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Revising teacher candidates' views of science and self: Can accounts from the history of science help?

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Our inquiry uses accounts from the history of science to develop teacher-candidate (student teacher) understanding of the nature of science (NOS) in a science teacher education methods course. This understanding of the NOS is then used as a foundation for developing teacher candidate appreciation of the attributes of authentic science lessons. Based upon their understanding of the nature of science, teacher candidates plan and teach lessons and critique the experiences provided for students using their own conceptual framework of authentic science learning experiences. The study uses an instrumental case study approach in which a case is examined mainly to provide insight into an issue or for refinement of a theory; that is, does the use of the nature of science have utility for supporting teachers of science in their planning and teaching, and, in particular, for assisting them in teaching science authentically and developing a more positive perception of self as a teacher of science. Implications of this inquiry in informing the development and utility of nature of science understandings in teacher education methods courses are also considered.

Key Words: nature of science, teaching of science, transformational learning model

Introduction

The significance of the nature of science (NOS) in the science education literature and science literacy reform efforts internationally over the past two decades is not easily overlooked. The current consensus and emphasis on the NOS from a curricular viewpoint essentially dictates that it is a component of teacher education that cannot be set aside or cursorily examined. Despite this emphasis, there appears to be little justification *pedagogically* for NOS inclusion in teacher education programs leaving NOS inclusion as somewhat of a mythical ideal rather than a supportive construct for pre-service teachers of science. One area for the advocacy for NOS inclusion is in developing teacher candidates' understanding of the nature of science so that as teachers they will present science to their students as it "really is," or authentically, rather than as a content-dominated, textbook science (Martin, Kass, & Brouwer, 1990). If, as Hashweh (1996) suggests, teacher epistemological beliefs about the nature of science are strongly correlated with their science teaching strategies, developing a view of science as it really is, during pre-service teacher education, is both critically important and currently overlooked.

Teaching authentic science is difficult to define, as the views of what constitutes authentic science or science grounded in the nature of science characteristics are diffuse and in need of considerable clarification (Martin et al, 1990). As Bencze and Hodson (1999) asserted,

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authenticity in science is an elusive and problematic notion, with diverse meanings and curriculum implications. It is rhetorically suggested that science instruction may be considered authentic if it is in accord with a commonly held agreement over what constitutes science (Martin *et al*, 1990). The literature on the NOS is well developed and testifies to the diverse views on what is perceived to be science's nature (Akerson, Abd-El-Khalick, & Lederman, 2000; Lederman, 1999). Despite this, there is some consensus that authentic school science should provide experiences that are more in line with the sorts of activities that scientists and technologists do in the real world of science and that such experiences should include student-directed tasks and more open enquiries (Braund & Reiss, 2006). Similar to Bensce and Hodson (1999), our interests were in assisting teacher candidates in both experiencing science and, subsequently, providing science learning experiences that acknowledge a more authentic or valid science.

Compounding this dilemma of the NOS and specific to this study is the question of how best to prepare teachers to understand the NOS (Abd-El-Khalick, Bell, & Lederman, 1998). These authors have cautioned that the NOS cannot be taught implicitly by having students participate in science activities and assuming they will arrive at NOS knowledge through their participation. Instead, they have recommended explicit attention to the NOS in science teacher education. As Lederman and Zeidler (1987) and Abd-El-Khalick and Akerson (2004) suggest, facilitating teacher candidates' understanding of the nature of science is best done by using a conceptual-change model involving infusion of strategies into science methods courses that elicit, confront, and challenge one's understandings of the NOS. This was also suggested by Solomon, Duveen, Scot, and McCarthy (1992), who stated that explicit reflection instruction about the NOS, integrated within a conceptual-change approach, might serve better to enhance pre-service elementary teachers' NOS views. Despite these suggested strategies for promoting NOS understandings, science educators are a long way from having a shared set of assumptions for both the *pedagogical reasons* and the *actual pedagogy* for incorporating the NOS into science teacher education (Abd-El-Khalick et al., 1998), especially for pre-service candidates in elementary and middle-years programs who, quite typically, have had 'non- and mis-experiences' in school science (Lewthwaite, 2000).

The literature is rife with accounts of how most pre-service teachers feel inordinately constrained by the degree to which they believe they have a firm grasp of the content and conceptual ideas that were considered the hallmarks of science for them as students (for example, Lewthwaite & Fisher, 2004; Lewthwaite & Fisher, 2005). Our hope in this study is to assist teacher candidates in developing a pedagogical framework for the teaching of science grounded in nature of science attributes. By so doing, we believe teacher candidate's will exchange anxiety over their perceived levels of content mastery with greater self-confidence in engaging their students by using a clear pedagogical framework for the teaching of science supported by the nature of science explicitly in their planning and instruction. This focus builds upon Kind's (2009) assertions that the most significant confidence for teacher candidates may be their ability to construct and deliver on effective science lessons focusing on the selection of appropriate classroom strategies based upon a pedagogical framework for guiding the planning and teaching of students' science learning experiences.

Theoretical Framework of the Study

Adult Education and Identity

The study is located theoretically in the teacher and, the more often overlooked, adult education literature on professional identity; the perception that teachers as adults have of themselves

(Cattley, 2007). Similar to the constructivist and conceptual-change tenets often touted in the science education and adult education literature, we believe the views of science and self that teacher candidates typically possess are durable, often miss-conceived, and actively developed as a result of an adaptive activity (von Glaserfield, 1995) through their own, often negative, school experiences. As suggested by Loughran (2006), it is thus likely that the core of their personally constructed belief system will impact the core of the professional belief system. In response to this, we believe that central to our work as teachers of science educators is the need to assist teacher candidates in developing a more positive and authentic view of science as a learning area, their role as teachers of science and, more significantly, their belief about their capability to teach science authentically. We see ourselves having the mandate of fostering teacher candidates in the interpretation and re-interpretation of their experiences in continually acquiring and redefining an identity that is a response to their beliefs about their role as teachers (Lamote and Engels, 2010).

Mezirow's Transformational Learning Model

We do not see this redefining as an easy task. Drawing upon the adult education literature (Mezirow, 1977, 2000), we believe that for our teacher candidates, who are adults, this redefining of science and their identity must be transformative in nature. We see our roles through the experiences we provide as critical in bringing about this transformation. We believe that our candidates view science as a curriculum area premised on science being, primarily, a body of knowledge, not a process of inquiry inextricably linked with a body of knowledge. We also believe they see themselves ill-prepared to teach science effectively. In their case, a new consensus of science and self is required. Lamote and Engels' writings on teacher identity, as that of Rots (200) and Canrinus et al (2008), suggest that there are various teacher 'sub-identities', one of which is teacher task orientation. This orientation refers to teachers' answers to questions such as: "What do I want to achieve with my students? How do I want to do this? What is my role as a teacher? What is their role as students?" Denessen (1999) points out that task orientation focuses on aspects such as the (1) pedagogical relation between teacher and students; (2) the educational goals motivating the teaching; and (3) the instructional emphasis. As Lortie (1975) asserts, pre-service teachers already have developed representations, whether accurate or not, of teaching and the kind of teacher they want to be through their own lived experience of apprenticeship of observation. Of importance to this inquiry is the suggestion by Denessen (1999) that the task orientations are primarily associated with two major ideologies – a less frequently identified student-centered approach in contrast to a more commonly identified content-centered approach. A pupil-oriented ideology will focus on a pedagogical relation that fosters involvement, educational goals that are social and personal and an instructional emphasis that is more process-oriented. In contrast, a content-oriented ideology will focus on a pedagogical relation focused on discipline, educational goals that are geared towards career development and an instructional emphasis that focuses on product. A shift in orientation, as Denessen (1999) suggests, requires a restructuring in one's identity.

As Mezirow asserts, transformative learning involves a cognitive restructuring involving change in habits of mind, points of view and behavioral practices (1997) and thus our theoretical premise moves beyond a conceptual-change model (Posner et al., 1982). In contrast to conceptual-change, in transformational learning one's line of action is altered. Learning is initiated through triggered or 'disorienting dilemmas' that set the learning process in motion. Mezirow suggests that for the adult learner, the disorienting experiences prompt reflection; that is, the examining of long-held, socially constructed assumptions, beliefs and values. Brookfield (2000) concurs that this critical assessment of assumptions is central to transformative learning.

