International Journal of Environmental & Science Education, 2015, **10**(3), 405-428

Multifaceted NOS Instruction: Contextualizing Nature of Science with Documentary Films

Mark Bloom
Dallas Baptist University, USA
Ian C. Binns
University of North Carolina at Charlotte, USA
Catherine Koehler
Southern Connecticut State University, USA

•*Received 20 February 2015* •*Revised 23 March 2015* •*Accepted 24 March 2015*

This research focuses on inservice science teachers' conceptions of nature of science (NOS) before and after a two-week intensive summer professional development (PD). The PD combined traditional explicit NOS instruction, numerous interactive interventions that highlighted NOS aspects, along with documentary films that portrayed NOS in context of authentic scientific discovery. Reflective dialogue was used throughout the professional development to encourage constructivist learning. The PD addressed seven commonly held NOS tenets that are deemed significant to K-12 science teachers. Finally, qualitative methodologies were used to analyze the Views of Nature of Science Questionnaire (VNOS-D) and the associated interview data to explore subtleties within each NOS tenet and to gain a richer understanding of how the teachers' NOS understanding differed before and after the PD.

Keywords: nature of science, professional development, contextualized instruction

INTRODUCTION

Understanding nature of science (NOS) is considered a critical component of scientific literacy (National Science Teachers Association [NSTA], 1982) and is highlighted as a necessary component to science education by the *National Science Education Standards* (National Research Council [NRC], 1996), *the Benchmarks for Science Literacy* (American Association for the Advancement of Science [AAAS], 1993), and the new Framework for K-12 Science Education (NRC, 2012). Acquisition of NOS understanding serves several critical functions for students; it: (a) allows them to become educated users of technological and scientific advances in their society (a utilitarian function), (b) empowers them to make informed choices about social and cultural issues (a democratic function), (c) enables them to appreciate the role of science in their own and others' cultures (a cultural function), (d) gives them

Correspondence: Mark Bloom,
Department of Biology, Dallas Baptist University, 3000 Mountain Creek Parkway, Dallas, Texas, 75211, USA
E-mail: markb@dbu.edu
doi: 10.12973/ijese.2015.252a

ISSN: 1306-3065

insight into the moral code of their society which is exemplified in the norms and values of the scientific community (a moral function), and (e) increases their ability to acquire and retain science content material (an academic function) (Driver, Leach, Millar, & Scott, 1996). When teachers lack an understanding of NOS, they lack scientific literacy, and by extension, lack the ability to guide their students toward scientific literacy. Further, without knowing the basic characteristics of the scientific endeavor, teachers lack the ability to determine what materials should and should not be incorporated in their curriculum. This deficiency is most notable when teachers allow the inclusion of alternative explanations for evolution or moral/ethical discussions of controversial topics such as stem cell research and cloning to be presented as science knowledge, or alternatively, when they altogether exclude topics such as these because they fear the moral and ethical discussions they might generate (Bloom & Weinburgh, 2007).

For over 50 years, research has determined that science teachers lack a sophisticated understanding of the philosophical NOS (Anderson, 1950; Barufaldi, Bethel, & Lamb, 1977; Behnke, 1950; Billeh & Hasan, 1975; Bloom, Sawey, Holden, & Weinburgh, 2009; Bloom & Weinburgh, 2007; Carey & Strauss, 1968; Gruber, 1963; Klopfer & Cooley, 1963; Miller, 1963; Riley, 1979; Scharmann & Harris, 1992; Trembath, 1972; Welch & Walberg, 1967-1968). This may, in part, be due to the lack of clear representation of NOS in curricular materials and/or a lack of NOS instruction to preservice science teachers. While the reform documents (AAAS, 1993; NRC, 1996, 2012) include NOS as an important component to scientific literacy, none of these documents provides a clear and concise definition that is useful to teachers in gaining a personal understanding of this facet of science for themselves, much less in providing authentic NOS instruction to their pupils. Rather, the characteristics of NOS are spread across chapters in the science textbooks as if these ideas will somehow coalesce into a larger abstraction that can be adopted by the reader. Although these documents generally emphasize the same major characteristics that define NOS, the views held by scientists, science teachers, and philosophers of science fail to achieve this same level of agreement.

Nature of science can be considered an epistemology of science, one way of knowing, and inherent in the development of scientific knowledge (Lederman, 2007). However, all researchers and philosophers have not accepted this definition. For example, Alters (1997) found disagreement among the philosophers of science as to what tenets best describe NOS. He further found differences among the views of science teachers and scientists. His ultimate appraisal of the situation was, "…there is no one agreed-on philosophical position underpinning the existing NOS in science education" (p. 48). While characteristics of NOS might be widely debated among and between philosophers, teachers, and practitioners of science, many researchers in science education argue that agreement does exist (Smith, Lederman, Bell, McComas, & Clough, 1997; Smith & Scharmann, 1999) and that the differences that exist are not relevant to K-12 science teachers (Lederman, 2007). Seven tenets of NOS, commonly held by philosophers, educators, and practitioners of science, are considered important for K-12 science teachers and are identified by leading researchers in NOS (Bell, Blair, Crawford, & Lederman, 2003; Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002; Smith et al., 1997; Smith & Scharmann, 1999). These tenets emphasize that scientific knowledge is:

- tentative;
- based on empirical evidence;
- subjective and theory-laden;
- advanced through creativity and imagination of scientists;
- socially and culturally embedded;
- driven by observations and inferences; and

- based on laws and theories.

Bringing NOS learning opportunities into preservice programs has been challenging and several models of introducing NOS instruction have been met with varying success (Abd-El-Khalick, & Lederman, 2000; Akerson & Hanuscin, 2007; Bell, Matkins, & Gansneder, 2011; Clough, 2006; Ozgelen, Hanuscin, & Yilmaz-Tuzun, 2013; Smith & Scharmann, 2008). Arguably the most widely used model for NOS instruction is the explicit-reflective approach (Abd-El-Khalick & Lederman, 2000; Lederman & Lederman, 2014). Traditionally, this type of instruction has been decontextualized, meaning that NOS is the primary focus of the instruction with no direct connection to science content. Despite the wide support for the explicit-reflective decontextualized approach, there is concern over the lack of context when NOS is taught (Brickhouse, Dagher, Letts, & Shipman, 2000; Olson & Clough, 2001; Ryder, Leach, & Driver, 1999; Smith & Scharmann, 1999). Clough (2006) argues that only using explicit-reflective decontextualized NOS instruction could lead teachers to view NOS as simply an "add-on" and in turn, they may decide to not take instructional time away from the rest of their curriculum.

Another approach is contextualized NOS instruction. In this type of instruction, NOS is integrated within specific science content (Bell et al., 2011; Clough, 2006). Fewer investigations have explored the effectiveness of contextualized instruction that is integrated with specific science content (Bell et al., 2011; Clough, 2006; Khishfe & Lederman, 2006, 2007; Matkins & Bell, 2007). Some results have shown that contextualized NOS instruction improves both NOS understandings and the content specific understandings (Matkins & Bell, 2007). Others found that NOS understandings improved regardless of whether the instruction was decontextualized or contextualized (Bell et al., 2011; Khishfe & Lederman, 2007). Nevertheless, incorporating instruction that has a mix of the decontextualized and contextualized approaches appears to be an effective strategy for improving NOS understandings as well as one's ability to apply these understandings to different contexts (Abd-El-Khalick, 2001; Brickhouse et al., 2000; Clough, 2006).

Egan (1997) emphasizes the historical role that visual imagery and storytelling has in the transmission of knowledge from generation to generation and indicates that content, embedded in stories, is a natural way for humans to develop new knowledge. The modern day storytelling is done in front of screens and television. Films can be an effective vehicle for teaching content, including science (Dubeck, Moshier, & Boss, 1988; Dubeck, Moshier, Bruce, & Boss, 1993; Koehler, Bloom, & Binns, 2013). Dhingra (2003) studied the effects of various types of television programs on students' understanding of NOS and found that students were more likely to accept scientific conclusions as absolute (not tentative) when presented in documentary format.

This study focuses on these seven specific NOS tenets with the primary objective of determining in what ways inservice science teachers' conceptions of NOS can improve through explicit NOS instruction using a variety of contextualized and decontextualized strategies. Specifically, eleven science teachers' conceptions of NOS were examined before and after engaging in an explicit, intensive professional development (PD), which included traditional decontextualized instruction as well as contextualized documentary films to teach about NOS tenets. The research question addressed by this study is:

How does a professional development experience, involving traditional NOS instruction (decontextualized) accompanied with documentary films (contextualized), effect inservice science teachers' conceptions of NOS?

