientific inquiry in the classroom, I thought I was fully prepared to work on scientific inquiry with PSTs before the semester began. Teacher educators with strong science background like me may express discomfort with the content of this course (Donohue et al., 2020). Unlike Donohue, I have passed the period to question scientific inquiry as a content, and I embraced the notion of scientific inquiry. Evidence emerges from my journal and critical friends meeting transcripts.

> *I'm very confident to teach this course because I'm familiar with the curriculum, I had experience teaching this course before… I have taken several graduate courses to support me teaching this course in which we had extensive discussion about the curriculum, scientific inquiry, nature of science, etc. Mostly important, I am a scientist (or a scientist under training) myself at the frontline of research.* (Journal Entry, 08/26/17)

However, my confidence got shaken after the very first critical friend meeting, which occurred before my teaching assignment began. I shared with my critical friends my understanding of scientific inquiry, "*it is nature of science makes general inquiry scientific*". This idea came from my interpretation of the literature. Inquiry is an act of human endeavor to understand the material world, both individually and collectively; from this process, people interact and try to make sense of the information they collected and therefore develop new knowledge to describe the material world (NRC, 2000; Osborne, 2014). Because of the characteristics of the scientific enterprise, including the conventions and ethics involved in the development, acceptance, and utility of scientific knowledge (Schwartz et al., 2014), we could distinguish scientific inquiry from inquiry in general. Nature of science describes the characteristics of science (Lederman, 2007), so it is nature of science that makes general inquiry scientific. This idea was challenged by my critical friends as they both kept asking me, "*Are there part of nature of science that is not scientific inquiry? Are these two different or they are the same?"* (Critical Friend Meeting, 10/31/17). To answer their question, I pulled out Lederman's (2007) framework, which views science as a body of knowledge, a method, and a way of knowing. However, I could not find a place for scientific inquiry in this framework. Scientific inquiry is not the method component, nor is it science as a way of knowing or a body of knowledge. Out of this critical meeting, I decided to include nature of science into my picture. Meanwhile, the second author made me realize I was relying on others to define scientific inquiry, and she suggested for me to explore the practical understanding of scientific inquiry and nature of science inherent in my research as well as in the classroom. This also highlighted the importance of including critical friends in a self-study, not only for establishing validity, but also challenging and questioning my thinking (LaBoskey, 2004; Loughran, 2007)

Stage two: The problem of "Everything is science" and "Scientific knowledge must be considered to define scientific inquiry."

I quickly found problems in my earlier understanding when I reflect on my teaching and research. If nature of science made inquiry scientific, everything could be science. I took a graduate-level course in which we discussed whether survey methodology is scientific. I noted in my journal:

> *Survey collect empirical data, developing a survey requires knowledge obtained from observation and inference, of course the knowledge we learned from a survey is tentative, creativity, subjectivity and social/cultural embeddedness are there. There is a reason social science is called science.* (Journal Entry, 01/11/18)

Another example is research in art history. People identify the age of porcelains according to the painting on them. They match the unknown painting pattern with a known database to figure out which year the porcelain was made. Although I had a hard time to accept that artists are doing science, one of my critical friends pointed out this practice is science. However, no matter survey or porcelain identification, they are different from "the science" I perceived. I questioned myself, "*if nature of science cannot warrant science, what about scientific inquiry process skills?* (Journal Entry, 01/25/18)." This idea was also turned down in my practice, both in the classroom and in my chemistry research. In one class, I saw a student using a pair of scissors to cut a pencil. I passed her a shorter one and told her, "You cannot cut it into halves." The student said, "I'm trying to remove the tape." I suddenly realized that I made an observation and inferred she was trying to cut the pencil into halves, and I predicted she cannot do so/ My actions represent one of the process skills, but I was not doing science. Practicing process skills does not make the action scientific; otherwise, everything is science.

Also, process skills cannot be examined separately. Excerpts from my journal and classroom practices are as follows.

> *Martin (pseudo name) asked me to propose a workflow for automated simulations. It is really just organizing and re-organizing files on computer. I will write program to achieve this. In what way is this science?* (Journal Entry, 01/16/18)
>
> *I teach pre-service teachers how to find investigable questions, but I did not define question for my chemistry research. My research project was suggested by the DMREF group as the team need to perform simulation on tricarb molecules.* (Journal Entry, 01/30/18)

Although I asked the question, "*am I doing science?"* (Critical Friend Meeting, 01/25/18), I would not deny I was doing science. Out of the discussion from my critical friend meeting, I realized one could do science and generate scientific knowledge by participating part of the science process. One does not need to participate in all processes to do science.