The disorientation, although a trigger for prompting change, in itself, does not bring about change. Mezirow asserts that a critical assessment of assumptions then needs to become the forum for discussion. Ongoing rational discourse, subsequently, provides the setting for pre-existing and new meanings to be discussed and evaluated. In rational discourse, bias [may be] set aside in order to arrive at a new consensus. Mezirow suggests that this critical discourse allows opportunity for 'resolutions' that in turn need to be, provisionally, acted upon and, in turn, evaluated. It is through this trial, evaluation and reflective discourse cycle, that new perspectives have the opportunity to be reintegrated into one's life. We believe Mezirow's transformational learning model underpins the learning required to be central and of first-order to science teacher education. If teacher candidates experience transformation in their views of science and self, we have assisted candidates in their most significant learning. This revising of science and self is the heart of pre-service and in-service science teacher education.

But, how can this transformation be accomplished? Our view is that the nature of science has the potential to serve as a pedagogical framework for assisting teacher candidates in developing a more authentic view of science as a curriculum area, especially in regards to transforming candidates' views of science as a mythic, textbook science (Martin, Kass, & Brouwer, 1990) and their role, solely, as content-deliverers. More importantly, we believe it has the potential to assist teacher candidates in developing a positive self-image of themselves as teachers of science because their role is focused more on an understanding of the pedagogical processes to be employed in science instruction rather than, simply, their content knowledge.

Methodology

Introduction

This study builds upon the first author's previous efforts to develop teacher candidate understanding of the nature of science in order to foster teacher candidate capability in planning and teaching authentic science (Lewthwaite, 2007). Although this previous study provided evidence that an understanding of NOS influenced candidates' ability to *evaluate* science lessons for their authenticity, the intervention questionably gave evidence that this understanding is actually translated into practice through candidate ability to *plan and teach* authentic science. It examines the theory asserted by Hashweh (1996) that teacher epistemological beliefs about the nature of science are strongly correlated with their science teaching strategies and practices. In response to the tenuous nature of this previous outcome, this study seeks to look for evidence that a teacher's understanding of the nature of science influences their planning and teaching of science and views of themselves as teachers of science. This focus is our puzzlement.

The context of this intervention a cohort of teacher candidates in their final year of a two-year Bachelor of Education (after degree) program preparing generalist rather than specialist teachers for the teaching of grades five through eight, the study focuses on one case, Annette. As described by Stake (1995) this qualitative study is best categorized as an instrumental case study where a particular case is of interest, in all its particularity. It, in itself, reveals a story. The instrumental case study is best utilized in a situation where there is a research question similar to ours that seeks answer to a puzzlement; a need for general understanding; and feeling that we may get insight into the question by studying a particular case (Stake, 1995). In instrumental case study what is most important is the identification of the revealing case rather than the typical case. In a combined class of 70 teacher candidates, a variety of cases might provide insight into how the course design influenced teacher candidate understanding of the nature of science, its application to the planning and teaching of science lessons, teachers' post-teaching reflection of the authenticity of their science teaching and their views of self as teachers of science. Rather than examining trends in data (Lewthwaite & Wiebe, 2011, 2012) and multiple cases, we choose but one 'rich' case. Through the sheer volume of her writing, inherent within Annette's account was multiple evidence elicited through questionnaire completion, daily journaling, large group discussions, personal conversation, direct observation of teaching, lesson planning and post-teaching personal critique of her rich insight into her own development as both a teacher who comes to understand and teaches authentic science. Overall, we sought to make sense of Annette's story about her learning as a teacher of science. As purported by Glesne & Peshkin (1992), as researchers we sought to understand her experience from her own frame of reference, specifically in regards to her thinking about the nature of science and how this informed her approach to the planning and teaching of science. Using her submitted diary as a form of expressed experience, we identified independently and then collaboratively those aspects that emerged to illustrate her story (Bogdan & Biklen, 1992). For the purpose of this journal, we then abbreviated this story into the narrative form that follows which was verified by Annette and, where necessary, altered to be consistent with her perspective. Because this instrumental case focuses upon one candidate's account, the study presented here lacks generality, notwithstanding that it does provide science teacher educators with considerable insight into a program intervention and the outcome of this intervention in the response of a single participant. As Stake (1995) asserts, a good instrumental case does not have to defend its typicality.

Context of the Study

The course intent was to explicitly introduce the teacher candidates to the principles and practices of science education relevant to grades five through eight of schooling within a social constructivist framework. The focus was on developing the planning skills and teaching strategies, through practical experience, necessary to implement a range of science topics relevant to those grades. Particular emphasis was placed on portraying science as a process of inquiry that leads to an evolving body of knowledge (Ministry of Education, 1993). Although the teacher candidates developed some understanding of scientific phenomena, the courses were implicitly intended to address the negative preconceptions that teacher candidates commonly have towards science and their own teaching capabilities as a teaching and learning area in the national curriculum within a reflective orientation (Abell & Bryan, 1997; Lewthwaite, 2007). Also, epistemological features pertaining to the nature of science were explicitly (as suggested by Abd-El-Khalick & Lederman, 2000) developed within the context of the science methods class. This was done believing that, as Hashweh (1996) suggested, teacher epistemological beliefs about the nature of science would strongly correlate with their science teaching strategies in developing and presenting authentic science lessons as future teachers of science.

The methods course spanned over a full northern hemisphere academic year; that is, from September, 2008 through to April, 2009 and involved twenty, two-hour classes held each week. Three concurrent sessions (classes 15, 16 & 17) in February were devoted to teaching with a peer, a series of three lessons with the same group of six to eight Middle Years students at a local school. The topics to be taught were negotiated by the teachers of the school and the authors. This negotiation revolved around a central idea, that being, what topic do you find as a middle-years teacher find difficult to teach and, equally, what topic do your students find difficult to learn? It is not surprising that the identified areas were in conceptual areas such as seasonal change and lunar cycles, earth structure and dynamics, simple machines and physical and chemical changes, topics often identified as difficult in the middle-years program. These topics became the context for one-hour presentations during sessions 1, 5, 9, 13. In these sessions, one of one of the authors would present an historical account of the development of understanding associated with the topic under consideration. Following the presentation, teacher candidates were asked to consider the NOS attributes embodied within the historical vignette, and, further, suggest implications of these NOS attributes to the teaching of science (TOS). It is noteworthy that the Manitoba provincial curriculum in which these topics are embedded commonly requires teachers to expose students to the historical events that contributed to current scientific thinking in these domains. As an example, in the Grade 7 unit on the Earth's Crust students are to:

> 7-4-12 Describe evidence to support the continental drift theory and explain why this theory *was not generally accepted* by scientists (italics ours)
>
> 7-4-13 Describe evidence to support the theory of plate tectonics, the role technology has played in the development of this theory and reasons *why it is generally accepted* by scientists (again, italics ours)

In the section that follows we describe the content of one of the four vignette lecture HOS presentations.

Using Historical Accounts for Developing NOS Understandings

Example 1: Alfred Wegener & Continental Drift Theory: Tensions & Frictions

As an example of how the nature of science can be revealed to teacher candidates through the historical lens of a major shift in thinking about Earth's history, we took hold of the experiences of Alfred Wegener and the notion of continental displacement, as mentioned above, a central idea to be investigated in the Grade 7 curriculum. This particular story line was developed into a 30 minute interactive lecture supported by Power Point and other visual formats such as a reading biography, computer-based simulations and physical models. The unfortunate manner in which Alfred Wegener's ideas about moving continents and opening ocean basins were met historically by his contemporaries requires more richness than simply developing a brief vignette. This episode in the history of ideas in the geological sciences was quite revolutionary, shaking the very foundations of modern geology a century ago. To us, the entire inclination of exploring Wegener's efforts to convince an institutionalized opposition, for the purposes here, is grounded in establishing a kind of "triggered experience" for the teacher candidates. Each candidate will be drawn to different aspects of Wegener's story, and the entirety of the class experiences then becomes the multivariate window on the nature of science in a particular instance of revolutionary change.