Context of study

This research focused on seven major characteristics of NOS deemed important to K-12 science instruction (Bell et al., 2003; Lederman et al., 2002; Smith et al., 1997; Smith & Scharmann, 1999). While more characteristics of NOS have been emphasized (NGSS Lead States, 2013), such new conceptualizations of science relate more to the practice of scientists and less to the overarching goal of the PD described herein: discriminating between science and non-science. A common concern, often expressed by practicing teachers who regularly attend the PD experiences provided by the authors, relates to their uncertainty about teaching evolution, intelligent design, and/or creationism in the classroom: a general concern with teachers throughout the southern United States (Berkman, Pacheco, & Plutzer, 2008). The seven traditional NOS tenets targeted by this PD were selected specifically because they are critical to discerning science from non-science. All study participants were practicing science teachers seeking novel pedagogical methods as part of their continued PD. NOS instruction via documentary films and NOS-focused activities was delivered using an explicit approach combined with reflective group dialogue as recommended by current and past research (Abd-El-Khalick & Lederman, 2000; Akindehin, 1988; Billeh & Hasan, 1975; Lavach, 1969; Smith & Scharmann, 2008). Verbal and written data were analyzed using qualitative research methodologies in order to describe the ways in which the participants' conceptions of NOS aligned with or deviated from the presentation of NOS in this PD experience.

The two-week PD experience was offered at a small private university in North Central Texas as a part of a yearlong Teacher Quality Enhancement grant program. The intention of the two-week summer portion of the PD was to use contemporary biological issues (as found in popular press) to increase/update the participants' biological content knowledge as well as to begin developing their understanding of NOS so they could effectively discern science from non-science. In order to help the participants increase their understanding of NOS, a series of interventions were planned and incorporated into the PD activities. Knowing that short term PD is not enough to affect lasting gains in NOS (Akerson & Morrison, 2006), the NOS instruction would be continued during monthly meetings throughout the academic year. The participants' conceptions of seven NOS tenets were measured before and after the two-week summer PD to help frame the subsequent NOS instruction.

Participants

The participants were public school teachers selected from a pool of applicants who responded to an announcement of the workshop that was sent to school districts in the surrounding area, or who learned of the workshop by word-of-mouth. Their years of teaching experience ranged from two to 19 years and the grade levels they taught ranged from kindergarten to twelfth grade. Participants were selected based upon their personal needs for PD. Those who were teaching out of their subject field or who lacked PD credits were given priority as per the grant requirements. Twenty-five middle school and high school teachers were invited to participate in the workshop and of those invited, 19 indicated interest in participating in this research. Only 11 completed all aspects of the PD including signing the consent form to participate in research, completing both weeks of instruction, completed both pre- and post-assessments, and meeting for interviews before and after the interventions. These 11 participants (the units of analysis) and their development of NOS understanding are the focus of this research. Table 1 includes the participants' years of experience, content area, grade taught, and pathway to certification.

Table 1. Teacher participant demographics

Participant	Years of Experience	Educational Background	Grade Taught	Pathway to Certification
1	6 years	B.S. Biology	9th	Alternatively Certified
2	4 years	B.A. Home Economics	6th	Alternatively Certified
3	8 years	B.S. Educational Studies	8th	Traditional
4	6 years	M.S. Educational Studies	6th	Traditional
5	4 years	B.S. Interdisciplinary Studies	9th	Alternatively Certified
6	19 years	M.S. Earth Science	4th	Alternatively Certified
7	12 years	B.S. Interdisciplinary Studies	1st and Kindergarten	Alternatively Certified
8	7 years	B.S. Movement Science	7th and 8th	Alternatively Certified
9	2 years	B.S. Secondary Education	9th – 12th	Traditional
10	2 years	M.S.	9th	
11	11 years	B.A. Interdisciplinary Studies	8th	Alternatively Certified

METHODS

All study participants voluntarily consented to be included in the research and all participated in each aspect of the professional development activities listed in Table 2.

Participants' knowledge of NOS was initially assessed using the Views of Nature of Science Questionnaire Version D (VNOS-D) (Lederman & Khishfe, 2002). The VNOS-D was administered 2 weeks prior to the PD experience. After reviewing the participants' responses to the VNOS-D, individualized interviews were conducted. The purpose of the interview was to give the participants opportunities to expand on their answers and to respond to semi-structured open-ended questions and statements related to particular NOS tenets. The participants were also asked to explain their answers and give examples when possible. Individual interviews were scheduled and conducted prior to the beginning of the two-week PD. Interviews ranged from 25-45 minutes in length, were audio recorded, and transcribed verbatim. The transcribed interviews and the VNOS-D responses were used to create individual participant profiles that represented each participant's understanding of NOS prior to the PD.

Table 2. Formative evaluation of the gene technology modules

Intervention	Description	NOS Tenets	Contextual (C) De-contextual (D)
Checks activity (Crue, 1932)	Groups collected data from checks and used their findings to develop a story. They revised their conclusions as they gathered more evidence. Once each group had developed their final story, they shared it with the rest of the class. When one group found flaws in another group's story, its members used their data to contradict the story thereby adding to the body of knowledge shared by the class.	T, E, S, C, S&C, O&I	D
The "15 Myths of Science" (McComas, 1997)	Used to inform participants about how their previous science learning may have fostered false understandings	T, E, S, C, S&C, T&L	D
Paired statements (Smith & Scharmann, 2008)	Participants were given 10 pairs of statements and asked to rate one of each pair as *more representative of science* and the other as *less representative of science*. They were asked to discuss why they choose to designate them the way they did. They completed the assignment individually and then as small groups. After all groups completed the activity, each group's answers were compared and discussed.	T, E, O&I	D
Proof wall	The *Proof Wall* was an ongoing opportunity to stress the importance of the tentativeness of science. To help participants replace the word proof (with more authentic descriptors like *supported by*, *validated by*, etc.), a poster was placed on the wall with the word *Proof* on it. Anytime a participant used the word *proof* or a derivation of it (or prove or proven), a check mark was placed on the poster. This was followed by a short discussion to reiterate the need to find a better way to make these statements.	T	D
Footpath murders: DNA profiling's landmark case (Dowling, 1997)	This documentary was shown to engage participants in the topic of DNA fingerprinting. The video tells the story of the first time DNA fingerprinting was used in a criminal case to exonerate a charged felon and to identify a murderer. To determine if the participants could recognize NOS tenets within the context of actual scientific research rather than just as an abstraction, each participant received a NOS checklist and instructed to fill in examples of the seven tenets while they watched the film. This was followed by a class discussion.	T, E, S, C, S&C, O&I, T&L	C
Ulcer wars (Mosley, 1994)	This documentary describes the discovery of the bacteria *Helicobacter pylori* and the subsequent cure for ulcers as well as the reticence of the scientific community to accept these new discoveries (which contradicted previous held scientific belief). A NOS checklist was provided to document any evidence of NOS tenets while they watched the film. This was followed by a class discussion.	T, E, S, C, S&C, O&I, T&L	C

Origin of AIDS (CBC, 2004)	This documentary describes a controversial, alternative theory of the origin of HIV and AIDS, e.g. HIV was spread through the Congo via a living polio vaccine. A NOS checklist was provided to document any evidence of NOS tenets while they watched the film. Time was given for individual group discussions to determine if the controversial Attenuated Polio Virus theory (APV theory) seemed scientific or non-scientific. This was followed by a class discussion.	T, E, S, C, S&C, O&I, T&L	C
How's your horoscope (Flammer, 2002)	Participants were given a list of twelve personality profiles and asked to identify which one best represented their personality. After participants decided which one best matched them, the birth dates associated with each profile were revealed. As a class, they calculated the percentage of participants who accurately identified their moon-sign (matched) and compared these findings to chance alone. They then discussed and debated the scientific merit of astrology. Arguments were based on the seven NOS tenets.	E, O&I	D
Evolution, creationism, intelligent design debate	Participants debated with an imaginary school board about what should be included in a science curriculum: evolution, creationism, or intelligent design. They were randomly divided into three groups and asked to investigate one of the three "*theories*." They were instructed to act as supporters for their particular theory and asked to use the seven NOS tenets and associated philosophy of science language to argue why their theory should be included in the curriculum. After a short presentation, school board members were given the opportunity to argue against the inclusion of each theory in their science curriculum (again using philosophy of science language and the seven NOS tenets).	T, E, S, S&C, O&I, T&L	C

Analyzing Pre-intervention VNOS-D

The VNOS-D (Lederman and Kishfe, 2002) consists of seven open-ended questions that are useful in determining respondents' conceptions of the seven NOS tenets targeted by this study. It includes questions such as 'What is science?' and 'How do scientists know that dinosaurs really existed?' Such questions have no single right or wrong answer, but rather strive to elucidate respondents' conceptions of the general nature of scientific understanding. The VNOS-D is a user-friendly version of the survey that can be administered in a relatively short period of time (approximately 30 minutes).

