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A Biology Teacher's Notions and Instruction of Nature of Science

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Abstract. This case study investigated a biology teacher's notions of nature of science (NOS), how and if he used nature of science aspects in his teaching and what he thinks impacts his teaching of nature of science in depth. The context of the study includes a big high school in a rural school district in the USA. The participant of the study is a male biology teacher with fifteen years of teaching experience. Data sources of the study include three interviews with the teacher, fieldnotes taken during the classroom observations, and handouts given to the classroom. Qualitative data analysis from the interviews, fieldnotes and handouts were utilized to provide triangulation of the data sources. Findings show that the teacher had adequate understandings in some aspects of NOS such as tentativeness of scientific knowledge, empirical aspect of scientific knowledge, and role of creativity and imagination in the scientific knowledge. Also, he had some partly-adequate understandings in other aspects such as subjectivity, the difference between scientific theory and law, social-cultural aspect, and the difference between observation and inference. According to the data, the teacher's conceptions of nature of science revealed from the interviews and his instruction and handout analysis do not match all together. Results were discussed in the context of biology teaching and teacher education.

Keywords. Nature of science, science teacher education, biology education, qualitative case study.

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Nature of science (NOS) is viewed as an important goal for scientific literacy for science classrooms (e.g., Allchin, Andersen, & Nielsen, 2014; Lederman 2007). It is usually suggested, "the nature of science is an important instructional objective that should be considered during the development, implementation of every instructional unit, lesson, and activity" (Lederman, 1999. p.927). The emphasis on NOS has been a continuous central point in various different countries' educational programs (Olson, 2018). For example, American educational reform documents, the Benchmarks for Science Literacy (American Association for the Advancement of Science (AAAS), 1993) and National Science Education Standards (National Research Council (NRC), 1996), emphasized the nature of science (NOS) for scientific literacy in the USA. Recently, Next Generation Science Standards (NGSS, Achieve Lead States, 2013) and Science Framework (NRC, 2012) describe the importance of science practices, disciplinary core ideas, and crosscutting concepts. Nature of Science (NOS) is not explicitly mentioned as a goal in the NGSS and the framework, its correspondence in these documents are science practices and crosscutting concepts as it is detailed in the Appendix H of NGSS (NGSS, Achieve Lead States, 2013). The connections of science practices and crosscutting concepts to NOS and its aspects were provided in each of the standards. Thus, this emphasis on the connections of NOS to the science practices and crosscutting concepts in the NGSS still puts importance to the studies about NOS. Understanding of nature of science can deepen students' engagement in the practices of science and crosscutting concepts as it provides a "sense of contextual understanding with regard to scientific knowledge, how it is acquired and applied, [and] how science is connected through a series of concepts that help further our understanding of the world around us" (NGSS Lead States 2013; Appendix A, p. 1). Thus, it is important for educators to understand NOS to be able to implement science practices and crosscutting concepts to help students' engagement with these practices.

In the literature, the nature of science has different definitions, but usually "refers to the epistemology of science, science as a way of knowing, or the values and beliefs inherent to the development of scientific knowledge" (Abd-El-Khalick, Bell, and Lederman, 1998, p. 418). Based on the research done over the years around NOS, philosophers of science, historians of science, and science educators have some concerns about what students should learn about NOS and if there is efficient consensus among scholars regarding how to conceptualize nature of science and how NOS to be taught in K-12 settings (e.g., Duschl, 1994; Allchin, 2011; Matthews, 2012; Hodson & Wong, 2017; Osborne, 2017; Irzik & Nola, 2014; Erduran & Dagher, 2014). A review of how nature of science conceptualized in the literature over the years and how different researchers' conceptualizations and instruments differ from each other are presented in the literature (Osborne, 2017; Hodson & Wong, 2017; Ayala-Villamil, 2020; Ayala-Villamil & García-Martínez, 2021). For other researchers NOS "refers to the characteristics of scientific knowledge that are inherently derived from how it is produced, that is scientific inquiry" (Lederman, Antink & Bartos, 2014, p. 286). They described NOS through a list of aspects of NOS and called tenets. In this study, I took into consideration these aspects: scientific knowledge is tentative; has empirical nature; is subjective (theory-laden); is based on human inference, imagination, and creativity; and socially and culturally embedded; distinction between observations and inferences; and the functions of, and relationships between scientific theories and laws (Abd-El-Khalick, et al., 1998; Lederman, Lederman, Kim, & Ko, 2012; Lederman et al., 2014).

In the previous studies of science education, researchers have explored various participants' conceptions and understandings of the NOS including preschool and elementary students (Akerson & Donnelly, 2010; Akerson, et al., 2014), middle and high school students (Kang, Scharmann, & Noh, 2005; Dogan & Abd-El-Khalick, 2008; Küçük & Çepni, 2015), preservice teachers (Abd-El-Khalick, et al., 1998; Kattoula, Verma, & Martin-Hansen, 2009; Sevim & Pekbay, 2012; Akerson, Elcan Kaynak, & Avsar Erumit, 2019), undergrad teaching assistants (Hanuscin, Akerson, & Phillipson-Mower, 2006), practicing teachers (Brickhouse, 1990; Lederman, 1999), and teacher educators (Irez, 2006). Some of these studies are descriptive to understand what the participants' understanding of the NOS is in some specific contexts; others are analytical aiming changes or enhancement of the NOS concepts of participants with some specific interventions. Some of the studies are discussed below.

For example, Brickhouse (1990) explored the effect of teachers' beliefs about the nature of science on their teaching practice. Her findings revealed that teachers' views about the nature of scientific theories, scientific processes, and the progression and change of scientific knowledge are divergent. The divergent views also impacted the explicit lessons about the nature of science and formed an implicit curriculum regarding the nature of scientific knowledge. Similarly, Lederman (1999) investigated the relationship between teachers' conceptions of the nature of science and classroom practices, and what factors influence this relationship. He found that although teachers have views consistent with those advocated by current reforms in science education, teachers' level of experience, intentions, and perceptions of students are the significant factors that influence classroom practice rather than their conceptions of science. In another study, Hanuscin et al. (2006) conducted a research with nine Undergraduate Teaching Assistants (UTA) about their views on integrating the nature of science instruction into a physical science content course. Their findings suggested that four modes of explicit-and-reflective interventions, including analysis of NOS views of preservice teachers, improved and changed UTAs' views from views inconsistent with science to robust understanding of NOS. Similarly, Kattoula, et al. (2009) investigated how preservice teachers' views of NOS developed and changed during a unit on waves in an algebra-based physics course. They found that preservice teachers' views change from naive to informed views. In another study, Irez (2006) investigated 15 prospective science teacher educators' beliefs about nature of science in the context of teacher education reform in Turkey. He found that most of the participants had insufficient conceptions regarding two aspects of NOS: scientific method and the tentativeness of NOS. The researcher concluded that participants' insufficient conceptions about NOS are connected to the lack of prior reflection about NOS.