From a NOS perspective, it was important for students to experience the inevitable tensions and friction that occur when one discipline is calling upon another to begin thinking radically about altering its fundamentals. For instance, geology has a particular epistemological manner in which it views the world, and its narrative/historical approach complements and contrasts with other ways in which scientific knowledge is developed and organized in other disciplines such as physics. In the Wegener story, the collision was between the principles of geology on the one side with the fundamental mathematical physics on the other. It is almost as simple as this: Wegener challenged the physical view by saying that the evidence in favour of shifting continents was undeniable, and so it had to have occurred. The physics community steadfastly claimed that it was a geophysical impossibility, and so could not have occurred. Hence, the tension. This tension was further accentuated by the fact he was a German climatologist and the adversarial response was primarily from the British geological community. As well, the means by which he 'poorly' communicated his ideas, both in terms of language and visual communication strategies, were likely further impediments for the scientific community in, psychologically, 'coming to terms' or in experiencing 'cognitive resolution' with these ideas. This sort of frictional, heated exchange of ideas is an important contrast for teacher candidates to foster in their classrooms. It provides their students with an opportunity to gain experience in the NOS through sensing important tensions by personally experiencing the varied interpretations of discrepant events or outcomes of student-generated investigations as a key purposeful strategy in their science teaching.

By designing a curriculum experience in areas such as geology that presents students with differing, if not completely opposing, sets of arguments (e.g. about the permanence of ocean basins on the one hand, and the impermanence of oceans in the Wegener model; a contracting Earth versus an expanding Earth) there may be enhanced potential to see the rhetoric of science in action first hand (Erduran *et al.,* 2001). It is argued in this instance that such point-counterpoint features in the delivered science curriculum will equip students well to formulate their first impressions of how scientific communities behave, how individuals respond to novel facts that erode cherished systems of belief, to understand the role of critical tests, evaluating the behaviour of individuals during a crisis period, and having a realistic opportunity to personally assess how the evidence was indeed validated, evaluated, and subsequently codified historically (Glen, 1994). We have, then, aligned our position with respect to the NOS somewhat with that of Monk and Osborne (1997) who indicated:

> "…in our model, the final review will require an opportunity for students to reflect on the products of the resolution of conflict, which have now become the products of the context of discovery, and compare them with their own thinking. Hopefully, such a phase will enable them to note that historical thought cannot be considered ignorant or stupid, for they too have had similar ideas. It may also become apparent that the ideas of science are not often based on what seems self-evidently salient. Rather, that it has taken imaginative and creative leaps of thought to transcend the limitations of commonsense thinking, and scientific ideas are the contingent product of a socio-historical and geopolitical context and culture. However, most importantly, this approach does focus on *what we think now* – that is, the science concept that is in the curriculum, whose knowledge and understanding by [students] is the main aim of the science teacher." Monk & Osborne, 1997 p. 420

The manner in which the Wegener storyline was presented to the teacher candidates was, initially, to provide that humanistic "door opener" to the important ideas and personalities that were at the centre of this "debate about the Earth". As Clough (2006; cited in Metz et al., 2007) has recommended, this satisfies four recommended guidelines for effective use of science stories as pedagogical content strategies: 1) A tight link should exist between the fundamental science content and the targeted NOS ideas; 2) [stories] should address both historical and contemporary instances so that students cannot easily dismiss past events as wrong thinking; 3) the actual voice of the scientist provides authenticity to the NOS point(s) being emphasized by drawing students' attention to more accurate ideas regarding the NOS; and 4) the focus of the vignette's content is a required area of learning within the provincial curriculum. The early 20th century conflict over continental drift, with Alfred Wegener at the center, provides a particularly accessible instance of a science story that has abundant connections to the NOS, the appropriate geological content, contributes the voices of the actual protagonists, and provides for scaffolds with which teacher candidates can construct science lessons having enhanced authenticity. Although we anticipated teacher candidates would construct their own ideas of what NOS attributes were evident in this vignette and, equally, how these NOS attributes related to the teaching of science (TOS), we anticipated that several connections would be made. These included providing a tangible example to teacher candidates of the importance of (1) students gathering evidence to support theoretical claims, (2) providing students with the time and opportunity to process their findings and come to a point of resolution in their thinking, and (3) using effective communication models to assist students in learning and communicating their ideas.

Data Collection

At the start of the course, prior to the candidates having any formal classroom-based science teaching experience, we decided collectively to use a variety of methods to assist candidates in self-examining their current beliefs regarding the teaching of science. As identified by Dennison (1999), we were committed to providing means by which we could capture students' beliefs about science as a learning area, their perceived role in the teaching of science, and their beliefs about self as teachers of science. To do this we used a variety of self-evaluation procedures that would allow them to monitor their own learning development, an asserted essentiality of adult transformational learning (Kegan, 2000). In the first session of the course before any course information was provided, teacher candidates completed three tasks. First they completed a questionnaire, the Teaching Efficacy Belief Instrument for prospective teachers (STEBI-B), a 23-item instrument to gauge aspects of their science teaching self-efficacy. Each item was scored on a 1 to 5 range of "strongly disagree" to "strongly agree". The instrument, as designed for science teaching efficacy by Enoch and Riggs (1990), is grounded on two sub-constructs of Bandura's psychosocial construct of self-efficacy (1977), namely: personal efficacy and outcome expectancy. Bandura (1986) distinguished between self-efficacy and outcome expectations in that they are differentiated because individuals can believe that a particular course of action will produce certain outcomes, but they do not act on that outcome belief because they question whether they can actually execute the necessary activities (p. 392). The personal science teaching efficacy (PSTE) subscale, consisting of 13 of the 23 items of the instrument, measures personal efficacy (Bleicher & Lindgren, 2005). High scores in PSTE indicate a strong personal perception in one's ability to teach science effectively. The science teaching outcome expectancy (STOE) subscale, consisting of 10 of the 23 items of the instrument, measures outcome expectancy (Bleicher & Lindgren, 2005). A high score on the STOE indicates high expectations that future students will effectively learn science as a result of one's science teaching. In our study, teacher candidates completed the STEBI-B on the initial and second-to-final session. In their post-course analysis they were asked to select only those items they believed were indicators of their development over the duration of the course. Although the STEBI-B is a popular research instrument associated with measuring pre-service teachers science teaching self-efficacy (Bleicher, 2007, Bleicher & Lindgren, 2009; Cantrell & Young, 2003), there are no known examples of it being used as a means of pre-service teachers self-evaluating their own perceptions of self-efficacy.

Second, they were asked to 'visualize' their ideal science teaching classroom and write a descriptive passage that described the activity of both students and teacher in the classroom, the content of the instruction, the purpose or intent of the activity and, finally, their feelings associated with their role. In reference to Denessen's (1999) claims, we were interested in the pre-service teachers' task orientations to the teaching of science.

Third, candidates were asked to provide in their descriptive passage a brief justification for the role taken by students and teachers and the intent of the activity. These three data sources were kept in their journals. The same tasks were then completed at the end of the course and became the focus of a final assignment where candidates critically examined their development during the course.

In each of the four presentation sessions (sessions 1, 5, 9, 13), an open grid with four headings but no further content (see Table 1) was provided for candidates to make individual recorded responses during the presentation. At the end of each presentation, candidates were asked to consider what they learned about science's nature as a result of the presentation. Often, an initial discussion would, as a starting point, identify an example of a NOS attribute and its applicability to the teaching of science. As an example, after the first presentation on Alex Wegener's suggestion of a continental drift theory, candidates were asked what NOS characteristics were evident. One of the teacher candidate's (Annette (pseudonym) – to be introduced later) open class response focused on 'serendipity'. In asking her to expand on this idea of serendipity, she remarked that Wegener's own inquiry into Earth's geological history was influenced by happenchance because of his curiosity and a series of life events including an accident that confined him to bed. There was no pre-calculated agenda to his life history as a scientist and certainly no systematically arranged process by which he arrived at his theory. As a class, we considered how this nature of science attribute challenged the view of their being a 'one-style-fits-all' scientific method, subsequently linked to the teaching of science, and how this attribute might be enacted by them as teachers of science. The collectively constructed outcomes of this initial application based upon Annette's initial NOS suggestion are presented in Table 1 below.