Evaluating responses to the VNOS-D requires careful interpretation joined with individualized interviews. Prior to this study, the first author and two trained VNOS-D co-raters established interrater reliability using a distinct set of VNOS-D responses. Initially, each co-rater individually evaluated 10 completed surveys. Each answer was read independently and unitized by identifying and electronically highlighting any phrase that related to any of the seven NOS tenets being studied (a different color was used to visually identify each NOS tenet). After evaluating all answers, the scorer determined if the respondent's conception of each tenet was informed, transitional, or naïve. Co-raters compared their results to reveal a 42% interrater match. After discussing the results of the initial trial surveys in depth, another set of survey responses were analyzed. After this next step, an 82%

interrater match was achieved. The first author then analyzed the eleven survey responses used in this study and allowed the co-raters to review his resulting scores. Once all data were unitized and color-coded for all seven tenets, pre-interview participant profiles were created.

The first author further analyzed the VNOS-D data using the constant comparative methodology; codes were created and modified, which were used to describe the data units (Patton, 2002). This same methodology was used throughout the research when analyzing other data sources (e.g. interview transcriptions) and provided triangulation between pre-intervention VNOS-D responses, pre-intervention interviews, post-intervention VNOS-D responses, and post-intervention interviews. By using this approach, the independent analysis of each data source was continually compared to previous sources, thus reducing the chance of bias and increasing validity of the analysis.

After coding all VNOS-D data units across all participants, the codes were reviewed and revised to accommodate redundancies with the original coding and to accommodate distinct differences among them. The first author consulted with the VNOS co-raters to assist in this process of code revision. Some codes became more inclusive to contain what was previously identified as distinct ideas. In other words, multiple codes might be collapsed into one when participants expressed the same concept. In other instances, codes were split to accommodate distinct ideas within a related area. Once all codes were created, each was classified as *informed, transitional*, or *naïve* (or a combination of these identifiers) based on how closely the idea of the code aligned with or contradicted the desired understanding of the NOS tenet to which it related. This classification strategy for coding was modified from the analysis used in other NOS research (Lederman et al., 2002).

Pre-intervention interview questionnaire

The pre-intervention interview served as an opportunity to clarify initial perceptions of the participants' understandings of the seven NOS tenets and added validity to the interpretation of their VNOS-D responses. Any ambiguity in the VNOS-D responses was addressed at this time. The interviews were transcribed and color-coded in the same manner as the VNOS-D responses. Because the interview questions were designed in response to the participants' VNOS-D responses, interview data were used to clarify participants' VNOS-D responses and to increase validity in the interpretation of the data.

Development of pre-intervention profiles

A pre-intervention profile was developed for all participants from the data collected (VNOS-D responses, follow-up interviews) prior to the PD. All data was color-coded (as previously described) and assimilated into preexisting codes (identified during VNOS-D analysis) or given new code names if needed. After the data units were identified in the transcription, each was added to the individual participants' profiles to further depict their conceptions of each NOS tenet. These profiles were working documents that included participant-generated data that represented their understanding of the seven NOS tenets. For each NOS tenet, the researchers categorized the participants' conception on a continuum from naïve to informed as described below.

The resulting overall collection of data units (from the pre-intervention VNOS-D responses and interview data units) was then used to evaluate participants' conceptions of each of the seven NOS tenets being studied. Because an individual participant's data regarding a single tenet could include naïve, transitional, and informed codes, their overall conception could not be categorized so simply; their understandings were more complex than this 3-tiered schema. Instead, the collection of all codes found was considered as a set. The participant's overall conception was then placed along a 5-tiered continuum and was categorized as: *informed, transitional/informed, transitional, transitional/naïve,* or *naïve*. Table 3 describes each classification category.

Table 3. Classification categories used in investigation

Classification Assigned for Each NOS Tenet	Description of Code
Informed	*only informed* codes demonstrated an understanding of *all* aspects of the NOS tenet
Transitional/Informed	Included mainly *informed* codes regarding the NOS tenet, but also included at least one *transitional* or *naïve* code
Transitional	Included both *informed* and *naïve* codes, or only *transitional* code
Transitional/Naïve	Included mainly *naïve* codes regarding the NOS tenet, but also included at least one *transitional* or *informed* code; the *naïve* codes were not reconciled during the follow-up interview
Naïve	*only naïve* codes or provided no data regarding the NOS tenet (including during the follow-up interview questions addressing the NOS tenet)

This strategy classified participants' conceptions of each NOS tenet and provided a baseline for their understandings prior to the intervention. It also allowed for consistent ranking across all participants.

Professional development (PD) as intervention

The summer portion of the PD took place over two weeks and included 10 days (Monday through Friday) of instruction that focused on the initial stages of the development of their understanding of NOS. Follow-up monthly academic year meetings would reinforce and further develop their NOS conceptions. The instruction consisted of nine explicit NOS instructional opportunities, including activities and films (Table 2), that ranged from highly contextualized (i.e. creation, evolution, intelligent design debate) to highly decontextualized (i.e. footprint activity). Many of these activities have been used previously in NOS instruction (Flammer, 2002; McComas, 1997; Smith & Scharmann, 2008) while others were created by the first author.

This study employed both decontextualized and contextualized instructional strategies to develop NOS understandings among the participants. The intention of the PD was to first demonstrate each NOS tenet via a decontextualized instructional strategy so as to operationally define the terms and provide a general abstract understanding of the tenet. Later, each NOS tenet would be demonstrated via contextualized instructional methods (e.g. science films depicting the scientific enterprise) to enhance their understandings using concrete examples.

After each NOS activity, the instructor led a class discussion to give the participants an opportunity to discuss how each NOS tenet was exemplified by the experience. The novel approach to NOS instruction used in this study was the incorporation of instructional documentary films that portrayed historical cases of scientific discoveries (CBC, 2004; Dowling, 1997; Mosley, 1994). These full-length documentaries were watched during the course of the PD. After viewing each film, the instructor initiated an explicit/reflective discussion to explore how each of the seven NOS tenets were portrayed (or not portrayed) in the story depicted.

Post-intervention VNOS-D and interview

At the conclusion of the two-week summer PD, the participants were again asked to complete the VNOS-D questionnaire. This was another opportunity for the participants to articulate their understanding of NOS concepts in relation to the VNOS-D questions. As with the pre-intervention questionnaire, some NOS tenets were more easily elucidated than others and, as recommended, a post-intervention interview was conducted via telephone by the lead author at the conclusion of the summer portion of the PD. During the interview, each participant was first asked to convey his/her conception of NOS and then asked to describe how their conceptions had changed over the course of the two-week PD. They were also asked to share their ideas about each of the seven NOS tenets individually. This allowed them another opportunity to overtly explain any other thoughts that they may have left out of previous data sources. At the end of the interview, the participants were asked whether they believed a better understanding of NOS empowered them to make decisions about what should and should not be included in a science curriculum. All interviews were audio-recorded and transcribed for analysis.

Development of post-intervention profiles

The post-intervention profiles were created by integrating the data from the post-VNOS-D and the post-interview into the participant's pre-intervention profile. The data from the post-intervention VNOS-D questionnaire and interviews were unitized and coded using the same methods as the pre-intervention data. As the data units were coded, comparisons were made between the post-intervention units and those from the pre-intervention data sources. For example, in the pre-intervention data, a participant may have only addressed the tentative nature of science by describing how scientific knowledge grows [*naïve* code: *New scientific knowledge will be added*]. In the post-intervention data, she may have referenced how scientific knowledge grows, but also described how, with new technology and new interpretations, previously held scientific claims could be improved and corrected. This post-intervention conception would have been given the *informed* code [*New knowledge grows AND is corrected*]. If a contradiction between the pre and post-intervention data were detected, a new ranking for the participant's conception of the tenet would be assigned to the post-intervention data set. If no contradiction were identified, the pre-intervention ranking for the tenet would remain under the assumption that the prior conceptions had persisted throughout the interventions.