Working with in-service secondary biology teachers, Pavez, Vergara, Santibañez and Cofré (2016) investigated the effect of a professional development (PD) program on in-service secondary biology teachers' views of NOS in Chile. Authors investigated the effects of an intervention that used history of science and decontextualized activities to teach NOS. From the analysis of the pre-intervention the initial profiles of teachers' understanding of NOS shows that teachers' responses show that they have either naive or mixed views about the NOS aspects at the beginning of the study. While many teachers demonstrated a naive view of NOS about some aspects of the NOS especially the myth of the scientific method, the differences between theory and law, and, the inferential and tentative aspects of NOS, most teachers exhibited a mixed understanding of NOS in creativity aspect and the social and cultural embeddedness of science. Authors reported that after the PD program, biology teachers showed improvements in the aspects of NOS. Another research on biology teachers was around the relationship between biology teachers' understanding of the nature of science and the understanding and acceptance of the theory of evolution (Cofré, Cuevas, & Becerra, 2017). Teachers with more knowledge of nature of science are more willing to teach theory of evaluation (Rutledge & Mitchell, 2002). In biology, some aspects of NOS, such as the difference between theory and law as well as the idea that knowledge can be tested and that science is not static, could be explained in teaching evolution (Glaze & Goldston, 2015).

The findings of the previous studies on students', preservice teachers' and teachers' insufficient NOS views led researchers to consider different approaches to teach NOS: explicit-reflective, implicit and historical (Allchin et al., 2014). Explicit-reflective NOS instruction requires teachers to design learning environments that direct learners' attention into specific NOS aspects through asking questions and by creating reflection opportunities on the science investigations that they involved in.

The focus on this approach is the explicit connection between the NOS aspects and the science investigations that students engaged in. This way, teachers can contextualize NOS aspects through engagement in the investigations. Implicit NOS instruction requires teachers to engage students in inquiry- based activities, without the addition of explicit questions for students to reflect and connect to the investigation that they are doing. Historical approach includes using the history of science as case studies in science teaching. Among these approaches, explicit-reflective NOS found to be more successful in helping students develop understandings of NOS. While results from studies (e.g., Sandoval & Morrison, 2003) show that implicit approaches are usually not successful in improving students' NOS views, others show that using explicit reflective NOS instruction increases students' NOS understandings (Khishfe & Abd-El-Khalick, 2002; Akerson & Donnelly, 2010; Akerson, et al., 2014). The results of studies concerning the effectiveness of the historical approach are inconclusive. Allchin et al. (2014) described merits, deficits and contexts of all these approaches and suggest using integrating all these approaches as complementary methods to teach NOS.

Literature review demonstrated that researchers investigated teachers' conceptions of NOS, and whether these conceptions are sufficient or not (Abd-El-Khalick, 2005; Akerson & Donnely, 2010; Çil & Çepni, 2012; Özgelen, Tüzün, & Hanuscin, 2012). Studies related to assessing teachers' conceptions of NOS are abundant. However, many of these studies are descriptive in nature. It is also important to see whether or not the teachers' conceptions of NOS are reflected in their classroom practice. Teachers' views of NOS and knowledge of approaches to teaching NOS may effect the transition of these views into their science teaching, thus impacting students' learning of NOS (Abd-El-Khalick et al. 1998; Mulhall & Gunstone 2008; Doğan, Çakıroğlu, Çavuş, Bilican, & Arslan, 2011). Studies investigating teachers' teaching practice regarding NOS are increasing (Allchin et al., 2014), however there is still need to explore teachers' practice in different content areas and grade levels. Particularly in biology teacher education, researchers suggested future research to establish the causal relationship between biology teachers' understanding of NOS and their instruction around NOS (Pavez, Vergara, Santibañez & Cofré, 2016). Also in a recent study, through document analysis Erdaş, Doğan, and Irez (2016) examined 134 published articles conducted in Turkey between 1998 and 2012 about NOS, and concluded that students of all grade levels, pre-service, and in-service science teachers have not attained the desired understanding of NOS. American educational reform documents require teachers to teach the aspects of the NOS for scientific literacy, and teachers' understanding of NOS is important to be able to implement science practices, thus describing the

NOS conceptions and instruction of actual implementers of the standards and the curriculum is crucial.

Aim

In this research, I investigated first what the conceptions of a teacher regarding his NOS views, and whether or not those conceptions are reflected in his teaching practice evidenced in the classroom observations and the classroom documents provided to the students. Thus, the findings will add to the literature around teachers' understanding of NOS, and teaching practice regarding NOS. Teachers' views of NOS and knowledge of approaches to teaching NOS may effect the transition of these views into their science teaching, thus impacting students' learning of NOS. The following questions guided this study:

1. What are the conceptions of a biology teacher about the nature of science?
2. Does he explicitly embed NOS and its aspects in his teaching of science concepts? If so, how? If not, why?
3. What does the teacher think impacts his teaching of the NOS?

Method

Research Model

The exploratory qualitative case study comprises the research design of this study. The case of this study is a biology teacher working in a local high school in a school district in the Northeastern part of USA. The case study design captures the *real-life* context of NOS teaching and the teacher's views on the NOS aspects (Yin, 2009). Qualitative case study design allows for a rich, in-depth and extensive inquiry of the real-life situation. This research acknowledges the difficulty of capturing the teacher's views and his teaching practice and understands that his teaching is mediated to an important extent by the curriculum he follows and his views are affected by the interview questions that are asked.

Context and Participants

It is important to describe the context in terms of making critical interpretations about teachers' views and conceptions. The participant of this research was one male biology teacher. I used convenience sampling to choose the participant (Creswell, 2007). I contacted teachers working in the local high school and only one of the biology teachers agreed to participate in the study. Thus, the participant was convenient to the researcher in terms of reachability at the time of the study. Having one participant also allowed opportunity for deeper analysis. The participant was given the name Mr. Taylor in order to provide anonymity. Mr. Taylor is in his mid-forties and has 15 years of experience in teaching. Mr. Taylor has a Bachelor's degree in secondary education with an emphasis on Biology. He has taught four different biology courses from freshmen to senior levels. He has been teaching in a big rural school district with a wide range of socioeconomic levels of students. The school was the only high school in the School District in the Northeastern part of USA, so it was a very big populated school. Mr. Taylor's class size ranges from 24 to 27 students, with 25 students in the biology class was observed in this study. He was following the state curriculum and the textbook used for the Biology-1 course was Prentice Hall, Exploring Life. He also uses supplementary materials to the textbook for his course.