Table 1. Annette's Initial Response to the Presentation on Alex Wegener

Nature of Science Characteristics evidenced in the Narrative	How and Where this Characteristic is Evidenced	How does this Attribute Link to the Teaching of Science?	Practical Example of how I might ensure this attribute might be enacted?
The development of scientific ideas often occurs serendipitously.	Wegener's arrival at a Continental drift theory was a product of observations from his field explorations as a meteorologist, but his ideas developed seriously only while convalescing from a serious wartime leg injury. He re-read earlier 19th century speculations on the issue as he healed.	Students are likely to be curious as they are investigating and may ask questions or seek explanations that are only obtusely or tangentially related to the topic of study. They may also have a variety of valid procedures for pursuing answers to questions.	I need my investigations to provide some opportunity for open-endedness. I need to be open and prepared to allow for alternative questions to be explored as a result of student curiosity. I also need to encourage students to explore their own investigative procedures rather than falling into the trap of doing brainless experiments.

After a few further NOS examples were considered collectively as a class from the geological storyline, candidates considered in groups independently other NOS attributes and their applicability to their teaching and entered these in their grids. This collaborative, co-generative strategy encouraged a social constructivist perspective in which learning is regarded as a social activity. They were engaged in constructing meaning through discussions and negotiations among peers, students, and teachers as a valuable method in developing the teacher candidates' understanding of the nature of science and its applicability to the teaching of science (Abell & Bryan, 1997).

This critical discourse approach as exhorted by Mezirow (1981) allowed the teacher candidates the opportunity to compare, debate, explore, and reinforce their ideas in a social setting, with each teacher candidate having the opportunity to recognize his or her ideas through talk and listening (Driver, Asoko, Leach, Mortimer, & Scott, 1994; Solomon et al., 1992). Through social interactions, the teacher candidates were likely to become aware of others' ideas, seek confirmation of their own ideas, and reinforce or reject their personal constructions.

Further Attributes of the Course

The two or three sessions (that is, sessions 2, 3, 4, 6, 7, 8, 10, 11, 12, 14) interrupting the NOS presentation sessions focused upon activities that introduced students in the two individual cohorts to the science conceptual areas that they would be teaching with a peer a small group of Middle Years students. That is, after the combined session on the historical development of Continental Drift theory, each cohort was exposed to activities specific to the Earth's Crust cluster. Thus, by lesson 14, candidates had been exposed to three history of science combined presentations and, also, associated activities supporting the teaching of the more difficult learning outcomes associated with the topics of Earth in Space, Earth's Crust and Changes to Materials.

School-based Teaching Experiences

As the course progressed, teaching options for the three sessions devoted to school-based experiences identified by the schools' teachers were presented to teacher candidates. Candidates, in pairs, selected a teaching option and were required to collaboratively plan three linked *authentic* science lessons that addressed the phenomena and provided some reasoning and justification as to why these lessons were perceived to be authentic science learning experiences. Candidates were required to use their developing understanding of the Nature of Science and its application to the teaching of science in their justification. As an example, one classroom teacher suggested that the focus of her class's three linked lessons would be day and night, seasonal changes and lunar cycles.

As the candidates co-taught their lessons, they were expected to document in their journals a critique of their teaching and the perceived quality of the lessons based upon student response to the lessons and their teaching. At the end of the course and based upon these peer reflections, candidates were asked to make modifications to the lessons and submit them for formal assessment. Correspondingly, candidates provided a post-teaching reflection of their teaching experience and identified why they perceived their lessons were authentic. The candidates were expected to identify at least five nature of science characteristics that they believed were of consequence in informing the development of their lessons and their teaching of science. Candidates were asked to critique their lessons based upon the shared experience they had had in teaching the lessons to their group of students. Specifically, how did students respond to the lessons? How well did the nature of science attributes selected assist teacher candidates in developing their lessons? Did the application of these attributes to their lesson planning assist in developing positive learning experiences for their students? Although there were other requirements for the teacher candidates in their post-teaching reflection, these questions focus specifically on the intent of this paper. That is, does the application of NOS attributes to lesson planning and teaching contribute positively to the development of a pedagogical framework that supports candidates in offering authentic science learning experiences for students?

Results

As mentioned earlier, this study because of its complex qualitative nature and variety of data sources emphasizes the results from one case, Annette. Again, selecting Annette as the case is primarily based upon the suggestion that in an instrumental case study what is most important is the identification of the *revealing* case rather than the *typical* case. Because we are seeking to determine whether the use of the NOS is a valid foundation upon which to support our teacher candidates in developing a pedagogical framework for the teaching of science and a positive perception of self, we are addressing our own professional puzzlement, and to seek a general understanding, we seek insight into the question by studying a particular case (Stake, 1995). For this reason, through our examination of the professional journals, we independently identified the teacher candidate that we felt best answered our puzzlement. We agreed upon Annette's selection because of the exceptional degree of consideration that Annette had presented in her diary in a variety of forms (for example, questionnaire completion and post-completion reflection, lesson planning detail and accompanying justification, evaluation and reflective consideration of her teaching and development during the course).

Similar to most teacher candidates in this university's teacher education program, Annette held an undergraduate degree in an area other than science. At 29, she is the average age of our education candidates. Annette's reference to 'serendipity' regarding a NOS attribute from the initiating full group presentation on the first session of the course based upon Wegener's life story and her willingness to elaborate on this response, provided the first two authors an initial, and soon to be noticed, ongoing awareness of how she, as an individual case, provided a richness of insight into how NOS understandings can serve to assist teacher candidates in formulating a heuristic for developing authenticity in their science planning and teaching. What follows are a variety of personal responses she makes that serve as data entries in revealing details of her case. Although the entries we present are her responses to the questions posed during the course to direct their diary entries and assignment requirements, we present some of her responses as data in the form of narrative of her journey through the academic year. We, then, use these data to answer our puzzlement in the discussion that thereafter follows.

Annette's Initial Perceptions of Science and Herself as a Teacher of Science

In the first entry to her journal at the commencement of the course in September, she was required to describe her ideal science classroom, her activity as a teacher in that classroom, and the activity of her students.

My Initial Entry:

> I am providing students with an activity that they carry out to find an answer to a problem. I have set the materials out and we have focused on the question. They know what is required of them and they work in groups, record results and come to a conclusion. We discuss the conclusion and make sure we have the same outcome and write it down. They work together collaboratively and by following instructions we have a foundation for moving on to another idea. Students' responsibility is to stay on task and complete activities and respect each other and the teacher. My role is to direct and instruct students. I will be preparing them for next year and beyond. There is uncertainty about my general knowledge. I see myself as an average student who never saw myself as a good science student. I wasn't good at science and really never enjoyed it. I have some doubts about my ability, but, overall, know I can manage what is required.

My Justification:

> My desire is to have students learning the necessary knowledge and a classroom where experimentation is important. As a teacher, I must provide accurate information to

> students during the learning process. A teacher must direct students through the curriculum and clear up any potential misconceptions. I see students doing experiments following the scientific method after we have discussed the topic in class. Students are engaged and actively doing science and coming to conclusions. They will be writing up their results and seeing that these results are consistent with what they read in texts and the notes that have been given previously.

The authors would suggest there isn't anything unique about Annette's responses in comparison to other teacher candidates in our program or teacher candidates internationally. Typical of many pre-service candidates, her emphasis is on a teacher directed classroom learning culture where emphasis is on theory acquisition, that is, her task orientation as Denessen (1999) would suggest, is content-oriented. For Annette, experimentation is seen to be useful for only engaging students and, to a lesser extent, verifying the theory taught didactically. More importantly, her views of science and the teaching of science are embedded within primarily a 'doing of science' that verifies knowledge claims previously asserted through a didactic mode of teacher delivery. As Bencze and Hewson (1999) suggest, her approach focuses on processes where the knowledge acquisition is seen to be unproblematic leading unambiguously to 'proven science'.