RESULTS

Results by NOS tenet

The primary goal of the study was to determine how inservice science teachers' NOS conceptions changed after engaging in an explicit PD experience that targeted tenets of NOS. Each participant's VNOS-D questionnaire and interview responses were unitized based on NOS tenets and the data units were classified as *informed*, *transitional/informed*, *transitional*, *transitional/naive* or *naïve* based upon their agreement with or deviation from the working description of each tenet put forth in this research. Each participant's data units for each NOS tenet were compiled into seven groups (one per tenet) to create individual participant's profiles. Individual participants' results are presented in Table 4.

Table 4. Individual participants' pre- and post- NOS conceptions

Participant	Tentative		Empirical		Subjective		Creative		Social & Cultural		Observations & Inferences		Theories & Laws	
	Pre	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**
1	I	I	T	TI	TN	TN	N	T	T	T	TI	TI	N	T
2	TI	TI	T	T	I	TI	TN	T	T	T	TI	TI	N	TN
3	TI	I	N	N	N	TN	N	T	N	N	TN	T	N	N
4	TI	TI	T	I	TN	TN	TN	I	T	T	TI	TI	TN	TN
5	T	TI	TN	T	T	TI	TN	T	TN	TN	TI	TI	N	T
6	N	I	T	I	TN	TN	N	T	TI	TI	TI	TI	N	TI
7	TI	T	N	N	N	N	T	T	TN	TN	T	T	N	TN
8	TI	I	N	I	I	I	I	I	I	I	TI	TI	N	T
9	TN	TI	T	TI	N	N	I	I	I	I	T	T	N	T
10	TI	TI	I	I	TN	TN	N	T	T	T	T	T	N	N
11	I	I	TI	I	T	T	T	TI	N	TI	T	TI	N	N

I = Informed
TI = Transitional Informed
T = Transitional
TN = Transitional Naïve
N = Naïve

Once the individual participant's NOS tenet profiles were created, a composite class profile for each tenet was developed. The composite class profile for each tenet was also displayed along the continuum as: *informed*, *transitional/informed*, *transitional*, *transitional/naïve*, or *naïve.* This class profile for each tenet demonstrated how the intervention was effective in changing the participants' collective conceptions of NOS. Pre- and post-intervention profile results for the 11 participants across each of the seven NOS tenets are found in Figures 1-7. The asterisk aligned to the title of the tenet indicates that there was overall

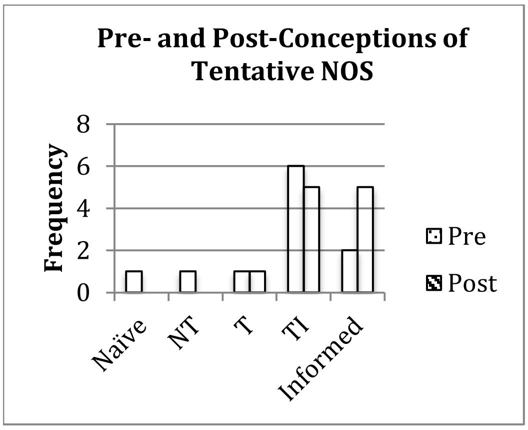

Figure 1. Pre-post intervention conceptions of tentative

improvement in the participants' understanding of that tenet.

Tentative nature of science*. Most of the participants began the PD with well-developed understandings of the tentative nature of science.

However, some did not convey an understanding that scientific knowledge is revised as new evidence is discovered and new technology is developed. Rather, they only conveyed that more knowledge would be gained, a common misconception. Other participants' had the misconception that scientific knowledge is relatively permanent and not subject to change. One participant demonstrated both of these misconceptions in her statement:

> …what we already know is going to be there from now on…but there's gonna be some new knowledge with our capabilities to go farther like space, for example…they're talking on t.v. about living on Mars and we're gonna learn new stuff about Mars that we don't know now. (Participant 5)

At the culmination of the PD, all participants demonstrated an understanding of this aspect of the tentativeness of science and most were classified as transitional/informed or informed for this NOS tenet. One participant, however, maintained the misconception that after further exploring a scientific phenomenon, the tentativeness is lost and ideas have been proven; this participant was classified as naïve at the conclusion of the PD. When asked to explain what she meant by "proven", she replied: *"…prove using experimentations and evaluating. Doing a lot of experiments over and over again…Everything is tentative until you explore it further"* (Participant 7).

Empirical nature of science*. Participants' conceptions of the empirical nature of science varied from naive to informed both before and after the PD.

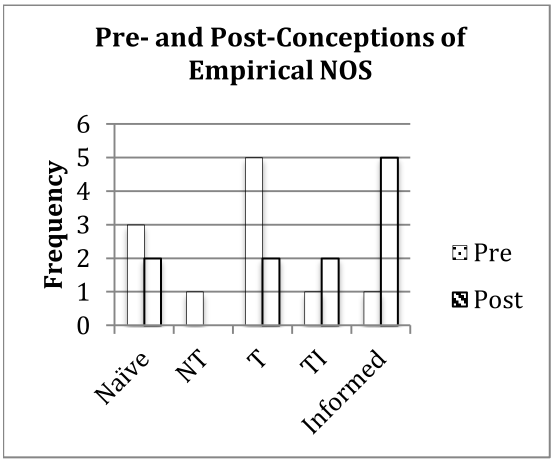

Figure 2. Pre-post intervention conceptions of empirical NOS

However, there was improvement in understanding among some of the teachers. Some teachers conveyed the misconception that no empirical evidence was needed to ground a scientific claim. This example was coded naïve.

> …I do believe that people can move forward with science on a hunch, so it doesn't necessarily have to be grounded in empirical evidence…I know there's some science stuff out there that the evidence isn't there, they still just believe that it should be and they're still working towards that. (Participant 3)

Many of the participants held the misconception that all scientific claims were directly supported by observational evidence and failed to recognize that scientists make inferences upon their empirical evidence to come to conclusions. The following example, which was coded transitional, demonstrates this notion: *"…faith* *is something you believe, science is something that you can physically test and physically experiment on. If it's not there, then it's not science"* (Participant 1).

At the conclusion of the PD, some of these teachers' understandings of the empirical nature of science had improved, but some naïve conceptions persisted. For example, when responding to the VNOS-D question regarding confidence in the weather forecast made by meteorologists, Participant 7 stated: "*Weather people can only be as certain as the satellites in space are to show them the weather patterns."*

Subjective nature of science. Participants' conceptions of the subjective nature of science ranged from naïve to informed both before and after the PD.

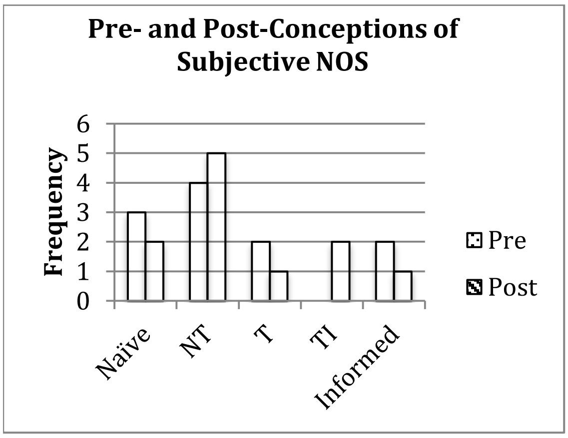

Figure 3. Pre-post intervention conceptions of subjectivity of NOS

Very little improvement in this tenet was detected. Generally, the participants failed to note that prior theoretical commitments influence how scientists interpret data and draw conclusions. Rather, many conveyed the idea that subjectivity was simply the possession of various opinions failing to identify the reason different opinions might exist. Two examples demonstrate the general concensus regarding this tenet; *"…everybody has their own opinion, right?"* (Participant 7) and *"I think it's background… I think it's personal experiences"* (Participant 9).

The overall understanding of the subjective NOS among the participants did not change over the course of the PD.

Creative nature of science*. Participants' conceptions of the creative nature of science ranged from naïve to informed at the outset of the PD. Their conceptions ranged from transitional/naïve to informed at the conclusion.