Data Collection Tools

I used qualitative data tools to understand the NOS conceptions of the participant and his teaching practice of the NOS concepts. These data sources included three semi-structured interviews, classroom observations of his teaching, and document analysis of instructional materials provided to the students. These tools are described in detail below.

The first semi-structured interview was designed to collect data on the teacher's academic background, teaching experience, the school context, general student profile, specific characteristics of students enrolled in the observed biology class by the researcher. This first interview took 10 minutes and conducted at the beginning of the observations. The interview questions are provided in the Appendix1.

The second interview was used to assess the teacher's conceptions about the NOS. The questions of VNOS form C (Views on Nature of Science Questionnaire) developed by Lederman et. al (2002) was used as the interview questions. Because these questionnaire questions are open-ended, they are also appropriate to use in the interviews. In the interview questions, the aspects of NOS include (1) scientific knowledge is both reliable and tentative, (2) scientific knowledge is empirically based, (3) creativity plays an important role in the development of scientific knowledge, (4) there is an important difference between observations and inferences, (5) though science strives for objectivity, there is always an element of subjectivity (theory-ladeness) and (6) social and cultural contexts play a role in the development of scientific knowledge. These aspects were investigated through the second interview, and the interview questions are provided in Appendix 2.

The third interview was used to assess the teacher's conceptions of teaching nature of science and conducted at the end of the observations. During the third interview, Mr. Taylor's answers to the second interview questions were also provided to him to get an approval from him for accountability issues, so part of third interview was used to get member check for the validity purposes. The third interview questions are provided in Appendix 3.

For observation of the classroom practice, one of the 10th grade Biology-I periods that Mr. Taylor teaches was randomly selected, and selected biology period was directly observed for three weeks every day. During the observation, the topics Mr. Taylor covered were pH-value and photosynthesis. Besides the field notes taken during class observations, all the handouts provided to the students were also collected each day. During the observations, I had the non-participating observer role (Creswell, 2007), and this role was advantageous to learn best about the teacher's practice and observe students in the classroom in-detail. This role also enabled me to jot down all my observation fieldnotes immediately.

Data Analysis

Three different data sources included interviews about Mr. Taylor's conceptions of NOS and his teaching practice, field notes from the classroom observations, and handouts that Mr. Taylor provided to the students. All the interviews were transcribed; detailed fieldnotes were cleaned and organized every day after the observation of the biology class (Emerson, Fretz, & Shaw, 1995). The transcription of the second interview was read several times and content analysis based on deductive approach was used for the analysis of the interviews. According to Elo and Kyngäs (2008), deductive content analysis is appropriate when the analysis is based on an earlier theory or model. In this approach, the analysis moves from the general to the specific and involves testing already developed themes, models or hypotheses (Marshall & Rossman, 1995). Thus, in this study I searched for the existing themes from the VNOS literature through the whole transcripts of the interviews. Elo and Kyngäs (2008) described when using deductive content analysis the researcher should develop a categorization table and code the data according to the categories. To analyze the data and make triangulation a categorization table format based on NOS aspects was constructed, and is provided in the Appendix 4. Classroom observations, handouts (instructional materials provided to students) and third interview questions were also analyzed to provide triangulation with the second interview to the existing nature of science themes. All the data from interviews, field notes and documents was coded according to existing themes, and interpreted according to the themes. Some of the third interview questions were analyzed according to both emerging themes specific to the third interview, and the existing themes.

In order to provide trustworthiness, I describe the analyzing process in detail when reporting the results and provide quotations from the teacher to show to readers how themes are grounded in the original data (Patton, 1990). In order to provide transferability, I tried to provide a detailed explanation of the context, and the characteristics of the participant, the data collection and the process of the analysis. The coding was also double checked by another researcher in the field for credibility purposes (Lincoln & Guba, 1985), and discrepancies are discussed. In order to improve credibility of the research findings data triangulations through using interviews, fieldnotes and document analysis was used. In the presentation of the findings, evidence from these data sources is provided for each theme.

Results

The findings are organized around the existing themes connected to the views of nature of science provided in the VNOS-C questionnaire. Table I, showing NOS themes and whether or not each theme is evidenced adequately or not in the interviews, observations and handouts, is provided below. The findings are supported with the quotes from the interviews, fieldnotes of classroom observation and analysis of classroom handouts provided to the students for each of the themes of the nature of science below. At the end of the interview quotes, question numbers and interview numbers indicating from which interview the quotes come are also provided.

Table I.

Mr. Taylor's NOS conceptions

NOS Themes / Data sources	**Interviews (II(conceptions)-III(teaching practices))**	**Classroom Observations**	**Documents (handouts)**
Tentativeness in scientific knowledge	Adequate	Adequate	Inadequate
The empirical basis of scientific knowledge	Adequate	Adequate	Adequate
The subjectivity aspect of nature of science	Partly-adequate	Inadequate	Inadequate

Creativity and imagination in the development of scientific knowledge	Adequate	Adequate	Inadequate
The difference between scientific theory and law	Partly-adequate	Inadequate	Inadequate
The difference between observation and inference in the development of scientific knowledge	Partly-adequate	Inadequate	Inadequate
Social-Cultural embeddedness of scientific knowledge	Partly-adequate	Inadequate	Inadequate

Tentativeness in Scientific Knowledge

Mr. Taylor explicitly mentioned that scientific knowledge always changes with new information and new evidence. His instruction also supported his conception of tentativeness of scientific knowledge, however, there was not any explicit evidence about the tentativeness of scientific knowledge in any of the handouts given in the classroom that are promoting tentativeness of scientific knowledge. Some of the examples of quotes that he mentioned about the tentativeness of scientific knowledge are: *"Thank goodness they [scientific theories] do [change], why consider the experiment, keep the experiment, that's the great thing about science, it changes all the time, the knowledge we have changes all the time" (Interview II, Q4)*.

"Well, we teach them [students] what we currently know, I tell my students all the time, we teach them what we currently know and understand, it not is a truth, we never say it is a truth, it is not the truth because science always changes or science scientific knowledge can change, but it is I teach them, science always changes" (Interview II, Q4).

In both of these quotes, Mr. Taylor explicitly uses the word "change" to talk about science and scientific knowledge, indicating his conception of tentativeness of NOS. Below is the description of classroom observation related to the tentativeness of scientific knowledge:

Mr. Taylor was talking about energy and he mentioned that there are six types of energy during the first classes of photosynthesis unit. When he was talking about the types of energy later, one of the students asked if they [scientists] have discovered all types of energy. Mr. Taylor's answer was "*I believe so, but it is science, science changes all the time*" (Field notes from February 24).

