

Explicit Teaching of the Nature of Science:
A Study of the Impact of Two Variations of Explicit Instruction
on Student Learning

by

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ABSTRACT

The nature of science (NOS) is included in the *National Science Education Standards* and is described as a critical component in the development of scientifically literate students. Despite the significance of NOS in science education reform, research shows that many students continue to possess naïve views of NOS. Explicit and reflective discussion as an instructional approach is relatively new in the field of research in NOS. When compared to other approaches, explicit instruction has been identified as more effective in promoting informed views of NOS, but gaps in student understanding still exist.

The purpose of this study was to deepen the understanding of student learning of NOS through the investigation of two variations of explicit instruction. The subjects of the study were two seventh grade classes taught by the same classroom teacher. One class received explicit instruction of NOS within a plate tectonics unit and the second class received explicit instruction of NOS within a plate tectonics unit plus supporting activities focused on specific aspects of NOS. The instruction time for both classes was equalized and took place over a three week time period. The intention of this study was to see if the additional NOS activities helped students build a deeper understanding of NOS, or if a deep understanding could be formed solely through explicit and reflective discussion within content instruction.

The results of the study showed that both classes progressed in their understanding of NOS. When the results of the two groups were compared, the group with the additional activities showed statistically significant gains on two of

the four aspects of NOS assessed. These results suggest that the activities may have been valuable in promoting informed views, but more research is needed in this area.

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Chapter 1

INTRODUCTION

Background

“Once a theory is proven it can’t change”. This is one seventh grade student’s view of scientific knowledge. This student later went on to describe science as “following the scientific method to do experiments”. Many science classrooms are guilty of embedding this idea in the curious minds of students. School science is about the accumulation of facts about the natural world through the scientific method; a rigid process not representative of the real work of scientists and the progression of scientific knowledge. Science is presented as an enterprise void of creativity, imagination, and change. Sadly, naïve views of science are held by many students, teachers, and adults around not only the nation, but the world (Lederman, 2007; Solomon, Duveen, & Scot, 1992).

Students who are unable to see the connections between the science they experience in school and the real world, struggle to use their knowledge of science when making decisions as adults. Science classrooms should provide all students with an accurate understanding of nature of science (NOS). NOS refers to the epistemology of science: how do we know what we know? Rather than focus solely on “what” we know, researchers suggest science educators place more emphasis on “how” scientific knowledge is acquired. As members of society, students will be faced with decisions daily that require scientific knowledge. These decisions may be personal such as buying a fuel efficient car or choosing a medication. These decisions may also involve the role of scientific

knowledge in policy decisions at the local, state, or national level. An understanding of NOS will better prepare students to be analytical and to evaluate scientific knowledge pertaining to their daily life. “Using scientific knowledge in decision-making involves understanding not only the products of science, but also the process by which these products are generated and the grounds for confidence in them” (Bell, 2008, p. 1).

The ability to use scientific knowledge in decision making is a characteristic of scientific literacy.

Scientific literacy means that a person can ask, find, or determine answers to questions derived from curiosity about everyday experiences. It means that a person has the ability to describe, explain, and predict natural phenomena. Scientific literacy entails being able to read with understanding articles about science in the popular press and to engage in social conversation about the validity of the conclusions. Scientific literacy implies that a person can identify scientific issues underlying national and local decisions and express positions that are scientifically and technologically informed. A literate citizen should be able to evaluate the quality of scientific information on the basis of its source and the methods used to generate it. Scientific literacy also implies the capacity to pose and evaluate arguments appropriately. (National Research Council [NRC], 1996, p. 22).

Scientific literacy and NOS are closely linked, both identified in the National Science Education Standards (NSES) (NRC, 1996) as importance goals of science

education. An understanding of NOS is a critical component in the development of scientifically literate students (National Science Teachers Association (NSTA), 1982).

Although the exact definition of NOS is not agreed upon by science researchers and educators, it is often described as “the values and assumptions inherent to science, scientific knowledge, and/or the development of scientific knowledge” (Lederman, 1992). There are different levels of understanding of NOS. Scientists, researchers, and educators disagree on NOS at higher levels of education, but tend to have a similar view of the aspects of the NOS appropriate for K-12 students. Aspects of NOS that are typically considered appropriate and accessible for K-12 students include scientific knowledge as tentative, subjective (theory-laden), empirically based, the product of inference, creativity, and imagination, and socially and culturally embedded. Also included as part of NOS at the K-12 level is the difference between observation and inference, and the roles and relationship between theory and law.