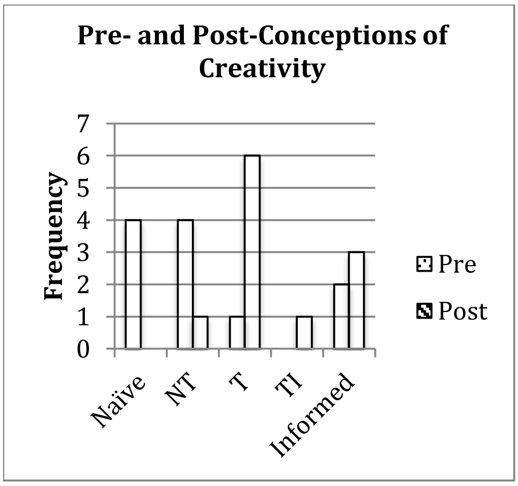

Figure 4. Pre-post intervention conceptions of creativity NOS

The most common conception of the creative nature of science held by the participants was that scientists use creativity only when setting up experiments;

> A scientist must stay detached from the outcome of an investigation, but sometimes creativity and imagination help in designing how to accurately investigate something. Part of planning maybe, but a scientist must remain detached from the results in order to fully understand the item being investigated. (Participant 11)

By the end of the PD, however, this same participant demonstrated the much more informed view of this NOS tenet;

> …and then you read science fiction and fantasy and now some of that stuff is coming true. Years ago, back in the 60's, they talked about building a little submarine with people in it and injecting it into a person's blood and sending it on its way to do the surgery or whatever. And now, we can put in little targets for cancer, piggy-back on viruses and we can target it! How much different is that? (Participant 11)

By the end of the PD, most participants described creativity as being important for all aspects of the scientific process, but only some were able to describe the role it played in inventing explanations for phenomena.

Social and cultural nature of science. At the outset of the PD, participants' conceptions ranged from naïve to informed and very little improvement was detected as a result of the PD.

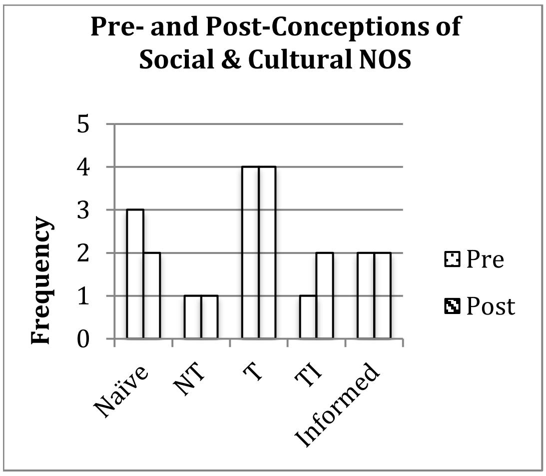

Figure 5. Pre-post intervention conceptions of social & cultural NOS

Some participants began the PD with informed views of how social and cultural values influence science;

> People are born with problems who are dying from diseases. We're looking for ways there because, again, we put value on human life. So maybe that gets more research than 'what planet is outside our universe?' There is funding for that, but I think we put our money where our heart is as a society. (Participant 8)

Others possessed naïve views that persisted throughout the PD. When asked how social and cultural values influenced the direction of scientific research, one participant stated;

> Actually, I don't think so. It might influence the direction we go at the time, but I really think science is so universal…I don't think it would have any effect on how we would do [science] or the outcome of research…I think science, across the board, is very, speaks the same

language in every country, in every language. So, I'd have to say I disagree. (Participant 4)

Observations and inferences of nature of science. Only one participant began the PD with a naïve/transitional conception regarding the difference between observations and inferences.

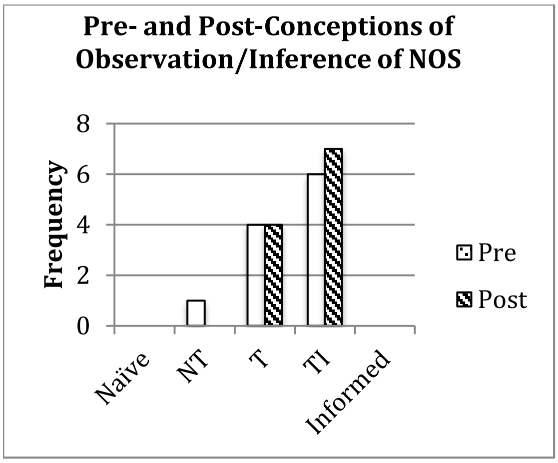

Figure 6. Pre-post intervention conceptions of observations & inferences of NOS

When asked how scientists infer the color and texture of dinosaur skin found on replicas in museums, one participant indicated that either they had fossilized evidence or they were purely guessing; *"The only whay they would know color… they would totally have to guess on that. But texture, there have been some…fossilized skin surfaces…that give them some idea, but again, they're going to have to grasp at that"* (Participant 3).

Others conveyed a much more informed understanding of how scientists use available evidence to make inferences about that which they have no direct observations. In response to the same question, another participant replied: *"Scientists can probably get close to what the dinosaurs looked like, again, by looking at what we find in the remains and common characteristics of present day living organisms"* (Participant 5).

Theories and laws nature of science*. All participants began the PD with either naïve or transitional/naïve conceptions regarding the difference between theories and laws.

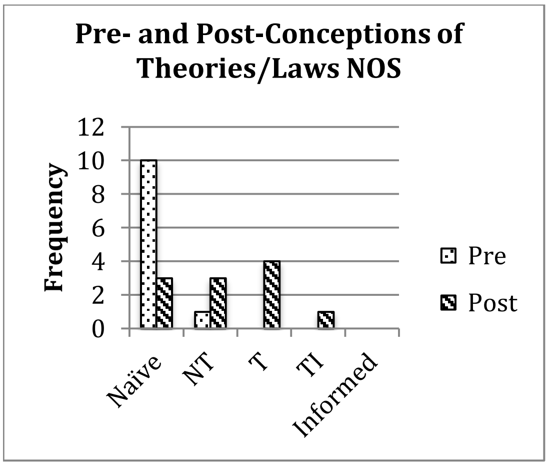

Figure 7. Pre-post intervention conceptions of theories & laws NOS

Most held the misconception that theories were tentative while laws were unchanging. In reference to the laws of heredity in genetics (as asked in the VNOS-D questionnaire), one participant stated;

> …if you cross this with this, this is what you're gonna get because that's the way it is and if something else happens then you have a problem. If anything ever does show up to be the contrary to the evidence and holds true, then we have to change the law, or say it's not a law, it's a theory. But a law is undisputable. (Participant 3)

Most also believed that there was a hierarchical relationship between hypotheses, theories, and laws and that theories could eventually become laws with enough confirming evidence;

> Well, you start with a hypothesis. Some question in mind…then you do experiments on it and you get enough people looking at it and then you go, 'okay, well we've got a theory…And then it happens over and over again, to me years, it's not gonna change…Then you go, okay, well then, it's a law. (Participant 1)

While no participant achieved an informed conception of theories and laws, most began to convey that they understood the difference between each construct and stated the difference qualitatively (e.g. hypotheses, theories, and laws are not hierarchically related to one another);

> …so now what I'm still trying to get in my head is that the laws are kind of like a generality or a pattern of things that happen, but theories try to explain why they happen. I was reading that article [McComas, 1997] about the hypothesis, the way we use them in school, they are really predictions…So maybe I might need a little more help on that one. But the big thing is that laws and theories are totally different things. (Participant 6)

Influence of films on NOS gains

The post-assessment VNOS-D and post-interview questions in no way referred to any of the PD interventions as these questions are standardized and validated. The VNOS-D questionnaire examines NOS conceptions in context of weather forecasting, inferring the physical appearances of dinosaurs as well as the cause of their extinction, and general questions about scientific methodology. The post-interview questions first probed the participants' general conceptions of science and NOS, and inquired about how these may have changed over the course of the PD, and then addressed each NOS tenet explicitly and asked the participants to explain each.