To this point, I realized the tenets of the nature of science or process skills of scientific inquiry alone could not warrant something to be science. There must be something else. When I worked on scientific explanation with my students, I found I resonate with the description of the claim, evidence, and reasoning (CER) framework (McNeill & Martin, 2011). CER framework states claim, the answer to a research question or problem, must be based on evidence. Reasoning is needed to bridge evidence and claim through the use of scientific principles or science ideas. Scientific knowledge must be present to warrant something to be science. So far, I feel I had a better picture of scientific inquiry. Scientific inquiry is an act that scientists are trying to understand the material world; through inquiry, scientists generate new knowledge on natural phenomena. Nature of science describes the characteristics of both scientific inquiry and knowledge. This understanding is in agreement with what I read from the literature (Osborne, 2014; Harwood et al., 2002). It seems I took a long trip to make sense of something I had read in the literature a long time ago, and it only makes sense to me when I reflected on my own experience. According to Mezirow (2003), personal growth occurs through a reflective process on one's own experience.

Stage three: "My students are doing authentic novice scientific research."

While feeling enlightened upon making sense of scientific inquiry, I was still wondering about the gap between authentic research and scientific inquiry in the classroom. I knew students' practice in an inquiry-based science classroom mirrors authentic scientific practice in many forms, but scientific inquiry in the classroom does not represent the real world of science as they have different goals (Schwartz et al., 2014). The goal of science is to generate new knowledge of the material world, while the goal of science teaching is to help students understand a body of existing knowledge, how such knowledge is derived, and learn skills for scientific practice (Osborne, 2014). As suggested by my critical friend, I paid attention to what I think my students have learned through their inquiry project. I concluded my third critical friend meeting by this:

> *I think one thing I want to do is to look at their scientific explanation and final inquiry project. To what degree they dive into science I'm satisfied with.* (Critical Friend Meeting, 02/20/18)

Our course was concluded by letting students work on an inquiry project in which they define the research question, design their research method, collect data, and form a scientific explanation. At the beginning, I viewed scientific inquiry to acquire knowledge, more specifically, science facts. For example, I listed what I thought my students could learn from their project as follows.

> *Cindy and Mia could learn the components of eggshell, the reaction between acid and calcium carbonate. Joey will learn knowledge about bacteria. Alice could test for the swollen rate of gummy bears. Hellen and Sun will give guidance about exercise type. Ross will learn the chemical indicators for testing water quality.* (Journal Entry, 03/08/18)

During this period, I was satisfied with my students' projects if I could predict the opportunity to learn science facts and principles during the process. They may need science facts/principles to enrich their research background, understand a procedure, or explain their data. I also felt satisfied to see that they generated practical knowledge.

As my students continued working on their final projects, I experienced a few moments that made me reconsider the meaning of scientific inquiry in the classroom. For example,

> *Emmy wanted to study the impact of different levels of violence in video games on heart rate. She told me there are a lot of studies on effect of video games on people's heart rate, but she did not find research about violent game versus non-violent games. She used to struggle a lot to come up with a research question, but she did it now. Isn't it "define research question from background knowledge"?* (Journal Entry, 03/08/18)

Another example was Keli, who was studying the effect of washing methods on the amount of bacteria on one's hand. She reached me to find a method to keep the temperature around 95 degrees F. While I was contacting my friends in the biology department for using their incubator, Joey came back to me with a simple solution – using a lamp. Joey demonstrated that she solved a technical problem by searching online information. The skills Emmy and Joey developed through their inquiry projects were more valuable than the science facts they acquired. It was these moments I recognized inquiry process skills and the nature of scientific inquiry as content for this course.

Although I recognized scientific inquiry as content, I still feel I was not satisfied with my students' final projects in two ways, as I reflected during my last critical friend meeting.

> *There were a lot of design flaw [in their final project]. That bothered me a lot. Second, when they said they have learned some fact, they could not accurately define the fact.* (Journal Entry, 05/03/18)

Through the discussion with my critical friends, I realized that I was expecting my students to gain understandings of content knowledge at real scientist level. Students in my class were future elementary teachers, and we did not aim to train them to be scientists. It was unreasonable to expect PSTs to acquire an accurate understanding of science facts as accurate as scientists, or even as undergraduate students in sciences majors. The purpose of experiencing scientific inquiry in this class is to demonstrate inquiry as a way to learn new knowledge. Students in my class were novice researchers, but they had designed and implemented authentic scientific research. Finally, the idea of "authentic novice scientific research" resolved my conflicting feelings. I could enjoy the moments when I feel students were learning about scientific inquiry, and also embrace the moments when I feel students' understanding about science facts or procedure were not accurate.