In this teaching moment, Mr. Taylor did not have any preparation to explain that the scientific knowledge can change or do change, this explanation incident was upon one of the student's question, so it wasn't explicitly planned in the Mr. Taylor's lesson plans. Nonetheless, this example provides evidence from his instruction where he explicitly mentioned that science changes. The handout analysis showed that all handouts were intended to ask a series of scientific facts, there was not any activity sheet that promotes the tentativeness of the nature of science; rather they were emphasizing constant one correct answer. An example of the questions in the handout is provided below.

A. Where does photosynthesis take place?

a. In the____________________

b. They contain _________________ in the photosynthetic membrane.

c. Cluster of pigments called a ______________within the chloroplast.

In the example, there is a question and it has three sub-answers and each one has one word blank space. These questions promote one single correct answer, thus imply absolute truth and do not leave a room for the interpretation of tentativeness of scientific knowledge.

The Empirical Basis of Scientific Knowledge

Mr. Taylor explicitly mentioned empirical basis of scientific knowledge and differentiated science from other disciplines with focusing on the empirical base of science. For the empirical basis of scientific knowledge, there is evidence in his instruction and a few examples of handouts promoting some of the scientific processes related to empirical nature of science. Examples of quotes from Mr. Taylor, filed notes of classroom observation, and classroom handout analysis about empirical nature of science are provided below. *"It deals with physical world and universe; it is based on measureable, anything measurable, things that you can see and touch, taste and smell"(Interview II, Q1).*

"You have to take into consideration of all the variables and make sure you're testing only that one you are trying learn about, and get data about it and gain knowledge about it, in a textbook kind of explanation" (Interview II, Q3).

In the quotes above, Mr. Taylor emphasize some of the scientific processes such as measuring, using senses, testing variables, and controlled experiments, showing his conception of empirical nature of science. He emphasized the empirical evidence resulted from the experimental studies, thus these quotes show his views around the empirical aspect of NOS. From the classroom observations, there is a teaching practice explained below. In this teaching practice, Mr. Taylor was explaining an experiment, which was done by a scientist many years ago. By explaining this experiment and the inquiry the scientist had done, Mr. Taylor pointed out the empirical aspect of nature of science for the students.

He put a question on overhead. The question was "where do trees (all plants in fact) get their mass from?" Some students said from seeds and some of them said from soil. Then, he began to tell the experiment the scientist did 300 years ago. Mr. Taylor: "*he (scientist) wondered the same question and did an experiment with a small tree and he (scientist) added dirt, water and give sunlight and measure the weight of dirt, and the mass of tree. The mass of the dirt was same, so it can't be dirt, so far we have water."* Then the teacher asks, "*What can we conclude from the experiment?*" Students said no soil is used and so far we have water. Mr. Taylor asked, "*Where does the carbon come from? Is there carbon in the air? In the Soil?*" Then, Mr. Taylor told that the mass comes from the air and water. (Field notes from February 24)

This teaching moment highlights the empirical aspect of the nature of science, but Mr. Taylor could have let students do an experiment, instead of just telling the case. He let them make predictions but then told the answer. He did not let students explore the answer or let students predict other possible reasons. Based on this moment, he could have used these types of historical experiments in his teaching to emphasize nature of science more. Teaching historical experiments is an effective method, but this case needs more explicit instruction.

Another observed teaching practice representing the empirical aspect of nature of science is:

Teacher put on the overhead the raw scores of wavelength (in Angstrom) and absorption percentages of chlorophyll A and chlorophyll B, and wanted students to draw the diagram from the data, form scale and scale of measurement (Field notes from March 3), and on the next day he gave a handout which requires students to answer questions about the graph that they drew with the data provided yesterday. Students discussed their graphs as a group about and thought about why the percentages are different for each chlorophyll for every wavelength of light (Fieldnotes from March 4).

In this field note, I described a teaching moment when the teacher engaged students in a graph drawing activity. Because this activity requires students take the raw data, organize it, draw the graph and answer questions with the data graph, it is considered that this activity helps students practice some dimensions of the empirical aspect of nature of science. Thus, this moment provides an example of teacher's inclusion of empirical aspects of NOS in his teaching.

In the handout analysis, the activity sheet, which includes some questions about the graph that helps them to read the graph and analyze the data about two chlorophyll types and visible light absorption, is related to the empirical aspect of the nature science. Again, this activity sheet helps to analyze the data, thus, considered to help students attend to the empirical aspect of the nature of science, and evidence to the teacher's practice of including empirical aspect of nature of science.

Subjectivity Aspect of the Nature of Science

Mr. Taylor mentioned objectivity and subjectivity in nature of science. When he was asked about what an experiment is in the second question, he emphasized the objectivity of the scientific knowledge. However, when he was explicitly asked about the subjectivity aspect of the nature of science in the eighth interview question, he mentioned about subjectivity by describing how scientists bring their perspectives to the scientific knowledge with their desire, thinking and beliefs. There are examples of him mentioning the objectivity part of the nature of science by saying the words "objective experiment" and "standard of acceptance". *"There are guidelines to follow, that need to be followed for it to be an objective experiment with the data that can be accepted."(Interview II, Q2)"There is a standard of acceptance for the work that is done, whether it is in this country or somewhere else, anybody in the world."(Interview II, Q2)*

The quotes representing the subjectivity aspect of the nature of science are below when he was asked the eighth question related to the dinosaur extinction and scientists' interpretation. He mentioned the human perspective in scientific knowledge. Before this question, he did not take into account scientists' perspectives and backgrounds in the experiment process or in the analyzing process; he emphasized the objectivity in scientific knowledge as it was shown in his quotes above.

"*You always have to figure in the human factor to science in pure sense is nonjudgmental but when you put in the human factor, everybody brings their own perspectives, their own desire and* *their own ideas to scientific information. So even though it might be the same data, human may look at differently, and interpret differently."(Interview II, Q8)*

There was no evidence of instruction emphasizing subjectivity during the classroom observations. The handouts provided students do not promote subjectivity because all of the questions in the handouts require one correct answer, even some of the handouts require students to go to textbook and write the exact definition of the scientific concepts from the textbook.