The post-PD data revealed that the films influenced participants' NOS conceptions and that they used examples from the films to explain many of the NOS tenets. This was observed in both their post-VNOS-D questionnaire and post-interview responses. Six of the eleven participants directly referred to *The Origin of AIDS* to give examples of how they conceived the various NOS tenets. None of the participants referred to *Ulcer Wars* or *Footpath Murders: DNA Profiling's Landmark Case*. Participants used *The Origin of AIDS* to explain their understanding of five of the seven NOS tenets examined in this study: tentative, empirical, subjective, creative, and social/cultural. It is important to note that during the post-interview, the first author did not elicit probing questions regarding the films, but instead, the participants voluntarily referred to the documentaries in their responses. For example, when asked to explain if scientific knowledge might change in the future (in response to a VNOS-D question about the tentative nature of science), Participant #9 replied,

> …yes I do feel that knowledge may change in the future. One example is based on the current accepted idea of how AIDS originated in humans

> (the cut hunter hypothesis). Yet there is another idea that is beginning to surface based on the polio vaccine given to millions in Africa and how this may be a better explanation for the origin of AIDS.

Participant #2 referred to how the film demonstrated the necessity of empirical evidence to support scientific claims. She referenced how this would be a determining factor in what she would teach in her classroom;

> I'm not going to go teach people that AIDS could… that AIDS has come from Polio. You know there's philosophies out there, there's thoughts out there, there's hypotheses, there's research that's being done and there's a lot of interesting data. But what do we know about AIDS is…and go through the empirical and canonical knowledge…

In the post-PD interview, Participant #11 pointed out the subjective NOS by referencing how the scientists and reporters in the film had differing theoretical commitments to the accepted scientific propositions about AIDS.

> The reporter saw things a certain way and the scientists saw things a different way. It's not that either one was wrong, but they came from it from a different perspective and that's part of what a scientist has to be careful of is making sure they are in a detached way. They're looking at things in a detached way and not bringing in their own subjectivity…

Three participants noted how the film portrayed the creative NOS. In response to the VNOS-D question regarding creativity, Participant #1 referred to the *Origin of AIDS* in saying, *"Scientists use creativity to explain occurrences that are not explained well or have questions about the explanations – HIV stemming from Polio*." Participant #7 felt the scientists in the film were *"…very creative in what they were using to fight the Polio.*"

Participant #9 leaned heavily on *The Origin of AIDS* to describe creativity among both scientists and non-scientists.

> Tom Curtis and Ed Hooper [journalists] both observed the data from the polio vaccine in Africa and the fact that they began to wonder if there was a connection between the administering of the vaccine and the original outbreak of AIDS was highly creative. Also, thinking of how to go about researching and putting together this information was creative, especially with Bill Hamilton [scientist] and his idea to study the blood and feces of the chimpanzees in that area. I feel that the majority of the creativity comes in the observations and creation of the experiment/research.

With regards to the social and cultural NOS, Participant #7 referenced the claim from the Origin of AIDS that in the race to discover the cure for Polio, scientists discounted the rights of test subjects who were from marginalized populations. *"So it brings you back again to they didn't think much of the African people. 'Oh just use them as guinea pigs and if they die, they die.' Kind of like when they brought African people to the United States*."

Participant #4 referred to how reading an article about developing countries triggered memories of *The Origin of AIDS* and reminded her of the social and cultural differences in Africa allowed science to progress differently than in the U.S.:

> It [the article] talked about as much as 66% of the population is living in conditions I couldn't even begin to understand and it brought back looking at the videos. When we saw that video, in that hospital, and the primitive conditions, and that's in my lifetime… And the way they're doing things, and even their culture makes them go at it a certain way, that I hadn't considered because it's something I don't even know.

Clearly, seeing the reality of life in a third world country allowed this participant to think about the science behind vaccinations in a very different way.

Films were not referenced to describe participants' conceptions of the roles of observations and inferences or the distinction between theories and laws. Five of the participants made no reference to the films in either their post-VNOS-D or in their post-interviews.

DISCUSSION

Despite being considered a critical aspect of scientific literacy (NGSS Lead States, 2013), many teachers and students fail to develop informed conceptions of NOS or recognize its importance in the development of scientific literacy (Sahin & Köksal, 2010). Much research has been done regarding the best practices to educate students about NOS and many studies have called for the implementation of conceptual change interventions (Abd-El-Khalick & Akerson, 2004, 2006; Ozgelun, 2012; Schwartz, Lederman, & Crawford, 2004) to assist in this understanding. To this end, this study implemented the use of documentary films in conjunction with decontextualized NOS activities to encourage conceptual change regarding NOS aspects among inservice science teachers. Based upon the results from this study, it appears that combining contextualized and decontextualized NOS activities in a PD experience can affect change among the teachers' views of NOS. In particular, it appears that teaching NOS tenets through viewing contextualizing-films and subsequent discussions about those films provided participants the opportunity to support their developing conceptions. The overall gains across participants' NOS understandings were observed in four of the seven NOS tenets.

Of the participants with less than *informed* views of the tentative NOS, 55% demonstrated improved understandings by the end of the PD. In addition, 70% demonstrated improved understandings of the empirical NOS, 89% demonstrated improved understandings of the creative NOS, and 72% demonstrated improved understandings of the distinction between theories and laws. Although each activity within the PD experience had direct, explicit instruction of all tenets of NOS, it appears that these four tenets showed the most change in accordance to the pre-post VNOS-D questionnaire and the follow-up interviews.

By contrast to these changes, less positive growth was detected when compared with the other three tenets (e.g. subjective, social and cultural, and the distinction between observation and inferences) being analyzed in this research. Among participants who began with less than *informed* views of the subjective tenet of NOS, 20% demonstrated improvement in their understanding. In relation to the socially and culturally embedded tenet of NOS, 11% of those beginning with less than *informed* views appeared to have developed an improved understanding. Finally, those participants beginning with less than *informed* understanding of the distinction between observations and inferences, 18% demonstrated improvement.

It should be noted that while improvement *toward* informed views of NOS was detected among several participants across multiple tenets of NOS, the improvements observed did not consistently translate into *informed* views. At the conclusion of the PD, participants achieving an *informed* view of NOS were observed in only three tenets of NOS being investigated: creativity, tentative, and empirical. A question arises as to why this phenomena was observed, e.g. what activities occurred during the PD promoted change toward *informed* views of NOS in three tenets instead of all seven tenets? What can account for this trend?

The activities addressed during the PD experience (see Table 2), were drawn from an array of classic NOS activities, e.g. check activity (Crue, 1932) and the McComas (1997) article, *The 15 Myths of Science*, taught in many NOS classes and PD workshops. Other activities were created by the PD providers (e.g. Proof Wall and Creation/Evolution/ID Debate). Each of these classic and novel NOS activities targeted one or more of the seven NOS tenets being researched and provided the common experience among the teacher participants to participate in a discussion of them in a decontextualized fashion. Research has indicated that incorporating instruction that has a mix of the decontextualized and contextualized approaches appears to be an effective strategy for improving NOS understandings (Abd-El-Khalick, 2001; Brickhouse et al., 2000; Clough, 2006) and this study aligns with this prior research. However, this study adds a new twist into the array of classic NOS activities as it introduced documentary films that highly contextualize NOS.

What separated this PD experience from other NOS PD opportunities is the unique feature of viewing documentary films from the perspective of NOS and the reflective discussion that followed the viewing of each film. The documentaries presented in the PD were: (1) *Footpath Murders: DNA Profiling's Landmark Case* (Dowling, 1997), (2) *Ulcer Wars* (Mosley, 1994), and (3) *The Origin of AIDS* (CBC, 2004). These documentaries, shown in in their entirety, gave the participants a visual description of what NOS would look like in an authentic scientific setting and allowed them to think about each NOS aspect in a contextualized way.

Egan (1997) contends that the role of storytelling provides vivid images that create an "affective charge" (p.62) that shapes the learners' emotional commitment to the content, in this case, NOS. Research has suggested that modern day storytelling in the use of films can be an effective vehicle for teaching content, including science (Dubeck, Moshier, & Boss, 1988; Dubeck, Moshier, Bruce, & Boss, 1993; Koehler et al., 2013). In addition, it was suggested that the effects of television programs on students' understanding of NOS indicated that students were more likely to accept scientific conclusions as absolute (not tentative) when presented in documentary format (Dhingra, 2003).

The post-intervention data indicates that the use of films may have been influential in the positive gains among the participants with regards to their NOS conceptions. While all three films strived to contextualize science with emotionally stirring imagery, not all were equally successful in their attempts. For example, *Ulcer Wars* is a 50-minute documentary about the discovery of *Helicobacter pylori* as the cause of stomach ulcers; among the three films shown, it is arguably the most textbook in its delivery. It offers some narrative into the thoughts of the scientist conducting the research and the challenges he faced by the scientific community in his efforts, but there is scant drama to the film.