Table 2. Annette's Initial and Final STEBI Responses

Statement	Response in Initial STEBI Application (September, 2009)	Response in Final STEBI Application (April, 2010)
1. When a student does better than usual in science, it is often because the teacher exerted a little more effort.	U	SA
4.When the science grades of students improve, it is often due to their teacher having found a more effective teaching approach.	D	A
5.I know the steps necessary to teach science concepts effectively	U	SA
8.I will generally teach science ineffectively.	D	SD
12.I understand science concepts well enough to be effective in teaching elementary science.	U	U
15.Student's achievement in science is directly related to their teacher's effectiveness in teaching science.	D	SA
19.I wonder if I have the necessary skills to teach science.	D	SD
23.I do not know what to do to turn students onto science.	U	D

Similar to most of our teacher candidates and candidates internationally in elementary and middle-years teacher education programs, she has anxieties of her science background knowledge and, consequently, as she implies, her overall science-teaching efficacy. Although there are 23 items on the STEBI, we choose to examine those items that Annette herself chose to use in her end-of-course post-reflection analysis. In Table 2 that follows, the items she chose to analyze are listed along with her level of agreement on a Strongly Agree (SA) to Strongly Disagree (SD) response scale. The items chosen are those of importance to her in providing some evidence to her in her own self-study of her own professional development as a teacher of science. Even though her post-analysis (to be discussed later) will draw into consideration these statements in more detail, what is evident to the authors is her initial uncertainty (U) in most of the items. As well, she does not perceive that teachers strongly influence the success of their students as science learners. She questions the role of the teacher in influencing student achievement, her ability to turn students on to science and her science conceptual knowledge background. Also noteworthy is her tentative perception of herself as a teacher of science. It is noteworthy that the statements selected primarily relate to her perceptions of a teacher's role in influencing student learning and her perceptions of self and her science teaching capability.

Annette's Journal Entries as Responses to the Nature of Science Sessions

What we present here only some of the entries Annette has recorded in her diary throughout the course. We collectively choose these entries because they provide answers to our puzzlement regarding the use of accounts from the history of science to assist students in developing new views of self and science. It is noteworthy that although the majority of these attributes were recorded through discussion in her journal after the four vignette discussions, some may have arisen from the discussions occurring within the non-combined sessions as well. Again, these items are primarily derived as her personal response to the vignettes or from discussion in small groups with her colleagues. Although her diary, in its entirety, lists at least 29 Nature of Science attribute applications to the teaching of science, we have identified those which she ultimately selects as being of utility in the planning and teaching of her three-linked science lessons in the topic of material changes. In her analysis of the presentation, *Alfred Wegener & Continental Drift Theory: Tensions & Frictions*, Annette made the following entries:

Annette's entries give indication of the identification of NOS attributes and application to the teaching of science.

Annette's Lessons and Teaching Experiences

Annette and her teaching partner, Jason, chose to teach a Grade 5 topic related to Properties of and Changes to Materials. Specifically, the learning outcomes they were required to teach focused on (1) selected properties of materials, (2) how these properties were related to their use and (3) how these materials changed (permanently or temporarily, physically or chemically) as a result of environmental influences. Again, this topic was selected by one of the school-based teachers as a valid context for our teacher candidates to work because the topic was both a topic difficult for teachers to teach and students to learn. Using their understanding of Nature of Science attributes and their application to the teaching of science, Annette and Jason developed a series of three-linked lessons revolving around the properties and use of kitchen materials that would cover, three one-hour instructional sessions with a group of eight Grade 5 students. As well, they were encouraged to use a planning template (presented in a completed form in Figure 1) used during the course.

Table 3. Annette's Initial Reponses to the Presentation on Alex Wegener

Nature of Science Characteristics evidenced in the Narrative	How and Where this Characteristic is Evidenced	How does this Attribute Link to the Teaching of Science?	Practical Example of how I might ensure this attribute might be enacted?
The development of scientific ideas often occurs serendipitously.	Wegener's arrival at a Continental drift theory was a product of observations from his field explorations as a meteorologist, but his ideas developed seriously only while convalescing from a serious wartime leg injury. He re-read earlier 19^{th} century speculations on the issue as he healed.	Students are likely to be curious as they are investigating and may ask questions or seek explanations that are only obtusely or tangentially related to the topic of study. They may also have a variety of valid procedures for pursuing answers to questions.	I need my investigations to provide some opportunity for open-endedness. I need to be open and prepared to allow for alternative questions to be explored as a result of student curiousity. I also need to encourage students to explore their own investigative procedures rather than falling into the trap of doing brainless experiments.
Scientists endeavor to understand the natural world	Wegener sought to come to resolution with things he had experiences in his field explorations.	Students also desire to understand the natural world, especially that which makes them curious.	I need to expose students to contexts that are meaningful and relevant to my students. I need to know their interests and that which is likely to engage them.
Outsiders are not always welcome or accepted as contributors in the advancement of science ideas	Wegener's views lacked credibility for a variety of reason. In post-war Europe, a German's views were likely marginalized by British geologists.	Outsiders, or people stereotypically discouraged from pursuing science such as girls and minorities deserve encouragement and opportunity as much as anybody else.	I need to be aware of the subtle dynamics that may operate within my classroom and ensure that no students' views or opportunities to contribute are marginalized either explicitly or implicitly. Each student can contribute to the overall learning of the classroom.

The completed lesson template requires the candidates to list the curriculum connections and assessment methods in column A; the actual teaching sequence in column B; and the materials, safety issues and how their planning was informed by Nature of Science Attributes in column C. In the lower right hand of the template, the guiding principles derived from the Nature of

Science attributes they were using as a foundation for their lesson planning are listed. As well, they were required to provide a one-two page justification for why they perceived their lessons were 'authentic' science lessons based upon how well they captured the Nature of Science attributes. Annette and Jason taught the lessons to a small group of seven students. An open-grid was supplied by the authors to assist the teacher candidates in evaluating each of the lessons in terms of student response and learning. The grid is presented below and contains Annette's first two entries.

Table 4. Annette's Evaluation of Her Teaching Experiences

What is the Nature of Science (NOS) Attribute?	What is its relevance to the Teaching of Science (TOS)	Was this attribute in the lesson? If not, why not? What needs to be done next time?	How significant is this attribute for making for a 'good' lesson in terms of fostering engagement and learning?
Scientists endeavor to understand the natural world	We need to employ a context for our teaching	Yes, we used common household substances	Context was important. Not just the materials we were using but we were making. They were fascinated we could make sponge toffee).
Scientists seek to make sense of what they have experienced. Psychological reasoning is important	We need to ensure we spend time and purposefully assist students in understanding their experiences	Yes. We knew that the rising of the batter and the sponge toffee would be a difficult concept to understand. How can a gas come out of a powder? This would be a challenge.	Essential. Without us focusing on the making sense stage, it would have just been a fun activity. Important to us was knowing why it happened.

Following the teaching of the lessons, Annette and Jason individually made modifications to their lessons based upon their perceptions of what they believed needed to be changed in their preliminary planning in response to their actual teaching experience with the students and ongoing evaluation of the success of their teaching. Annette's post-teaching submitted second lesson of three is shown in Figure 1. Again, what is noteworthy is her inclusion of several NOS attributes that she perceives underpinned her lessons. As well, accompanying the three lessons was a descriptive account of her teaching experience. Although there were several requirements in this submission, what is central to the intent of this paper was the requirement that the candidates evaluate the value of using the Nature of Science attributes in formulating their planning and teaching successfully in terms of fostering student engagement and learning.

Annette's Response to Using the Nature of Science Attributes to Inform Her Teaching

Annette provided a description of the nature of science attributes she used in her lessons. These guiding principles underpin her statements made on the lower, right hand section of the planning grid.

> My lessons are authentic because they are mindful of several Nature of Science characteristics. First, they take into consideration that just as scientists seek to make sense of their world, students should be *engaged in contexts relevant to them*. The use of

> kitchen materials and processes was an appropriate selection. Instead of using words like 'materials' and 'substances', we started by using words meaningful for them like 'ingredients'. Just as scientists gather evidence, the lessons start with an *experiential phase* where students encounter scientific phenomena first-hand. These tangible, observable and measurable experiences are often associated with occurrences [like the frothing of the baking soda in syrup] that are not expected or discrepancies that foster student dissonance and curiosity. It is here we move into a *psychological phase where there is a need to satisfy curiosity,* seek answers to questions and wrestle with the implications of these experiences. During this time, we endeavor to provide space for *all* students to ask and answer questions, especially those 'what-if' type questions that lead to further investigations. In seeking answers to these questions, like scientists, we use *systematic processes* to answer our questions with validity. We ultimately want students to come into a final lesson phase where there is equilibrium, a *theoretical phase,* where they have made sense of their experiences. Coming to this resolution often required us as teachers, like scientists, to communicate their understanding of abstract ideas [like the formation of a gas while a substance is heated] using models and illustrations. Just as scientists need and take time to come to a point of resolution based upon making sense of their experience, we provided time for students to make sense of their experiences, especially through what they were trialing as modifications to their recipes. We wanted students to realize that there are *implications* of what is learned, especially in regards to understanding that in all recipes, what is in a recipe has purpose and intent.