Creativity and Imagination Aspect of the Nature of Science

Mr. Taylor mentioned creativity and imagination as a required aspect for scientific knowledge in every stage of the investigations from designing and planning investigations to analyzing and collecting the data. He gave examples of how creativity and imagination is necessary in the experiments from his students' classroom activities. However, during classroom observations there wasn't any evidence of instruction that he explicitly emphasized creative and imaginative nature of science. Also, in the handout analysis, there wasn't any handout promoting creativity and imagination aspect of scientific knowledge. Example of his quotes about creativity and imagination aspect of the nature of science are: *"Ohhh, they [scientists] have to, absolutely they have to use their creativity and imagination during their investigations." (Interview II, Q10)*

"I give them parameters to work on, but they have to use some ingenuity on their own because I usually provide all materials but they have to manipulate those materials to try to get to the ends that they are looking for a particular experiment, so in scientific inquiry there is, it has never really cut and dry. It could be easier when an individual has to think outside of the box, to try to figure something out, use his or her own ingenuity to do it. Absolutely, we couldn't go much further if it wasn't for that human aspect."(Interview II, Q10)

"In some of the experiments that they [students] set up, the data they collect doesn't seem to make sense to them, and they just don't see the trend that is showing up in the data. You have to try get them different direction to look at things differently, to open up their minds and use some creativity when they look at hard numbers, how they can manipulate these numbers or what the data is trying to say them."(Interview II, Q10)

These quotes show Mr. Taylor's conception of how scientists use imagination and creativity and how his students also need to use their imagination and creativity in the classroom activities he engages them in; he referred to imagination and creativity when he used the words *"ingenuity" and* the term *"think outside of the box*" in his interview. While there is no evidence of instruction about creativity and imagination aspect of the scientific knowledge during the classroom observations, the activities he talks about in his interview in the above quotes represent moments of requiring students to use imagination and creativity from his instruction. Due to the limited time I made observations in his classroom I did not see examples of students' needing to use imagination and creativity in their experiments, but from his response to interviews we may interpret that he uses imagination and creativity in his instruction. For the handout analysis, there is no handout that promoted creativity and imagination, rather students were given unit objectives sheet at the beginning of the every unit, and these unit objective sheets may impede the creativity and imagination of the students.

The Difference between Scientific Theory and Law

Mr. Taylor mentioned the difference of scientific theory and scientific law, but he did not see them as separate kinds of knowledge when he said theory can eventually get elevated to the status of a law, so he couldn't recognize that scientific theories and scientific laws are different types of knowledge. Examples of his quotes mentioning the difference of scientific knowledge and law with a misconception in it are represented below.

"The difference between theory and law is that a law if I go back to my definition, or the definition that I have in class, a law has a observable physical phenomenon that withhold in specific circumstances without question, theory doesn't do that, a theory might eventually get elevated to status of a principle or a law, but it takes time to do that." (Interview II, Q5)

"When it comes to a law like gravity, you can't dispute gravity, now we can anyway and I tell my kids the particular situation with gravity might be in their lifetimes who knows, that they find a better explanation for what is happening, Einstein did that, so may be in their life time the idea of what gravity is, and how it works might change, because science is always testing." (Interview II, Q5)

In his first quote there is a misconception that theory can elevate to the law, in his second quote, he recognized that laws can also change and he gives an example of it with Einstein. In the classroom observations and document analysis, there is no evidence of his instruction about the difference of scientific theory and law. This is may be because of the topics (pH-value and photosynthesis) he was teaching during the observations, as those topics do not include theory or law.

The Difference between Observation and Inference in the Development of Scientific Knowledge

Mr. Taylor couldn't demonstrate an understanding of the difference between observation and inference when he was asked the sixth question about the model of the atom and how certain scientists are about that model. In the classroom observations and document analysis, there wasn't any evidence about the difference between observation and inference. *"You have to ask somebody who understands quantum physics and mechanics to add to that one. I have no idea, it is beyond me" (Interview II, Q6).* In another interview question, Mr. Taylor tells:

"We can say the parts of the evolution theory, like natural selection certainly does happen, it is quantifiable, we see this in species all the time, but try to apply that same concept to long term evolution, like the species evolution over geological time we weren't there, we can only hypothesize only theorize using the evidence that we have today, that might be would have happened, but somebody might come along and say wait a minute I have some new evidence that would dispute that particular portion of theory of evaluation." (Interview II, Q5)

In this quote, he was asked the fifth question about the difference between theory and law, he was giving an example of the difference. From this quote, we can also notice how he was explaining the observation with words "quantifiable", "see" and inference with words "hypothesize" and "theorize using the evidence we have today". So even though the question related to the model of atom did not reveal his ideas about the difference between observation and inference, we can infer from his answer to the fifth question about his conception of difference between observation and inference. In the classroom observations and document analysis, there is no evidence of his instruction about the difference of observation and inference.

Social-Cultural Embeddedness of Scientific Knowledge

Mr. Taylor mentioned that scientific knowledge is cultural and universal when he was asked the ninth question. *"It is certainly cultural and it is certainly universal" (Interview II, Q9).* When I asked to elaborate upon his answer of why it is cultural and universal, he emphasized the human nature and human perspectives, represented in the quote below, so Mr. Taylor did not want to select science being cultural upon science being universal or vice versa. His view of science was rather including both cultural and universal aspect of science. He mentioned about the subjectivity aspect of the nature of science. However, when he was asked about creativity and imagination question, he gave examples about social aspect of nature of science.

"We are humans, I don't know how better to explain it, other than that everybody perhaps has their own perspectives for various reasons, what their motivations are for their thinking and their beliefs and what they see in scientific knowledge. If there are 6 million different scientists on the surface of the planet, there will be six million different opinions, some of them agreed upon that it is universal, but there is still six million ideas out there, that's just human nature." (Interview II, Q9)

"In a group of three or four kids working together to solve a problem, each one has a strength, each one has a weakness, and if it matches properly, they don't all have the same strengths and across the board they will do a better job that way, each one can bring something different to the task."(Interview II, Q10)

In his first quote, by using the words "perspectives", "motivations", and "beliefs", I considered he was referring to the subjectivity aspect of the nature of science. In the second quote, Mr. Taylor was touching the social aspect of scientific knowledge by using words "working together", and "each can bring something different". In the classroom observations, there is no evidence of his instruction about the social and cultural embeddedness of scientific knowledge. There is no evidence of a handout that promotes social or cultural embeddedness of scientific knowledge. None of the handouts include group study or group experiment that students can experience this aspect of science.