Over the past twenty years, NOS has received increased emphasis in science education reform documents. The NRC has included NOS as part of the History and Nature of Science Standards in the NSES (NRC, 1996). The NSTA strongly supports the inclusion of NOS in science education and includes in their position statement, “The National Science Teachers Association endorses the proposition that science, along with its methods, explanations, and generalizations, must be the sole focus of instruction in science classes to the exclusion of all non-scientific pseudoscientific methods, explanations,

generalizations and products” (NSTA Position Statement: The Nature of Science, 2000).

Science researchers support the inclusion of NOS in science education, the NSES (NRC, 1996) require it be taught, and the NSTA insists that it must be the “sole focus of instruction in science classes” (NRC, 1996; NSTA Position Statement, 2000). In addition to the reasons above, NOS should be taught in science classrooms because it enhances students understanding of content knowledge, increases student interest, encourages students to see science as a human endeavor, and prepares our students to make decisions in their everyday lives requiring an understanding of scientific knowledge (Bell, 2008). Although NOS is a key component of science education, it is still misunderstood by many students, adults, and science educators. Research in the past fifty years has focused on student learning of NOS, but many questions still remain pertaining to effective instructional strategies. Explicit and reflective discussion has been identified as a more successful instructional approach, but there is limited research on the variations of explicit instruction.

Problem Statement

The research question guiding this study is: Is an explicit and reflective approach with supporting activities focused on NOS more effective than an explicit and reflective approach without supporting activities in promoting adequate views of NOS?

Purpose

In this study I will be investigating student learning of NOS through two different variations of explicit and reflective instruction. This study will help cast some light on the question asked by many researchers – How do different variations of explicit and reflective instruction promote informed conceptions of NOS? The following aspects of NOS will be the focus of this study: the difference between observation and inference, observations are theory-laden, the role of creativity and imagination, and the tentativeness of scientific knowledge. NOS activities unrelated to content have been suggested as a way to develop informed views of NOS. The purpose of this study is to see if the additional NOS activities help students build a deeper understanding of NOS, or if a deep understanding can be formed solely through explicit and reflective discussion within content instruction.

Rationale

Despite the inclusion of NOS in the NSES (NRC, 1996), many science teachers do not see the value of including NOS in their instruction. Content standards receive highest priority in classrooms, and the integration of NOS doesn't come easily for most teachers. Even teachers who see the value, often have naïve views of NOS or the ways in which students learn NOS. In addition to the barriers of time, integration, and naïve views, many teachers hold the belief that NOS will be learned implicitly through scientific inquiry, but this is not the case.

Over the past ten years, explicit teaching has been explored as an effective instructional strategy in promoting informed views of NOS. Explicit teaching refers to instructional strategies in which the aspects of NOS are clearly stated and explained as they relate to the progression of scientific knowledge. Many questions still exist as to how students develop informed conceptions of NOS and how variations of explicit and reflective instruction promote meaningful learning. “However, even with an explicit approach, much is still desired; the utilization of an explicit approach has met with limited success in enhancing more informed understandings among students” (Khishfe & Lederman, 2006). The lack of research in explicit and reflective discussion creates a need for a study that investigates more deeply the variations of explicit instruction. This study will investigate the influence of two different variations of explicit instruction of student learning with the intent of closing the gaps that still exist in conceptions of NOS.

Definitions

Scientific Inquiry consists of two parts *a)* “...the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work”, and *b)* “...the activities of students in which they develop an understanding of scientific ideas, as well as an understanding of how scientists study the natural world” (NRC, 1996, p. 23).

Scientific Literacy refers to “...the knowledge and understanding of scientific concepts and processes required for personal decision making,

participation in civic and cultural affairs, and economic productivity” (NRC, 1996, p. 22).

Chapter 2

LITERATURE REVIEW

Aspects of NOS

Of the eight commonly researched aspects of NOS in K-12 instruction, four will be the focus of this study:

- a) The difference between observation and inference
- b) Scientific knowledge is subjective (theory-laden)
- c) Scientific knowledge is partly the product of imagination, creativity, and inference
- d) Scientific knowledge is tentative

These four aspects will be explained in the following paragraphs.

An understanding of the difference between observation and inference is crucial in understanding the ways in which scientific knowledge progresses.

Observations consist of statements that involve the senses. Inferences are conclusions made based on one or more observations. Observations are directly accessible to the senses, whereas inferences extend beyond the senses and begin to draw conclusions. For example, students may infer that South America and Africa were once connected based on the observation that the continents have matching coastlines. Inferences show a relationship that goes beyond the senses and begins to explain our observations.