Further, she provided a critique of the value of the nature of science attributes in informing her science planning and teaching.

> What tests the value of the Nature of Science Attributes is simply the response we received from our students. They were not only engaged in science, they were learning science both in terms of the process and knowledge. The nature of science attributes provided me with a conceptual framework to organize my science teaching experience. During the course we frequently made reference to these attributes and applied them to the experiences we were having in class. When we looked at examples of science lessons [from other sources such as textbooks], this developing framework was applied. I began to believe it held so much more virtue than the common 'word on the street message' that science teaching needs to be, simply, hands-on. This framework made sense and added some substance to what planning should be like. It is a challenge to incorporate these [NOS] attributes into your lessons, but when you do and you see how effective they are in making science lessons engaging for students.

Annette's Final Journal Entries

At the end of the course in April, Annette was required to write a further description of her ideal science teaching classroom and accompany this with a justification for this approach. As well she was required to give consideration to her own development as a teacher of science based upon a variety of sources. These included examining her initial ideal science teaching description and justification for such an approach. As well, she was to compare this to her final description and justification. As well, she was to, again, complete the STEBI and by comparing to her initial completion identify several items or statements for consideration in supporting her claims about her science teaching development. Finally, she was to identify what factors had influenced her development.

We present below an account of these responses starting with her final teaching of science description and justification.

My final entry:

> I am providing students with every opportunity to experience science as it relates to their world. I want them to be engaged with their world and learn to understand their world through the experiences we have. We will spend time making sense of difficult concepts, by using models, simulations and other supports. I will gauge students' interest and engagement as a measure of my success as a teacher. If they are not asking questions and explaining answers through the result of the investigations we conduct then I am not doing my job. My students will learn about science stories and history from a broad cultural basis and learn to appreciate the contribution of 'others' and that there is bias in the ideas we celebrate. As much as possible, I want to introduce and awaken their sense of the science occurring right under their noses –in the kitchen, at the water treatment plant, in our farming practices – the good and bad of the science occurring right under our noses. I want them to smell its power and mystery as well as have a healthy respect for its potential to do a lot of damage if wielded carelessly. I know there is uncertainty rather than clear direction in what is expected of me. This will be challenging and I can be responsive to this. My anxiety is not in knowing the answers but being responsive to their interests and being able to assist them in answering questions of interest. But, this is what is required of me. I know it because that's what I know students want. They want to be engaged and I am the one that can make or not make this happen. I choose the former.

My Justification:

> I see science as a human activity, precipitated primarily as a means of seeking understanding of our world through the questions that arise from our own encounters with it. My role is to assist students in encountering their world in a way that prompts their inquisitiveness and then provides them with the skills and attitudes that are necessary to seek resolution to these questions. My role is more of a facilitator. I need not know all the answer, but I do need to know how to respond to the questions they ask and make the initial experiences of interest to them. I want them to see that others [other than European scientists] have and continue to contribute to science, especially within the area I live [in proximity to Aboriginal Canadians].

Finally, looking at the initial and final STEBI results (see Table 2), her initial and final orientations and, finally, her reflective considerations of her overall experience, Annette provided the following summation.

> This course provided me with a very useful conceptual model for developing and critiquing quality science lessons as well as tools to build an interesting and engaging science classroom in a confident and competent manner. I felt quite comfortable teaching science before this course but only if it was in a prescribed manner with the teacher in charge. I definitely lacked a deep conceptual understanding of what makes for meaningful science experiences for students. I see myself now operating on a different level.
>
> I have undoubtedly developed as a teacher of science, and the evidence lies in my descriptions of an ideal class. It's weird how you think your views are solid and justifiable one day, and a year later, think that they are a bunch of useless jargon. Not that my initial views were wrong, they are just so superficial and, I believe, misinformed. I didn't seem to ever identify the real core of teaching science in my description. I described my specific

> role and my students' specific role – basically I teach, you learn- that explained how and what my students would do and learn, but I never identified the processes that would contribute to my students' learning.
>
> When I look at the STEBI [Items 1, 4 & 15], I am amazed I did not appreciate the influence I have as teacher on student learning. I saw learning as a passive process and limited to the theoretical level. I now see teaching as a dirty job, a fight in the trenches if you will. Our job is to provide those initial experiences that probe and make them begin to wrestle with answers and ideas. My job is to help THEM build connections to pre-existing schema. I need to patient and purposeful in how I assist them in making those connections. It isn't all about me, as I originally thought, it's about facilitating student learning through experiences, supported reasoning and coming to an understanding. It's in understanding the processes scientists experience helps me to understand the levels of experience I need to support student learning. Before I saw the experiential side (demonstrations and experiments) as just an add-on to get students engaged. It had no purpose. Now I see it as part of an amalgam of experience that needs to occur in science lessons. I can see why I now see [from items 5, 19 & 23of the STEBI] why I have a much more positive view of my ability to teach effectively.
>
> The Nature of Science attributes provide me with a mind-map for putting lessons together and teaching. They don't tell me directly HOW to engage students, but it does make it clear I MUST engage my students and foster initial disequilibrium. I used to think there shouldn't be questions asked and if a student was asking questions, it was a sign of my ineffectiveness. Now I see it as a positiveReal [authentic] science learning occurs when students are intimately interacting with science –first-hand. The sustained emphasis on the Nature of Science and authentic science teaching challenged me. Every teacher is tempted to grab a prepared activity and run with it. Or, maybe just provide some notes, do a little activity to verify what's been said, and then do some book problems. However, knowing what I know now, this will be harder to do without feeling guilty. Students deserve better and now I know better. Anything less is a compromise.

Analysis and Discussion – Answering Our Puzzlement

In this section, we use Annette's responses from the previous section as a source of evidence in coming to some resolution concerning our puzzlement (Stake, 1995); that is, are teacher candidates' beliefs about science as a learning area and themselves as teachers of science changed as a result of using vignettes from the history of science as triggering experiences for challenging their perceptions of science and self? Although there are several perspectives we could take in responding to Annette's narrative and believe that her narrative, in itself, testifies to changed views of science and self, we have decided to focus on only those aspects identified as central to our initial puzzlement. Is there value in using historical accounts pertaining to scientific developments pertinent to the science curriculum to foster student understanding of the nature of science? In turn, is this understanding then transferable and applicable to developing a personalized pedagogical framework for science planning and teaching? As such, does it contribute to an epistemological change rather than, more simply, knowledge of the often-stated list in science education of NOS attributes?

Revising Views of Science

Annette's account presents compelling evidence of a teacher candidate who has revised her views of science and her teaching orientation from a content-oriented view to a pupil-oriented ideology that focuses on involvement, educational goals that are social and personal and an instructional emphasis that is more process-oriented (Denessen 1981). As she states,

> I see science as a human activity, precipitated primarily as a means of seeking understanding of our world through the questions that arise from our own encounters with it.

Coupled with this is a clear awareness of her role in facilitating this experience.

> My role is to assist students in encountering their world in a way that prompts their inquisitiveness and then provides them with the skills and attitudes that are necessary to seek resolution to these questions.

This view of science and her role as a teacher of science from her initial course considerations,

> Students' responsibility is to stay on task and complete activities and respect each other and the teacher. My role is to direct and instruct students. I will be preparing them for next year and beyond.

Her comments reflect a revised orientation towards student-centered science learning rather than content-dominated experiences with her role now as a facilitator rather than knowledge disseminator.

Most apparent is the development of a pedagogical framework that is embedded within the nature of science attributes she has experienced. She states, "The Nature of Science attributes provide me with a mind-map for putting lessons together and teaching". She acknowledges in her summation that her exposure to the vignettes has been significant in bringing about this re-orientation in her role as a teacher in fostering student learning, "It's in understanding of the processes scientists experience that helps me to understand the levels of experience [experiential, psychological, theoretical] I need to support student learning". She identifies the inextricable link between process and knowledge. As she states,

> I didn't seem to ever identify the real core of teaching science in my description. I described my specific role and my students' specific role – basically I teach, you learn- that explained how and what my students would do and learn, but I never identified the processes that would contribute to my students' learning.