Teacher Educator Identity

Professional identity formation in this section is described according to the Beijaard et al. framework (Beijaard, 2004; Akerson et al., 2014). Data analysis indicates the development of my professional identity as a teacher education was influenced by personal struggles, contextual influence, and competing identities. According to Table 1, personal struggles were the most influential factor (with a total of 69 instances) on my professional identity formation as a teacher educator of scientific inquiry. Contextual influence (with a total of 36 instances), in terms of student influence and program support, also plays a role in helping me develop a professional identity. Throughout the semester, I experienced competing identities as a chemist, as a teacher educator, and a learner of scientific inquiry (with a total of 27 instances).

Personal Struggles

Personal struggles on the value and belief dimension are about how I view science, scientific inquiry, authentic scientific practice, and how scientific inquiry should be taught in this course. Keywords associated with emotional struggles were uncomfortable, nervous, happy, bad, failure, disaster, satisfied, excited, disappointed. My personal struggles occurred for the following two reasons: (1) scientific facts and principles are not identifiable from an activity (or students do not have opportunities to learn science facts/principles), and (2) students are not doing experiments accurately. These struggles revealed my hidden assumptions that I highly valued science as a body of knowledge. Excerpts from my journal entries indicate I have concerns about decontextualized activities because they lack science concepts.

> *I feel it is necessary to give them a solid example that is considered as real science. Why I comment "real science"? The activity represents nature of science, but it is decontextualized. Scientific knowledge is missing.* (Journal Entry, 01/09/18)

Similarly, I believed a scientific explanation must involve scientific principles.

> *A statement about a picture of cat is "The cat is hungry". Well, it can be an inference but not a good one, and it's not a scientific statement at all. The statement "the calico cat in the picture is a female" is a scientific one because it involves reasoning using genetics.* (Journal Entry, 02/13/18)

As students proceed on their final inquiry projects, I experienced struggles if they could not learn science facts from their inquiry projects.

In Ella's case, I do believe the ice cream melting is beyond her current knowledge, but I feel uncomfortable to let her study something already well understood by the science community. (Journal Entry, 04/10/18)

I was also experiencing negative emotions when I feel science facts were missing.

I feel nervous about the topics they choose since I'm not familiar with them at all. I know it's OK if I don't know the science concepts, I should focus on how they support their claims of process skills. Still feel uncomfortable. (Journal Entry, 02/06/18)

My students' presentation disappointed me lot because they can make a decision without knowing the science behind each graph. (Journal Entry 02/25/18)

The second reason leads to my struggles, i.e., students are not doing experiments accurately, are associated with science as a method. Excerpts from my journal entries are as follows.

If I do not make a connection to the real experiment, I thought the activity lose its value. (Journal Entry, 01/25/18)

Oh my god, she measured 100 ml water with a beaker. The result will be off a lot. (Journal Entry, 04/12/18)

I was disappointed that none of my students came up with effective ways to figure out what's inside the box. (Journal Entry, 01/25/18)

When I told my students "you should be more knowledgeable than me after your inquiry project", their reactions made me feel uncomfortable, as if I should be teaching them. (*Journal* Entry, 02/04/18)

I emphasized the importance of the inclusion of science facts and accuracy use of science principles or scientific methods. I carried this belief until the end of this semester. This idea was challenged by my critical friends. After I shared my thoughts about how I define authentic science, one of my critical friends said:

I suspect you are narrowly defining science by your own experience, your very traditional view of science. (Critical Friends Meeting, 02/22/18)

My critical friends' comment was consistent with data analysis. My personal struggles also explain why I think there is a gap between authentic scientific research and scientific inquiry in the classroom. I had the assumption of viewing authentic research as what I do in my chemistry lab, expecting to see how my experience was replicated in the classroom.

Similarly, I kept saying scientific inquiry in the classroom, and authentic research have different goals, but the difference was blurred in my teaching practice. Ponser et al. (2000) indicate that conceptual changes may challenge one's fundamental assumptions about knowledge and knowing. This self-study allowed me to recognize my assumptions about how I view scientific inquiry, which enables me to develop conceptual changes. Although the description above focuses more on the negative emotion I have experienced, many positive emotions also emerged throughout the semester, highlighting my personal growth as a teacher educator.

Contextual Factors

Two contextual factors, program support, and student influence, emerged from data analysis that contributes to my professional identity formation. Program support includes related graduate-level courses I took in the past, interactions with faculties and peers within our program, and my prior teaching assignments. Through program support, I developed an initial understanding of scientific inquiry; my initial understanding was elaborated and deepened through the interactions with my students. For example, I knew scientific inquiry is a content before I teach this course through a graduate seminar, but I did not fully understand what it means.