In summary, Mr. Taylor explicitly mentioned tentativeness of scientific knowledge, empirical aspect of scientific knowledge, and role of creativity and imagination in the scientific knowledge. However, for subjectivity aspect of nature of science, he also mentioned objectivity in science. When he was asked very explicitly in eighth question, he mentioned subjectivity. Mr. Taylor also partially recognized the difference between scientific theory and law, the difference between observation and inference, and social and cultural aspect of nature of science. From the summary of the fieldnotes of classroom observations and handout analysis, there wasn't a clear evidence of instruction and handout promoting subjectivity, creativity and imagination, difference of scientific theory and law, difference of observation and inference, and social-cultural embeddedness of scientific knowledge. Empirical aspect of nature of science was the only aspect that was evidenced in the classroom observations and handout analysis. According to the data, Mr. Taylor's conceptions of nature of science revealed from the interviews and his instruction and handout analysis do not match all together. Even though he has an adequate understanding of some aspects of nature of science, in his instruction, he did not use explicit connections to some aspects of NOS.

Teaching Nature of Science

When Mr. Taylor was asked what nature of science is in his opinion, he mentioned that nature of science provides natural explanations for the physical world. "*Providing natural explanations for the physical world, universe. To me that's the nature of science."(Interview III, Q2)*. He thinks that teaching NOS is important, but when asked about the most important thing to emphasize in his teaching he mentioned about problem solving skills. When Mr. Taylor was asked if he taught nature of science and how he did it, he mentioned the inquiry labs he did at the beginning of the school year and the scientific method he used from start to end with some certain steps (setting question, hypothesis, and etc.).

"Oh, absolutely! I start off the school year with inquiry labs that really don't get them going in any particular direction, and just give them some materials within different labs and tell them to figure something out, take the materials and work on it. But when I just put materials out, it will take them just a little while to figure out what I want them to do. They are so unused to using their mind to be creative and come up with things and try to solve problems. And I do labs like that at the beginning of the year to try to get them into that frame of mind, nature of science and scientific inquiries are really important. In our classes overall yes, partly in advance classes, we get them labs where we tell them "okay you design the lab", we give some different materials, "you choose your variables, you choose your parameters, you create your main questions, you come up with your own hypothesis", and they have to be able to do that. So, the beginning of the school year we did inquiry and scientific inquiry pretty much, and nature of science." (Interview III, Q5)

In his quote above, he mentioned that he used inquiry labs to teach nature of science usually at the beginning of the school year. His quotes represent that he teaches inquiry labs and NOS in an implicit way. From his descriptions of his teaching, it seems that he wanted his students to understand empirical aspect of NOS through the inquiry labs he did with students at the beginning of the semester by setting up open-ended experiments and letting students decide their research questions and control the variables. However, the way he uses inquiry and NOS interchangably may also imply that he thinks they refer to the same thing. When he was asked why he taught NOS in that particular way, he responds:

"Well, just starting off the school year like that, that's what we are trying to do, we are trying to get them think and use their brains that way and you know trying to get that 2 year-old kid back when they wanna know everything, they have this intense curiosity, somewhere along the line they

lost it, we wanna get back to that. So, we start of the year like that. If we start of the year like just, "okay, take notes and test is next week", maybe there will be a lab, may be there won't be a lab, you just do straight cookbook type labs. Wow, they just get this mind frame, "okay I just do what I am told to do and that's it".We want them to use their brains." (Interview III, Q5)

In his quote, he mentioned *bringing student's curiosity back* and *making students think* are the most important goals in his teaching. One of the important aspects he mentioned in his quote was also that he teaches this at the beginning of semester, and he doesn't do these kinds of labs during the semester again.

Constraints to Teach Nature of Science

When he was asked if he thinks that he taught enough about the nature of science, his answer was, *"No I don't" (Interview III, Q6*). Then, when he was asked why, he mentioned time constraints, heavy curriculum, lack of good curriculum that promotes nature of science and the difficulty to do that kind of teaching.

"Why? Because it is very, very difficult, very time consuming, and a lot of work to do that kind of teaching and the amount of materials we have to cover just can't do it. I mean, well can't say you can't do it, it is difficult to do, and then the time frame of nine months the curriculum we have to give them, it is very difficult to try to teach the way you really want to teach the material, but it can be done, just haven't devised a really good curriculum for it, working on it." (Interview III, Q6)

In his quotes, he emphasized the time constraints, and heavy curriculum as reasons to not being able to teach NOS enough in his teaching. When he was asked about if there are problems he encountered teaching the nature of science, his answers were problems related to engagement and students' resistance.

"The problems I have when teaching the NOS, a lot of it is kids don't want to. Just give me the answers, throw down the test and we'll be done; a lot of them just don't want to sit down and think too hard. So, that's one of the problems trying to teach it, trying to get an audience that really wants to participate is difficult, so you try to come up with activities that turn it into something that might be fun for them to do, they might pick up some learning as they go, if they are having fun of doing it, they might actually learn as well"(Interview III, Q10).

These quotes evidences that he focused on participation problems and resistance he gets from the students to this kind of teaching.

Discussion

This study explored a biology teacher's conceptions about NOS, if he embeds NOS and its aspects in his instruction, and what he thinks impacts his teaching of NOS. The results revealed that while Mr. Taylor had adequate understandings in some aspects of NOS such as tentativeness of scientific knowledge, empirical aspect of scientific knowledge, and role of creativity and imagination in the scientific knowledge. He also had some partly-adequate understandings in other aspects such as subjectivity, the difference between scientific theory and law, social-cultural aspect, and the difference between observation and inference.

From the summary of the fieldnotes of classroom observations and handout analysis, the inclusion of NOS aspects in instruction and classroom handouts was inadequate for most of the aspects. There wasn't a clear evidence of instruction and handout promoting subjectivity, creativity and imagination, difference of scientific theory and law, difference of observation and inference, and social-cultural embeddedness of scientific knowledge. There was adequate evidence of inclusion of empirical aspect of NOS in his instruction and handouts. For the tentativeness aspect of NOS, there was explicit evidence from his instruction, but there was not any evidence promoting the tentativeness of scientific knowledge in the handouts.

According to the data, Mr. Taylor's conceptions of nature of science revealed from the interviews and his instruction and handout analysis do not match all together. His lack of knowledge on some aspects of NOS and alternative conceptions he has may be due to his lack of pedagogical courses on NOS, as Mr. Taylor doesn't have a graduate degree. Research also revealed that teacher preparation on the understanding and teaching of NOS seems to be uncommon (Cofré et al., 2015). In the USA, most of science teacher education programs do not have any required NOS coursework or have as an elective course. In addition, NOS is considered just as a project topic in the science content and teaching courses (Backhus & Thompson, 2006). Research literature also shows that students, curriculum designers, scientists, teacher educators do not have adequate conceptions about many aspects of NOS (Lederman, 1992; Irez, 2006). Similarly, this research revealed that Mr. Taylor's conceptions of nature of science has some limitations, confirming the previously conducted research in this area.