Footpath Murders: DNA Profiling's Landmark Case is a 24-minute documentary of the discovery of DNA fingerprinting technology and its subsequent use to convict a criminal of murder. It offers more drama with some recreated murder scenes, authentic video footage of witness interrogation, and interviews with key both scientists and law enforcement agents who worked to solve the double murder investigation. However, the film is quite dated and the recreated scenes in no way compare to what is seen on crime scene shows every night on popular television networks (e.g. NCIS, CSI).

The Origin of AIDS, however, is qualitatively different. This film was relatively new (less than five years since production), is a full length, 91-minute documentary. It provides much more drama than the other two films and is filled with graphic images of vivisection of chimpanzees and other primates, multiple interviews with scientists from around the globe promoting and contesting a proposed alternative explanation of HIVs emergence (via oral polio vaccines), and has an emotion-inducing background classical music score. *Origin of AIDS* was created for the purpose of engaging the audience and convincing the viewers to consider an alternative explanation of AIDS origins as opposed to the accepted scientific explanation (the Cut Hunter explanation).

While all three films were used to contextualize the scientific process (Clough, 2006) and targeted all seven NOS tenets, participants only referred to *Origin of AIDS* to justify their answers regarding NOS. We feel it is the nature of the *Origin of AIDS* in contrast to the other two documentaries that explains this fact. While all three did a good job of demonstrating scientific methodology and conveying scientific knowledge, only the *Origin of AIDS* was designed to be an emotion-triggering, dramatic story. This quality provided the vivid imagery as Egan (1997) contends that is necessary to influence learners. As such, this made the *Origin of AIDS* the most effective film to transform the participants' views of NOS.

The results revealed that six of the 11 participants referenced *The Origin of Aids* to explain their conceptions of one or more of the NOS tenets targeted by this PD intervention. One participant explained how the *Origin of Aids* portrayed the tentative NOS by exposing the uncertainty of medical science as the film portrayed novel treatments for the disease as well as the negative outcomes of some individuals that were depicted in the film. Another participant used this film to describe the empirical NOS as the criteria that she would use to rule out presenting the APV theory of HIV. One participant described how the strong theoretical commitment exhibited by the research scientists in the film demonstrated the subjective NOS well. Two participants were reminded of the social and cultural NOS by the film as it depicted how the scientific endeavor portrayed in the African Congo so greatly contrasted to that in developed, Western countries. Three participants provided examples from the film to describe their conception of the creative NOS by describing how scientists use creativity in three distinct ways: to develop new explanations of natural phenomena, to develop new technology (medical), and to identify unexpected consequences of scientific progress.

The fact that these six participants all referred to this one film without any prompt or solicitation from the researcher suggests that contextualizing NOS in dramatic, story-telling films, can prove effective in impacting learners metacognition about NOS. Knowing this adds to the growing body of knowledge that inform PD providers about the benefit of contextualizing NOS instruction using documentary films.

IMPLICATIONS

This research promotes the notion of contextualized NOS instruction utilizing films. The short nature of the PD does not inform the long-term effectiveness of this teaching strategy, but does provide evidence on how the use of films can affect change in inservice teachers' conceptions of core NOS tenets. This early change in understanding NOS sets the stage for follow-up PD to reinforce and further develop more informed NOS understanding (Akerson & Morrison, 2006). Further research is currently investigating the effectiveness of other types of films, including Hollywood box office hits, for teaching NOS, scientific inquiry, and the dispositions of scientists (Koehler et al., 2013). Specifically, contextualized, scenario-based, activities are currently being employed to determine how this form of NOS instruction can improve preservice teachers' argumentation skills regarding scientific issues. Early research into the use of mainstream films for NOS instruction is promising; further research can determine if such a strategy can have long-term effectiveness in promoting NOS understanding for the students of the 21st century.

ACKNOWLEDGMENT

The professional development described in this paper was funded through the Texas Higher Education Coordinating Board and the Teacher Quality Enhancement grants program.

REFERENCES

Abd-El-Khalick, F. (2001). Embedding nature of science instruction in preservice elementary science courses: Abandoning scientism, but…, *Journal of Science Teacher Education, 12*(3), 215–233. DOI: 10.1023/A:1016720417219

Abd-El-Khalick, F., & Akerson, V.L. (2004). Learning as conceptual change: Factors mediating the development of preservice elementary teachers' views of nature of science. *Science Education, 88*(5), 785-810. DOI: 10.1002/sce.10143

Abd-El-Khalick, F., & Akerson, V.L. (2006). On the role and use of "theory" in science education research: A response to Johnston, Southerland, and Sowell. *Science Education, 91*(1), 187-194. DOI 10.1002/sce.20189

Abd-El-Khalick, F., & Lederman, N. G. (2000). Improving science teachers' conceptions of nature of science: A critical review of the literature. *International Journal of Science Education, 22*(7), 665-701. DOI: DOI:10.1080/09500690050044044

Akerson, V. L., & Hanuscin, D. L. (2007). Teaching nature of science through inquiry: Results of a 3-year professional development program. *Journal of Research in Science Teaching, 44*(5), 653-680. DOI: 10.1002/tea.20159

Akerson, V. L., & Morrison, J. A. (2006). One course is not enough: Preservice elementary teachers' retention of improved views of nature of science. *Journal of Research in Science Teaching, 43*(2), 194-213. DOI: 10.1002/tea.20099

Akindehin, F. (1988). Effect of an instructional package on preservice science teachers' understanding of the nature of science and acquisition of science-related attitudes. *Science Education, 72*(1), 73-82. DOI: 10.1002/sce.3730720107

Alters, B. J. (1997). Whose nature of science? *Journal of Research in Science Teaching, 34*(1), 39-55. DOI: 10.1002/(SICI)1098-2736(199701)34:1<39::AID-TEA4>3.0.CO;2-P

American Association for the Advancement of Science. (1993). *Benchmarks for Science Literacy*. Oxford Press: New York.

Anderson, K. E. (1950). The teachers of science in a representative sampling of Minnesota schools. *Science Education, 34*(1), 57-66. DOI: 10.1002/sce.3730340114

Barufaldi, J. P., Bethel, L. J., & Lamb, W. G. (1977). The effect of a science methods course on the philosophical view of science among elementary education majors. *Journal of Research in Science Teaching, 14*(4), 289-297. DOI: 10.1002/tea.3660140404

Behnke, F. L. (1950). Reactions of scientists and science teachers to statements bearing on certain aspects of science and science teaching. *School Science and Mathematics, 61*(3), 193-207. DOI: 10.1111/j.1949-8594.1961.tb08537.x

Bell, R. L., Blair, L. M., Crawford, B. A., & Lederman, N. G. (2003). Just do it? Impact of a science apprenticeship program on high school students' understanding of the nature of science and scientific inquiry. *Journal of Research in Science Teaching, 40*(5), 487-509. DOI: v40 n5 p487-509

Bell, R. L., Matkins, J. J., & Gansneder, B. M. (2011). Impacts of contextual and explicit instruction on preservice elementary teachers' understandings of the nature of science. *Journal of Research in Science Teaching, 48*(4), 414-436. DOI: 10.1002/tea.20402

Berkman, M.B., Pacheco, J.S., & Plutzer, E. (2008). Evolution and creationism in America's classrooms: A national portrait. *PLoS Biology, 6*(5), 920-924. DOI: 10.1371/journal.pbio.0060124

Billeh, V. Y., & Hasan, O. E. (1975). Factors influencing teachers' gain in understanding of nature of science. *Journal of Research in Science Teaching, 12*(3), 209-219. DOI: 10.1002/tea.3660120303

Bloom, M.A. & Weinburgh, M.H. (2007). Why all middle school teachers should know the nature of science. *Association for Childhood Education International – Focus on Middle School, 20*(3), 4-5, 8.

Bloom, M.A., Sawey, A.T., Holden, M.E., & Weinburgh, M.H. (2009). To what degree can explicit classroom interventions change pre-service elementary teachers' conceptions of nature of science? *Council for Elementary Science International – Science, 40*(2), 27-39.

Brickhouse, N. W., Dagher, Z. R., Letts, W. J., & Shipman, H. L. (2000). Diversity of students' views about evidence, theory, and the interface between science and religion in an astronomy course. *Journal of Research in Science Teaching, 37*(4), 340–362. DOI: 10.1002/(SICI)1098-2736(200004)37:4<340::AID-TEA4>3.0.CO;2-D

Canadian Broadcasting Corporation (CBC). (Producer), Chappell, P. (Director), & Peix, C. P. (Director). (2004). *The Origin of AIDS [originally Les origins du SIDA]* [Motion Picture]. Canada: Galafilm.