Scientific knowledge is also subjective and/or theory-laden. Scientists, like all people, are influenced by beliefs and prior knowledge. To say that science is objective is not realistic. Current beliefs and knowledge affect the ways in which

scientists conduct their investigations and their interpretations of observations. Theories provide a framework that guides observations and allows meaningful interpretation. “Accordingly, an individual who is developing scientific literacy will increasingly understand the relationship of theory to observations – without theory man does not know what to observe” (Robinson, 1968, p. 132).

Scientific knowledge is partly the product of inference, imagination, and creativity. Students often believe that scientific knowledge is based on facts, and to use imagination or creativity means distorting the facts. Sometimes students believe in the usefulness of creativity and imagination, but only in the generation of hypotheses. “Science involves the invention of explanations, and this requires a great deal of creativity by scientists” (Lederman, 2007, p. 834). Most classroom experiences discourage creativity. If students are given the freedom to be imaginative and creative, it is typically only in the generation of hypotheses. Creativity is rarely encouraged in the explanation of data and evidence. In most classroom investigations students are working towards a known explanation in which creativity and imagination isn’t necessary.

The understanding of the tentativeness of scientific knowledge is often lost among K-12 students. In many classrooms, scientific knowledge is taught as absolute (Khishfe & Abd-El-Khalick, 2002). In a typical science classroom experiment, students follow a set of procedures to arrive at a result known in advance by the teacher. If students collect data and evidence that does not fit the known result they are sometimes given the opportunity to repeat the experiment, but more often are just told they conducted the experiment incorrectly. The idea

that a different explanation could exist is never considered. This is not the work of scientists. Scientific knowledge is never certain and theories can never be proven. “Experiment makes the scientist’s path to truth more, not absolutely certain. ‘The truth, the whole truth, and nothing but the truth is an illusion’ even if we found it, there would be no way of knowing that we had done so” (Aicken, 1984, p. 49). To be true to the field, scientific knowledge should be presented as tentative. Students should be provided with opportunities to experience how science changes, and understand that the knowledge we hold today is not certain.

Instructional Approaches

Science educators and researchers agree that students possess naïve views of NOS. In an attempt to strengthen science instruction of NOS, many instructional strategies have been explored. In the following pages I will describe the three most prevalent instructional strategies in the literature: a historical approach, implicit instruction, and explicit and reflective discussion. A discussion of the limitations of each strategy as well as suggestions for further research will also be included.

Historical approach. Supporters of the historical approach propose that students will develop informed conceptions of NOS through studying the history of science. The purpose of a historical approach is to provide students with real examples of the progression of scientific knowledge and the practices of scientists. Through a historical approach it is easy to see that science has changed and is continuing to change. Copernicus tested the limits of science in the 16th century when he challenged the widely held belief that the Earth was the center of

the universe. With further research and data collection, Copernicus realized that it no longer made sense to consider a system in which everything revolved around the Earth. “Copernicus had decided to consider the possibility that the model, not the evidence, was wrong” (Aicken, 1984, p. 42). In this example the tentativeness of scientific knowledge is clearly portrayed.

Abd-El-Khalick and Lederman (2000) conducted a study in which they assessed the influence of history of science courses on students’ views of NOS. Participants included 166 undergraduate and graduate students and 15 preservice secondary science teachers. The participants’ NOS conceptions were assessed pre- and post-instruction to determine the influence of three different history of science courses on the students’ understanding of NOS. Although it was found that students did progress in their understanding of NOS, this progression was attributed to the explicit discussion of NOS. “The results of this study do not lend empirical support to the intuitively appealing assumption held by many science educators that coursework in HOS will necessarily enhance students’ and preservice science teachers’ NOS views” (Abd-El-Khalick & Lederman, 2000, p. 1057). This research suggests that HOS instruction alone is not enough to promote informed views of NOS. Abd-El-Khalick and Lederman (2000) emphasized the importance of explicit and reflective discussion within a historical context.

Solomon, Duveen, and Scot (1992) conducted an action research study focused on the impact of NOS instruction through a historical approach. The researchers investigated the development of knowledge of middle school students

in five classrooms in a British school system. Classroom materials were designed specifically for the study and addressed concepts found in the National Curriculum. Data from interviews and a pre- and post-questionnaire showed that students progressed in their understanding of some concepts of NOS. “Our data cast some light on arguments about whether learning from history of science can lead to a better understanding of school science. In the first place it was the unanimous view of the teachers that their pupils had learned some concepts better through studying them in the controversial situations in which they first arose” (Solomon, Duveen, & Scot, 1992). The historical approach was found to be valuable, but because the students did not show growth for all aspects of NOS, further evidence is provided that the historical approach alone is not enough.