The reason I did not see evidence of his instruction about, for example the difference of scientific knowledge and law, is may be due to the topics that he was teaching during the classroom observations as those topics (pH-value and photosynthesis) do not include these kinds of scientific knowledge. The classroom I observed was a 10th grade biology class and the observations were made everyday for three weeks between February and March, thus Mr.Taylor may not teach all the aspects in three weeks of instruction.

Empirical aspect of nature of science was the only aspect that was evidenced in the classroom observations and handout analysis. In the empirical aspect of the nature of science, Mr. Taylor tried to use a historical experiment to teach the case. The historical approach is an effective method to teach the nature of science, but if it could be instructed in a more inquiry type, rather than directly telling the story of the experiment, it may help teachers to teach nature of science more effectively and may help students understand NOS through historic examples. Thus, Mr. Taylor's use of historical example can help motivate engagement through cultural and human contexts, can support understanding of complexity of scientific practice and how scientist solve problems. According to Allchin et al. (2014), if historical examples are used only text-based, it limits students' development of hands-on experimental competencies and if historical cases are presented as final-form content, these cases will not support students' understanding of "science-in-the-making".

In the tentativeness aspect of nature of science, in the classroom observations Mr. Taylor explicitly mentioned that science could change, however, it was not in his lesson plans to address the tentativeness of scientific knowledge. This instruction happened simultaneously based on a student's question. Thus, teachers should have explicit intentional plans to teach the aspects of nature of science. Researchers recommend explicit-reflective NOS instruction to help students learn aspects of NOS through the specific activities and discussions that are focusing on introducing NOS aspects (Akerson, et al., 2014; Lederman, et al., 2013; Khishfe & Abd-El-Khalick, 2002). Explicit-reflective NOS instruction requires direct emphasis on NOS aspects through specific reflection questions on the science investigations students conduct. Explicit reflective NOS supports contextualization of the topic with scientific practices and disciplinary core ideas through connecting NOS aspects with the science investigations students involved in.

One of the findings is that Mr. Taylor teaches NOS at the beginning of the school year, this may be the result because the nature of science is in the first units of standards, and textbooks usually include this unit at the beginning of the semester, and thus, teachers teach NOS at that time, and then during the semester they don't emphasize it. This result was actually one of my motivations of why I observed the teacher's conceptions and instruction during the semester, instead of the beginning of the semester. Thus, findings of this study confirmed that NOS is not taught explicitly later in the semester. However, prior research conducted in science classrooms recommends introducing NOS conceptions early in the semester and continuing to support these concepts in each science investigation throughout the rest of the year through contextualized instruction. Contextualized NOS instruction requires connection of NOS aspects with the science content students are learning and could improve NOS conceptions of learners (Clough, 2006; Akerson & Donnelly, 2010; Khishfe & Lederman, 2007). Another reason why Mr. Taylor taught aspects of NOS at the beginning of the school year and not later in the semester may be due to how NOS is included in the standards. Researchers investigated how NOS is addressed and portrayed in various science standards documents from different countries (McComas & Olson, 1998; Olson, 2018). Insufficient NOS appearance and poor state of inclusion of NOS in the standards documents may impact inaccurate NOS concepts to be included in the textbooks, then inattention to accurate NOS teaching by the teachers (Olson, 2018).

Some of the questions in the VNOS questionnaire may stimulate Mr. Taylor's answers. For example, when talking about experiments, Mr. Taylor first mentioned the necessity of objectivity in experiments and did not take into account scientists' perspectives and backgrounds in the experiment process or in the analyzing process. When he was asked very explicitly the eighth question about dinosaurs, targeting subjectivity aspect, he mentioned how scientists' perspectives, desires and interpretations may be different. This result is maybe because VNOS questionnaire questions may stimulate Mr. Taylor's answers to these aspects. Even the question about the tentativeness of nature of science includes "change" in it, so this may be considered as a limitation of the study.

Some of the constraints to teach the nature of science that Mr. Taylor mentioned were time limits, heavy curriculum, and lack of good curriculum that promotes nature of science. The problems Mr. Taylor encounters in the classrooms are also represented in the literature confirming results of other research studies (Bartholomew, Osborne, & Ratcliffe, 2004; Allchin et al., 2014; Karampelas, 2018). These constraints are common when implementing a new approach in the classrooms. Using inquiry approach to teach NOS is time consuming and requires substantive amounts of resources (Allchin et al., 2014). It is important to support teacher's instructional practices through good curriculum that includes NOS concepts. Other constraints that Mr. Taylor mentioned were about engagement problems and students' resistance to that kind of teaching. Using inquiry approach to teach NOS can be difficult to motivate all students especially as a group, and the students may think about inquiry labs as artificial exercise or school "game," and not as genuine science (Allchin, et al., 2014).

Conclusion and Recommendations

The purpose of this study was to explore a biology teacher's conceptions of the nature of science, his instruction about nature of science, and what he thinks impacts his teaching of NOS. The study was based on a case study of a local high school biology teacher, Mr. Taylor. Findings of this study showed that Mr. Taylor had adequate conceptions about some of the aspects of NOS; however, there was limited evidence in his instruction and in the handouts promoting these aspects. Therefore, there was not a match between his conceptions of NOS aspects and his instruction of those aspects. This finding is also consistent with the literature; researchers also found that teacher's conceptions of the NOS do not necessarily influence their classroom practice (Brickhouse, 1990; Duschl & Wring, 1989: Lederman & Zeidler, 1987, Abd-El-Khalick, et al., 1998; Lederman, 1992). Thus, this research confirms that even though he has an adequate understanding of some aspects of nature of science, in his instruction, he did not use explicit connections to some aspects of NOS. Teachers should use explicit-reflective NOS instruction to help students learn aspects of NOS through providing opportunities to explicitly engage in NOS aspect and reflect on those aspects in their classroom investigations.

History, philosophy, sociology of science course should be a mandatory for certification programs and it should include mandatory explicit teaching applications for preservice teachers. Thus, teachers' knowledge and understanding of NOS aspects could be improved before they start their profession. School districts and universities should provide in-service training regarding teaching the nature of science concepts in specific science contexts. Some of the aspects of NOS may not be observed because of the nature of the lesson topic; so long term classroom observations should be done to make more effective conclusions. During this study a high school biology class was observed, more studies involving classroom observations in other content areas as well as in other biology concepts should be conducted.