Embedded within her account is a developing knowledge of what processes are inherent within authentic science lessons, especially at the psychological level in assisting students in making sense of experiences.

> My job is to help THEM build connections to pre-existing schema. I need to patient and purposeful in how I assist them in making those connections. It isn't all about me, as I originally thought, it's about facilitating student learning through experiences, supported reasoning and coming to an understanding.

Within her commentary is a revised understanding of science teaching authenticity.

> [It is] a very useful conceptual model for developing and critiquing quality science lessons as well as tools to build an interesting and engaging science classroom in a confident and competent manner. Before I saw the experiential side (demonstrations and

> experiments) as just an add-on to get students engaged. It had no purpose. Now I see it as part of an amalgam of experience that needs to occur in science lessons.

This framework has become personal to her – it is the foundation of a new epistemology (Kegan, 2000) for her teaching of science. As Mezirow (2000) asserts in regards to evidence of adult learning, Annette's values, beliefs and assumptions are viewed through a new lens. Personal experiences are discriminated by a greater autonomy enabled by the establishment of a new interpretation and understanding. As she states,

> However, knowing what I know now, this will be harder to do without feeling guilty. Students deserve better and now I know better. Anything less is a compromise. It's in understanding the processes scientists experience helps me to understand the levels of experience I need to support student learning.

Revising Views of Self

Annette's narrative journey is punctuated with both overt and subtle references to her changing perception of self as a teacher of science. Annette opens her journal with an honest self-evaluation of her prior experiences in science in writing:

> I see myself as an average student who never saw myself as a good science student. I wasn't good at science and really never enjoyed it. I have some doubts about my ability, but, overall, know I can manage what is required.

The items she chooses to address in her STEBI analysis affirm this initial perceived questionable capability as a teacher of science. As well, she locates the source of this uncertainty. First, she doubts her knowledge of steps necessary to teach science concepts effectively (Item 5). Interestingly, despite her concerns about her science content knowledge (Item 12), she reports a confidence in that she will manage (Item 8). This was a pivotal introduction to Annette's thoughts and identity as she acknowledges the perceived existence of two distinct and independent entities; pedagogical content knowledge and content area knowledge. Her sense of being able to overcome any challenges or limitations as a subsequence of her science content knowledge is significant. In fact, her poor perception of self is initially located in both her limited and uncertain knowledge of pedagogy and content. Bandura (1986) identified that the theoretical center of the social cognitive theory are self-efficacy beliefs, which manifests as, "people's judgments of their capabilities to organize and execute courses of action required to attain designated types of performances" (p. 391). People who believe in their abilities to accomplish tasks and prosper through challenges are the source from which continued effort and perseverance arise. If Annette believes she can succeed in being a science teacher, it is that confidence that becomes part of the motivation necessary to act to succeed. However, an absence of such belief, in the face of challenge and resistance, will result in minimal incentive to persevere or alter behavior as a mechanism to find personal accomplishment.

In her summarizing STEBI results (Table 2), she continues to be uncertain about her perceived content knowledge (Item 12), but she has made significant shifts in her perceptions of her pedagogical content knowledge (Item 5). She sees herself as confident in being able to engage students and plan lessons effectively (Item 8), aspects she was uncertain with initially. In the arena of science teaching, Annette believes she has the pedagogical knowledge to teach science effectively, and she will likely carry this forward do so in real classrooms outside of the teacher education program. This evidence appears in Annette's journey not only in her writing, but also from her responses to questions from the STEBI. Specifically, Item 15, 'Student achievement in science is directly related to their teacher's effectiveness in teaching science", which was a relationship that Annette initially disagreed. Annette modified her thinking with a Strongly Agree response in the final STEBI. Annette acknowledges that her initial thoughts reflected a passive and solely theoretical level of science teaching and learning. This transformation of thought is significant as it illuminates her growth and integration of her teacher identity, pedagogical foundations, and efficacious perspectives. Again, despite her uncertain regard for her content knowledge, her knowledge of an appropriate pedagogical approach is now deemed more important.

What is of great interest in Annette's transformative journey in revising her view of self is her comments regarding her idea of what will be happening in her future classroom. Annette scribes, "We will explore areas of interest to them within the framework of the curriculum, but we will be guided primarily by their interests not by a curriculum." Again, her focus is on classroom process rather than content. The notion of being able to move away from traditional teaching and learning of science and progress to a more responsive approach reflects a high level of self-efficacy. Bandura (1997) described the role of self-efficacy beliefs in the human agency in suggesting, ″people's level of motivation, affective states, and actions are based more on what they believe than on what is objectively true″ (p. 2). Bandura (1997) contends that people with confidence can sometimes outperform those with advanced skill sets who suffer from self-doubt. Unfortunately, even an enormous amount of confidence in one's ability can result in success when the background information, knowledge and skills are absent. For teaching, this means that people with a good, but perhaps not superior, sense and understanding of science content knowledge and, instead, pedagogic knowledge can embrace their energies to design, organize and implement effective science teaching as long as they have the confidence that they can do so. Annette is uncertain, yet comfortable with her content knowledge. However, her improved pedagogic knowledge provides her the confidence to see herself effectively teaching science.

For Annette, she has heightened her sense of science teaching self-efficacy. It is refreshing to see that Annette turns her attention away from her own efficacious positions and focuses on the efficacy on the students. This is very significant. "Clearly, I need more tools to appropriately structure my lessons in such a way that students have the time and confidence, with my support, to think through their science experiences and to come to deep understanding of their learning". Self-efficacy is a context driven social cognitive theory that evolves over time and experience. Annette has begun her progression. There is a sense of an underlying orderliness and set of principles that now guide her pedagogical decisions and actions (Kegan, 2000) as a teacher of science. She is able to identify and clarify the movement she, herself, is making and contributors to this development. As Mezirow (2004) asserts, this is the heart of adult transformational learning. Judging by her journey presented in this paper, she will continue strengthening her efficacious positions and behaviors to best become an effective science teacher.

Summary

As middle-years teacher educators, we believe our primary role is to assist teacher candidates in developing a positive perception of science as a learning area, and, with more challenge, teacher candidates' perceptions of their capabilities as teachers of science. Our hope and ongoing practice as science teacher educators is to assist teacher candidates in developing a revised view of self and science as a teaching area. Our focus is on the narrative of the transformative story; providing our candidates with opportunities that foster their self-development and means by which they can see their evolving self-development (Kegan, 2000)

We see that this revision can be supported by assisting teacher candidates in developing a pedagogical framework for the teaching of science grounded in nature of science attributes. By so doing and as evidenced in Annette's narrative, we believe teacher candidates' attributes exchange anxiety over their perceived levels of content mastery with greater self-confidence in engaging their students with a clear pedagogical framework for the teaching of science supported by the nature of science. Various authors (for example, Lederman & Zeidler, 1987) suggest that facilitating teacher candidates' understanding of the nature of science is best done by infusing strategies into science methods courses that elicit, confront, and challenge one's understandings of the NOS. We would suggest that infusion is an understatement. NOS needs to be the foundation upon which teacher education science courses should be premised, especially in using the human story of science as vignettes for teacher candidates to come to an appreciation of what science is.

But, we are not endorsing NOS understanding for simply knowledge's sake or for some other mythical reason. We believe that using vignettes of historical accounts to elucidate NOS characteristics and, subsequently, teaching of science ramifications have the potential when accompanied by associated planning, teaching and evaluation experiences to assist teacher candidates in a transformational learning experience. We believe teacher candidates' views of science and self are likely to change dramatically as a result of the triggered disequilibrium and critical dialogue that can ensue from the use of historical narratives. The key is to ensure that these accounts are prepared and presented in a manner that ensures that science is presented as a human endeavor, transcending race, motivated by an innate motivation to seek understanding and address human needs and concern. As a human endeavor, it is fraught with frailty, influenced by the social context and, rarely, is a solo enterprise. Certainly the use of historical narratives may be of value in elucidating NOS attributes, but to see these become an integrated perception of science and self requires a well-developed, coherent and purposeful effort on behalf of the science teacher educator facilitating the learning process for our teacher candidates as adults. The vignettes become the context for disorienting initial preconceptions of science. Reflective discourse provides opportunity for candidates to seek resolution through discussion and evaluation of these new orientations through classroom-based experiences. A revising of their assumptions needs to be applied to new courses of action (Mezirow, 2000) and, as evidenced in Annette's case, provides the opportunity to apply this acquired knowledge in teaching and validate its provisional status (Mezirow, 1981). Through this experience, they are able to build confidence and competence in a new 'role' (Mezirow, 2000) that is grounded in their newly generated perceptions of what it means to be an effective teacher of authentic science.