Carey, R. L., & Strauss, N. G. (1968). An analysis of the understanding of the nature of science by prospective secondary science teachers. *Science Education, 52*(4), 358-363. DOI: 10.1002/sce.3730520410

Clough, M. P. (2006). Learners' responses to the demands of conceptual change: Considerations for effective nature of science instruction. *Science & Education, 15*, 463-494. DOI:10.1007/s11191-005-4846-7

Crue, W. (1932, February). Ordeal by cheque. *Vanity Fair*.

Dhingra, K. (2003). Thinking about television science: How students understand the nature of science from different program genres. *Journal of Research in Science Teaching, 37*(2), 234-256. DOI: 10.1002/tea.10074

Dowling, P.A. (Producer & Director). (1997). *Footpath Murders: DNA Profiling's Landmark Case*. [Motion Picture]. USA: Films for the Humanities.

Driver, R., Leach, J., Millar, R., & Scott, P. (1996). *Young People's Images of Science*. Buckingham, U.K.: Open University Press.

Dubeck, L. W., Moshier, S. E., & Boss, J. E. (1988). *Science in Cinema: Teaching Science Fact through Science Fiction Films.* New York, NY: Teachers College Press.

Dubeck, L. W., Moshier, S. E., Bruce, M. H., & Boss, J. E. (1993). Finding the facts in science fiction films. *The Science Teacher, 60*(4), 46-48

Egan, K. (1997). *The Educated Mind*. Chicago, Illinois: University of Chicago Press.

Flammer, L. (2002). *How's your horoscope?* Retrieved from http://www.indiana.edu/~ensiweb/lessons/hor.les.html

Gruber, H. E. (1963). Science as doctrine or thought? A critical study of nine academic year institutes. *Journal of Research in Science Teaching, 1*(2), 124-128. DOI: 10.1002/tea.3660010207

Khishfe, R., & Lederman, N. (2006). Teaching nature of science within a controversial topic: Integrated versus nonintegrated. *Journal of Research in Science Teaching, 43*(4), 395–418. DOI: 10.1002/tea.20137

Khishfe, R., & Lederman, N. (2007). Relationship between instructional context and views of nature of science. *International Journal of Science Education, 29*(8), 939–961. DOI: 10.1080/09500690601110947

Klopfer, L. E., & Cooley, W. W. (1963). The history of science cases for high schools in the development of student understanding of science and scientists. *Journal of Research in Science Teaching, 1*(1), 33-47. DOI: 10.1002/tea.3660010112

Koehler, C.K., Bloom, M.A., & Binns, I.C. (2013). Lights, camera, action! Developing a methodology to document mainsteam films' portrayal of nature of science and scientific inquiry. *The Electronic Journal of Science Education, 17*(2).

Lavach, J. F. (1969). Organization and evaluation of an inservice program in the history of science. *Journal of Research in Science Teaching, 6*(2), 166-170. DOI: 10.1002/tea.3660060211

Lederman, J. S., & Khishfe, R. (2002). *Views of nature of science, Form D*. Unpublished paper. Illinois Institute of Technology, Chicago, IL.

Lederman, N. G. (2007). Nature of science: Past, present, and future. In S. K. Abell & N. G. Lederman (Eds.), *Handbook of Research on Science Education* (pp. 831-880). Mahwah, NJ: Laurence Erlbaum Associates, Inc.

Lederman, N. G., Abd-El-Khalick, F., Bell, R. L., & Schwartz, R. S. (2002). Views of nature of science questionnaire: Toward valid and meaningful assessment of learner's conceptions of nature of science. *Journal of Research in Science Teaching, 39*(6), 497-521. DOI: 10.1002/tea.10034

Lederman, N. G., & Lederman, J. S. (2014). Research on teaching and learning of nature of science. In N. G. Lederman & S. K. Abell (Eds.), *Handbook of Research on Science Education* (Vol. 2, pp. 600-620). New York: Routledge.

Matkins, J. J., & Bell, R. L. (2007). Awakening the scientist inside: Global climate change and the nature of science in an elementary science methods course. *Journal of Science Teacher Education, 18*, 137–163. DOI: 10.1007/s10972-006-9033-4

McComas, W. (1997). 15 myths of science. *Skeptic*, 5(2), 88-96.

Miller, P. E. (1963). A comparison of the abilities of secondary teachers and students of biology to understand science. *Iowa Academy of Science, 70*, 510-513,

Mosley, M. (Producer), & Bennett, J. (Editor). (1994). *Ulcer Wars* [Motion Picture]. United Kingdom: BBC TV.

National Research Council. (1996). *National Science Education Standards*. Washington, D.C.: National Academy Press.

National Research Council. (2012). *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*. Washington, D.C.: National Academies Press.

National Science Teachers Association. (1982). *Science-technology-society: Science education for the 1980's.* (An NSTA position statement). Washington, DC: Author.

NGSS Lead States. (2013). *Next Generation Science Standards: For States, by States*. Washington, DC: The National Academies Press.

Olson, J. K., & Clough, M. P. (2001, November). *Secondary science teachers' implementation practices following a course emphasizing contextualized and decontextualized nature of science instruction*. Paper presented at the 6th International History, Philosophy, and Science Teaching Conference, Denver, CO.

Ozgelen, S. (2012). Exploring the relationships among epistemological beliefs, metacognitive awareness and nature of science. *International Journal of Environmental & Science Education, 7*(3), 409-431.

Ozgelen, S., Hanuscin, D. L., & Yilmaz-Tuzun, O. (2013). Preservice elementary science teachers' connections among aspects of NOS: Toward a consistent, overarching framework. *Journal of Science Teacher Education 24*, 907-927. DOI: 10.1007/s10972-012-9274-3

Patton, M.Q. (2002). *Qualitative Research and Evaluation Methods* (3rd ed.). Thousand Oaks, CA: Sage Publications.

Riley, J. P., II. (1979). The influence of hands-on science process training on preservice teachers' acquisition of process skills and attitude toward science and science teaching. *Journal of Research in Science Teaching, 16*(5), 373-384. DOI: 10.1002/tea.3660160502

Ryder, J., Leach, J., & Driver, R. (1999). Undergraduate science students' images of science. *Journal of Research in Science Teaching 36*(2), 201–219. DOI: 10.1002/(SICI)1098-2736(199902)36:2<201::AID-TEA6>3.0.CO;2-H

Sahin, C.T. & Koksal, M.S. (2010). How are the perceptions of high school students and teachers on NOS as a knowledge type presented in schools in terms of "importance" and "interest?" *International Journal of Environmental and Science Education, 5*(1), 105-126.

Scharmann, L. C., & Harris, W. M., Jr. (1992). Teaching evolution: Understanding and applying the nature of science. *Journal of Research in Science Teaching, 29*(4), 375-388. DOI: 10.1002/tea.3660290406

Schwartz, R., Lederman, N.G., & Crawford, B. (2004). Developing views of nature of science in an authentic context: An explicit approach to bridging the gap between nature of science and scientific inquiry. *Science Education, 88*(4), 610-645. DOI: 10.1002/sce.10128

Smith, M. U., Lederman, N. G., Bell, R. L., McComas, W. F., & Clough, M. P. (1997). How great is the disagreement about the nature of science: A response to Alters. *Journal of Research in Science Teaching, 34*(10), 1101-1103. DOI: 10.1002/(SICI)1098-2736(199712)34:10<1101::AID-TEA8>3.0.CO;2-V

Smith, M. U., & Scharmann, L. C. (1999). Defining versus describing the nature of science: A pragmatic analysis for classroom teachers and science educators. *Science Education, 83*, 493-509.

Smith, M. U., & Scharmann, L. C. (2008). A Multi-year program developing an explicit reflective pedagogy for teaching preservice teachers the nature of science by ostention. *Science & Education, 17*(2-3), 219-248. DOI: 10.1007/s11191-006-9009-y

Trembath, R. J. (1972). The structure of science. *The Australian Science Teachers Journal, 18*(2), 59-63.

Welch, W. W., & Walberg, H. J. (1967-1968). An evaluation of summer institute programs for physics teachers. *Journal of Research in Science Teaching, 5*(2), 105-109. DOI: 10.1002/tea.3660050203

◈◇◈