> *I was struggling to interpret what it means when our course coordinator said "Q200 is a content course" in J762.* (Journal Entries, 08/26/17)

My understanding of scientific inquiry was challenged and expanded when working with PSTs. At the beginning of the semester, the key word from my journal entries indicating students' influence is "silent".

> *I thought I did a great job on the Calico cat example, but the class was silent*. (Journal Entry, 02/13/18)

Such scenarios occurred when I was trying to bring science concepts and principles that are beyond their proximal development zone. Recognizing this gave me the chance to re-consider my expectations toward what science concepts students can learning from their inquiry projects, as well as activities in our curriculum.

Students' reactions also altered how I view authority in the classroom. At the beginning, I believe my identity as a chemist and my science knowledge granted by the authority in the classroom.

> *I think I had more first-hand examples than what the literature has presented. First-hand experience made me different from other teacher educators.* (Journal Entry, 01/11/18)

As the semester continued, I found students worked on projects across a broad spectrum of topics, and I realized it is impossible for me to be an expert in every science field. Knowing science as a body of knowledge does not grant me the authority to be an instructor of this course. I expressed negative emotion when I started to realize the sense of losing authority as in my journal excerpt.

> *I was not able to comment on their scientist presentation because I know little about the topic they choose. I feel terrible about losing control of their assignments.* (Journal Entry, 02/08/18)

The growth in in my professional identity were indicated by the positive emotion towards losing authority by the end of the semester.

> *Every student/group seems know what to do. I constantly check with them "is there anything I could help?" the answer was "no". I felt they do not need me anymore, but I enjoyed it.* (Journal Entry, 04/26/18)

The idea of authentic novice scientific research contributed to my emotion shifted from negative towards the perceived lack of authority at the beginning of the semester to positive at the end of the semester. First, I realized that I was also a novice in area that I was not familiar with, so I accepted the fact that students might be more knowledgeable than me in the topics they selected. Second, it allowed me to shift my focus from examining the accuracy of their understanding of specific science facts to weather they understand scientific inquiry.

Competing Identities

My identity as a chemistry researcher, a learner of scientific inquiry, and a teacher educator provided tensions when I worked with PSTs. By resolving these tensions, my identity as a teacher educator developed. At the beginning of the semester, my identities as a learner of scientific inquiry and a chemist dominated my instructional decisions. For example, when I first introduced the nature of science to PSTs, I incorporated examples like "*structure of benzene ring to show tentativeness and related story of to distinguish empirical evidence vs. non-empirical experience* (Journal Entry, 01/11/18)"; I used my research collaborator's quote to illustrate subjectivity and objectivity. Reflecting on how I learned nature of science and scientific inquiry, I often memorize some concepts (e.g., tenets of the nature of science or process skills of scientific inquiry) before developing a conceptual understanding. Then, I used examples from my prior research experience to interpret the nature of science and scientific inquiry. Because this mechanism worked for me, I was eager to share my experience with students with the assumption scientific inquiry should be learned in this way, ignoring people may take multiple paths to learn scientific inquiry. As I documented in my journal,

> *To be honest, I memorized these definitions myself before I understand them, do they need to do the same thing as I did?* (Journal Entry, 01/30/18)

I quickly realized two problems with my approach. First, I learned science facts and procedural knowledge in a traditional way, and I had accumulated plenty knowledge before I encountered the idea of scientific inquiry. In contrast, the PSTs in my class were learning scientific inquiry through inquiring in authentic scientific research. Second, as mentioned before, the science concepts and research experience that resonated most with me were way beyond PSTs' proximal development zone. I also realized that it was appropriate to share my research experience or any other cutting-edge authentic research, but the purpose of sharing should be helping students understand certain concepts in their own way, as opposed to forcing them to follow my path. This is a sign of the emergence of my teacher educator identity. I adjusted my instructional strategy and had a successful example in the middle of the semester. In my 3rd critical friends' meeting, I said,

> *I brought in an STM imagine, I asked them to make observations, out of that activity was that we realize what count as observation depend on the knowledge of a social group. If a student makes an observation, their observation is just triangle, bright or dark spots, when I asked my research peer, he said it's an STM imagine, the scale the molecule size is so and so. Something considered as inference in my class were observations in the authentic world. That's something I think was successful when I brought in my research there.* (Critical Friends Meeting, 02/22/18)

My identity as a chemist made me value a project based on if they can contribute to a research field, especially chemistry. When I realized scientific inquiry in the classroom has the goal of helping students to learn knowledge and skills, I noticed the projects I valued most were those had room for chemistry concepts. As one of my critical friends pointed out,