We emphasize here that in light of what Mezirow regards as the 'common phases' or 'steps' associated with adult learning, the use of the historical accounts are likely to be only the instruments that serve to provide the disorienting dilemma for teacher candidates. They, in themselves, do not create the learning. Instead, they, like discrepant events commonly used in science instruction, create the initial conditions for contributing to learning by provoking their views of science and self. It is the purposeful, articulated subsequent activities including the critical discourse, collaborative planning, field-based experiences and evaluation, which combine to create a transformational experience for teacher candidates. Central to the learning process is ensuring that the learning that occurs through these experiences is from a self-authored frame (Erickson, 2007). It focuses upon teacher candidates understanding their evolving self and the epistemological changes they identify in science and self over their science teacher education experience. We are confident that the learning our students have experienced will, at least as Annette claims, make subscription to such orthodox practices "harder to do without feeling guilty".

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Öğretmen adaylarının fen hakkındaki görüşlerinin ve (öğretmen olarak) kendilerinin değerlendirilmesi: Bilim tarihinden hikayeler yardım edebilirmi?

Bu çalışmada fen bilgisi öğretimi dersi içerisinde öğretmen adaylarının bilimin doğasına yönelik anlayışlarını geliştirmek için bilim tarihinden hikayeler kullanılmıştır. Bilimin doğasına yönelik bu anlayış öğretmen adayları için gerçek fen derslerinin niteliklerini anlamada temel olarak kullanılacaktır. Bilimin doğasına yönelik anlayışlarını kullanarak, öğretmen adayları ders planı hazırlar ve uygularlar. Aynı zamanda gerçek fen öğretimi derslerinde öğrencilere sağladıkları deneyimler hakkında kavramsal yapılarını kullanarak kritikler yaparlar. Bu çalışmada araçsal durum çalışması yaklaşımı benimsenmiştir. Bu yaklaşım bir olgunun ya da bir teorinin derinlemesine incelenmesini sağlar. Bu çalışmada bilimin doğasının kullanımının öğretmen adaylarının fen derslerini planlama ve öğretme süreçlerinde özellikle doğru bir şekilde fen öğretmelerine yardımcı olup olmadığı ve fen öğretmeni olarak kendilerinde olumlu bir algı geliştirip geliştirmediğine bakılmıştır. Bu çalışmanın bilgilendirici etkileri öğretmen adaylarının bilimin doğası anlayışlarının gelişmesi ve bunların kullanılmasında ve ayrıca öğretmen eğitiminde yöntem derslerinde de dikkate alınacaktır.

Anahtar kelimeler: bilimin doğası, fen öğretimi, dönüşümsel öğrenme modeli

Appendix.

Planning Sheet for Single Science Lesson	**Lesson 2 Title: Ingredients, Their Uses and How They Change**	**Cluster: Properties of Materials** **Grade 5, SLO 5-2-02**

	Teaching – Learning Sequence	**Materials Required:**
A. Cluster 0: Scientific Inquiry **Initiating, Researching & Planning** Formulate questions that lead to investigations Formulate predictions/hypotheses Create an investigative plan with guidance	1. Initiating Activity: Start the lesson by having several household substances on display. Get students to consider what each kitchen ingredient gets used for. Provide them with time to discuss and respond. Follow-up discussion by considering what everyday properties or descriptions apply to each ingredient. On a whiteboard, write down the ingredient and words that describe. Draw upon words that extend their awareness of properties that are physical - words such as texture, state (solid, liquid, vapour),	Various kitchen substances – sugar, salt, flour, baking soda, citric acid, water, Kool-Aid. Hot plates and small beakers (250 mL) Spoon Clean saucepan Newspaper

fgjkl

<u>Implementing; Observing, Measuring & Recording</u> Make observations relevant to the question at hand Use tools and materials appropriately Record and organize observations <u>Analysing & Interpreting</u> Interpret patterns and trends in data and infer and explain relationships. **Concluding & Applying** Draw a conclusion based upon investigation results **B. STSE Issues/ Design Process/ Decision Making:** Value honesty, perseverance, precision as scientific habits of mind. C. **Essential Science Knowledge Summary:** Students will be exposed to common household substances. Each substance has properties and each property makes the substance useful with purpose. Substances may change when heated and these changes as well can be useful **Will you assess? If so, what?** Student understanding of these properties and how the properties relate to use. Can students associate properties with uses? Can they explain the uses, how the changes are useful **How will you assess it?** Oral responses during lessons and completion at end of lesson of a list of ingredients, their properties and their uses. Application of these properties and changes to recipes.	transparency, powders, crystal. 2. Extending Activity: Get students to consider why we use these ingredients are in the kitchen. What properties do each have that makes them useful. Consider the sweetness of sugars and syrups and how this can be used in food items, sourness of citric acid and how this can be used in food items. Extend the conversation to more difficult ingredients such as baking soda. Focus on its bitter taste. Allow students to experience how the mixture of small amounts of citric acid and sugar can make a sweet and sour taste as is found in crystal drinks such as Kool-Aid. Extend this to see the result of mixing citric acid and baking soda which results in fizzing sensation because of the interplay between the two and the production of carbon dioxide as a by-product of the mixing. Consider 'fizzy' candies students likely have had experience with. Add these ingredients to the list and their properties and suggested uses.Follow-up by demonstrating to students what happens when some of these substances are heated. Show students how sugar melts and then caramelizes when heated. Repeat with corn syrup. Show students how baking soda dissolves only in cold water but begins to effervesce when placed in hot water (because it decomposes to produce carbon dioxide). Talk about the use of baking soda as a rising agent because of the gas release when heated or mixed with an acid. Add these details to the chart. 3. Investigating: Demonstrate to students the addition of 1 tsp corn syrup with 2 tsp sugar. Bring to boil and then after 30s of boiling. Get students to consider and justify what will happen if baking soda is added. Note changes to boiling syrup and sugar and then add ¼ tsp baking soda. Stir the frothing mixture and pour out on wax paper. Allow time for students to consider the reasons for the change. Get students to review the reason for each ingredient in the sponge toffee. Get students to consider how the process might be changes to produce different results. How could it be made more brittle? How could it be fluffier? Use the fair-testing planning sheet with students to plan an investigation to determine how a recipe adjustment of one ingredient may influence the final recipe product. Suggest boiling time as a means by which the brittleness might be changed. Consider how boiling time could be altered and how brittleness might be measured. Emphasize the importance of changing and controlling for variables to make the trial test fair. Students carry out the investigation making two or three batches by altering the boiling time. Share and discuss outcomes. Carry out other investigations altering other variables if time permits. 4. Lesson Closure: Draw lesson to end by giving attention to the focus of the lesson. Properties of materials relate to their use. Provide students with a recipe for pancakes	**Safety Considerations:** Safety focus on hot plates & food hygiene **What NOS attributes are embedded in my lessons? *<u>Change these for you!</u>*** 1. Scientists make sense of their world. Is there a context for the lesson that is applicable to students' lives. 2. Curiosity can drive the scientific process. Does the initial phase of the lesson foster student engagement possibly by creating disequilibrium? 3. Is there an emphasis on first-hand experiences – an <u>evidential</u> phase? 4. Am I helping students to make sense of these experiences – a <u>psychological</u> phase? Am I using methods such as models and illustrations to help their learning? 5. Is there a phase for them to ask questions and pursue answers to their questions through investigating? 6. Do they carry out the investigation systematically but with opportunity to be creative? 7. Is their a theoretical phase where the essential science <u>knowledge</u> is articulated and consolidated? 8. Does the lesson require collaboration both in doing activities and sha-