This research has some limitations. One of the limitations is that it investigated only one case study of a biology teacher. Thus, the results are not generalizable to the other biology teachers. However, because it is based on an interpretive analysis of data from the interviews, fieldnotes and classroom materials of one teacher as a case study, the design was used to understand the situation in depth. Thus, the results are grounded in the data, and not generalizable across universal contexts, but at the same time studies in qualitative nature do not try to make generalizations. Another limitation could be due to the questions asked to the teacher. Although VNOS questionnaire helps to understand teachers' views on NOS, some of its items are directional. Therefore, we may not truly understand the teachers' own views. Some of the questions in the VNOS questionnaire may stimulate Mr. Taylor's answers. Even the question about the tentativeness of nature of science includes "change" in it, so this may be considered as a limitation of the study. Another limitation of the study could be the duruation of the observations. I observed the teacher's classroom everyday for three weeks from February to March thus, claims about the instruction of NOS depeneded on the topics covered during those times. Therefore, for a better understanding of teachers' instruction, long-term observations are suggested.

This research showed that Mr. Taylor used implicit approach to teach NOS through the inquiry labs, but from his descriptions we may understand that he teaches inquiry labs only at the beginning of the semester. NOS and inquiry are considered to be major components of scientific literacy in teaching biology (Roberts & Gott, 2003). Reseach shows that engaging students in science inquiry labs in biology education is important and encouraged; however, it is not enough to proceed from inquiry to suphistiacated NOS aspects (Kremer, Specht, Urhahne & Mayer, 2014). Previously, it was considered that teaching science as inquiry has a strong relation to advance understandigs in NOS, however research studies found that beliefs around NOS are not easy to change through inquiry activities (Khishfe & Abd-El-Khalick, 2002). Researchers argue that "biological inquiry processes can introduce the formation of NOS understandings, but learners are in need of explicit instructional support to adequately connect science processes to NOS" (Kremer, et al., 2014, p. 6) Thus, teachers should be given workshops around how to teach NOS and what approaches are being used to effectively teach NOS conceptions. Specifically, professional development opportunities that help teachers articulate individual aspects of NOS relevant to scientific literacy, and that show how to integrate different approaches to teach NOS, as the complementary NOS lessons, should be provided to help teachers teach NOS in the science classrooms effectively.

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I have carried out the research within the framework of the Helsinki Declaration; the participants are volunteers, informed consent is obtained.

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Appendix

Appendix 1- Interview 1 questions

1. Why did you choose to study biology?
2. For how many years have you been teaching in this school?
3. What degree do you have? Did you do anything before being a teacher?
4. (If he has a masters or a PhD.) What kind of courses did you take in your masters or PhD?
5. What courses did you teach? What topics did you teach?
6. What grade levels are you teaching?
7. What are your students like?(achievement levels, where they live, parents)
8. What is the usual class size you teach?
9. What is your school like?(students, parents, administration)
10. Which curriculum are you following? How did you choose this curriculum?

Appendix 2 - Interview 2 questions

VNOS-FORM C

1. What, in your view, is science? What makes science (or a scientific discipline such as physics, biology, etc.) different from other disciplines of inquiry (e.g., religion, philosophy)?

2. What is an experiment?

3. Does the development of scientific knowledge require experiments? If yes, explain why. Give an example to defend your position. If no, explain why. Give an example to defend your position.

4. After scientists have developed a scientific theory (e.g., atomic theory, evolution theory), does the theory ever change? If you believe that scientific theories do not change, explain why. Defend your answer with examples. If you believe that scientific theories do change: (a) Explain why theories change; (b) Explain why we bother to learn scientific theories. Defend your answer with examples.

5. Is there a difference between a scientific theory and a scientific law? Illustrate your answer with an example.

6. Science textbooks often represent the atom as a central nucleus composed of protons (positively charged particles) and neutrons (neutral particles) with electrons (negatively charged particles) orbiting the nucleus. How certain are scientists about the structure of the atom? What specific evidence do you think scientists used to determine what an atom looks like?

7. Science textbooks often define a species as a group of organisms that share similar characteristics and can interbreed with one another to produce fertile offspring. How certain are scientists about their characterization of what a species is? What specific evidence do you think scientists used to determine what a species is?

8. It is believed that about 65 million years ago the dinosaurs became extinct. Of the hypothesis formulated by scientists to explain the extinction, two enjoy wide support. The first, formulated by one group of scientists, suggests that a huge meteorite hit the earth 65 million years ago and led to a series of events that caused the extinction. The second hypothesis, formulated by another group of scientists, suggests that massive and violent volcanic eruptions were responsible for the extinction. How are these different conclusions possible if scientists in both groups have access to and use the same set of data to derive their conclusions?

9. Some claim that science is infused with social and cultural values. That is, science reflects the social and political values, philosophical assumptions, and intellectual norms of the culture in which it is practiced. Others claim that science is universal. That is, science transcends national and cultural boundaries and is not affected by social, political, and philosophical values, and intellectual norms of the culture in which it is practiced. If you believe that science reflects social and cultural values, explain why. Defend your answer with examples. If you believe that science is universal, explain why. Defend your answer with examples.

10. Scientists perform experiments/investigations when trying to find answers to the questions they put forth. Do scientists use their creativity and imagination during their investigations? If yes, then at which stages of the investigations do you believe scientists use their imagination and creativity: planning and design, data collection, after data collection? Please explain why scientists use imagination and creativity. Provide examples if appropriate. If you believe that scientists do not use imagination and creativity, please explain why. Provide examples if appropriate.

Appendix 3 - Interview 3 questions

1. What do you think are the most important things to emphasize in your teaching? Why?
2. What in your opinion is the NOS?
3. (At this point interviewee was provided with his second interview answers, was asked to familiarize himself with his earlier responses and to comment on and clarify these responses.) What did you mean by your response to question number 1 (interviewee's responses to all 10 questions were explored and clarified)?
4. What do you think about teaching the NOS? Why? (or why not?)
5. Do you teach the NOS? If yes, how? Why did you teach the NOS in that particular way? (If not, why?)
6. Do you think you do enough in teaching NOS? Can you elaborate?
7. How do you know your students learn the NOS?
8. (The participant was then provided the handouts he gave to the students.) On reviewing your handouts, what are your intentions that you want your students gain with these handouts?
9. How do you think about the possibility to teach the NOS in every science class? Why? Why not?
10. What are the problems you encounter teaching the NOS?

Appendix 4

NOS Themes / Data sources	Interviews (II(conceptions)-III(practices))	Classroom Observations	Documents (handouts)
Tentativeness in scientific knowledge			
The empirical basis of scientific knowledge			
The subjectivity aspect of nature of science			
Creativity and imagination in the development of scientific knowledge			
The difference between scientific theory and law			
The difference between observation and inference in the development of scientific knowledge			
Social - Cultural embeddedness of scientific knowledge			