> *Jing: … I was expecting her to tell what is the component of egg shell, and what is the reaction between egg shell and acids. I was even expecting her to write the reaction equation, but she was not at that level.*

> *When I asked the component, she just said, oh, egg shell contains calcium. I was thinking what kind of calcium.*
>
> *Critical Friend: You are a chemist. Imagine if it was a scenario about macroinvertebrates, about something you are not so knowledgeable about, you may be standing there going, wow, instead of what kind of calcium.* (Critical Friends Meeting, 05/25/18)

My identity as a chemist made me set up unrealistic expectations towards students in terms of their science knowledge and experimental skills. Recognizing this gave me the chance to re-consider my expectations toward what science concepts students can learn from their inquiry projects, as well as activities in our curriculum.

Conclusions

What one learns about oneself as a teacher educator is at the heart of self-study research (Pithouse et al., 2009). Through this self-study, we have reported how a teacher educator with a strong science background (i.e., chemist) develops an understanding of scientific inquiry and professional identity as a teacher educator. It has been reported that teacher educators with strong traditional science backgrounds expressed feelings not like a science teacher in a student-centered inquiry classroom due to the disconnection between her role in the classroom and her epistemology of science (Donohue et al., 2020). We believe stories of becoming a teacher educator are context-dependent and personal history-dependent. Therefore, the stories are unique and contribute different aspects of our understanding of teacher educator development. This study is not only intended to report the evolution of personal understanding but also to bring out the discussion of teacher educator development, especially for those transitioning to science education from natural sciences.

Many self-study researchers focused on the career transition phase for teacher educators when they were new to the role of a teacher educator. This self-study made one step forward to examine the first author's understanding of scientific inquiry and her identity when she was in her third year of the curriculum and instruction PhD program. Unlike new doctoral students, the anxiety due to the epistemology of science to teach this course no longer plays a key role. However, her traditional science background, such as how she learned science, teaches science, and conducts scientific research, still conflicts with her role as a science teacher educator. These conflicts might be masked by the positive emotion and teaching practice at the surface. According to Kegan (1992), professional growth occurs at behavioral and conceptual levels. This self-study has shown professional identity growth at the behavioral level, and conceptual level may not occur simultaneously. The first author's knowledge of scientific inquiry came more from the studies in the science education program, not from her scientific research experiences. This is not surprising since an understanding of scientific inquiry is essentially tacit in the science community. Although the first author received adequate support from the program through graduate courses and research experience, being reflective of her practice working with PSTs helped her build a more solid foundation of content. According to the transformative learning theory (Mezirow, 2003; Taylor, 2017), learning occurs with the revision of one's frame of reference due to rational discourse and critical reflection. This self-study shows student influence plays an essential role in the first author's discourse identity.

This self-study also demonstrated the power of self-study research to uncover hidden assumptions underlying one's practice. As a chemist herself, the first author was well positioned to bridge the inquiry in the classroom to authentic research. While engaging PSTs in authentic scientific research is attractive to promote science learning, learners often experience a sense of conflict between their teacher and scientist identities (Varelas et al., 2005). This study revealed not only PSTs and students but science educators with authentic research experience also experience such conflict. This conflict resulted from the confusion of goals in different contexts, i.e., science practice vs. science education (Osborne, 2014). Scientists involved in science practices seek to create new knowledge, while students involved in scientific inquiry learn existing knowledge (Osborne, 2014). Also, the first author's experience only reflects part of the authentic research because science enterprise becomes more and more collaborative in nature. It is rare for a researcher in graduate school to experience the whole process of scientific practice. However, in the science classroom, we expect students to gain a sense of the entire inquiry process. One can develop a deeper understanding of scientific inquiry by resolving personal conflicts. This deeper understanding can then be used to improve teaching about scientific inquiry as well as develop new perspectives of inquiry for one’s own research practices. In this way, self-study positions the educator as teacher, learner, and researcher, allowing for a reconciliation of all three identities.

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Author Information

Jing Yang
https://orcid.org/0000-0002-2708-035X
Indiana University
W.W. Wright School of Education
201 N. Rose Avenue
Bloomington, IN 47405
United States
Contact e-mail: *yangjing@indiana.edu*

Gayle Anne Buck
https://orcid.org/0000-0002-1247-7223
Indiana University
W.W. Wright School of Education
201 N. Rose Avenue
Bloomington, IN 47405
United States

Nichole Nageotte
https://orcid.org/0000-0003-4401-1871
Cleveland Metroparks Zoo
3900 Wildlife Way, Cleveland, OH 44109
United States