Experiencing the history of the development of scientific knowledge can be a powerful instructional tool if used correctly. A historical approach is not characterized by lectures and readings of historical narratives. The use of historical narratives presents science in the finished form and often does not adequately portray the resistance and struggles the scientists may have encountered in the development of scientific knowledge. Students are not able to see the way in which the scientific knowledge progressed, and instead view the historical explanations as incorrect rather than as incomplete. Further research should investigate the influence of a historical approach that allows students to experience the changes in scientific knowledge (rather than view the finished product).

In order to be effective, the historical approach also needs to be paired with explicit and reflective discussion. A discussion of the research on explicit and reflective discussion can be found in the following pages.

Implicit vs. Explicit and Reflective Discussion. In the years leading up to the research in explicit teaching of NOS, students were expected to learn NOS through implicit teaching involving inquiry-based activities. It was assumed that students would automatically develop accurate conceptions of NOS through the development of science process skills. Evidence has been collected over the past ten years in support of the belief that students need explicit and reflective instruction in order to develop informed conceptions of NOS. Explicit instruction is planned for and involves specifically addressing the aspects of NOS during instruction and reflective discussion. "...an understanding of NOS should be taken to be a cognitive learning outcome, which needs to be explicitly addressed and should be planned for instead of being anticipated as a side effect or secondary product" (Khishfe & Lederman, 2006, p. 396). Explicit and reflective does not mean didactic instruction in which the teacher simply tells the students the connection to NOS. Explicit and reflective discussion refers to the approach in which students are given multiple opportunities to reflect on the activities in which they participate from different perspectives, and connect these new conceptions to the progression of scientific knowledge and the work of scientists.

In order for students to develop informed conceptions, they need explicit discussion in which connections are made between the activities and the aspects of NOS (Lederman, 2007). Three studies will be reviewed below. In each study

an explicit approach was found to be more successful in enhancing student views of NOS.

Akerson, Abd-El-Khalick, and Lederman (2000) concluded that explicit, reflective NOS instruction was successful in enhancing student views of NOS. The study looked at the NOS beliefs of 25 undergraduate and 25 graduate preservice elementary teachers. The explicit, reflective instruction was provided in an elementary science methods course. All students were assessed pre-instruction and were found to have naïve views. At the conclusion of the course the students were assessed again and showed substantial gains in their understanding of NOS. Although the students showed growth in their understanding of NOS, this growth was not equitable among the aspects of NOS. Some aspects of NOS, such as observations are subjective (theory-laden), were more difficult for students to grasp. The instruction and curricular materials did not provide an in-depth historical study, which the authors described as a possible explanation for the limitations in student growth of NOS. There is a need for a study that provides students with a historical example in which the subjectivity of observations is clearly represented.

According to a study on the influence of instruction on views of NOS with 6th grade students, it was found that an explicit and reflective approach was much more effective than an implicit approach (Khishfe & Abd-El-Khalick, 2002). The study focused on four aspects of NOS: scientific knowledge is tentative, empirically based, inferential and imaginative and creative. Prior to the instruction, it was confirmed that students in both groups held naïve views of

NOS. After the intervention the researchers found that the views of NOS in the implicit group didn't change, however, the views on the explicit and reflective group improved significantly. Although the study provided a clearer view of the effective strategies of NOS, the instruction continues to be in need of improvement. Substantial gains in student understanding did occur, but gaps in student understanding remained at the conclusion of the study. Khishfe And Abd-El-Khalick (2002) conducted a study in which students experienced explicit and reflective discussion through inquiry-based activities, detached from content. . One suggestion for improvement involves the use of content-related inquiry activities.

Although research existed in support of explicit and reflective discussion, researchers were still investigating different forms of implicit instruction. Bell, Blair, Crawford, and Lederman (2003) conducted a study with ten students in grades 10-11 who participated in an 8-week science apprenticeship program. The students were placed in a science laboratory in which they worked closely with a science mentor and actively participated in a research project. At the conclusion of the program the students were required to present their research, again experiencing an aspect of real science. The intent of this program was to provide the students with authentic science experiences in which they would develop an adequate understanding of scientific inquiry and NOS. An implicit approach was used, assuming that students would understand science by doing science.

The results of the study showed that even though the students progressed in their understanding of the process of scientific inquiry, their beliefs of NOS

experienced very little change. It was not enough for students to engage in authentic science experiences. In addition to the opportunities to engage in real science, students also needed opportunities to reflect. Students who participated in the program struggled to connect the science they experienced in the program with the big picture of the scientific enterprise. The authors concluded that explicit and reflective discussion was necessary in the development of informed conceptions of NOS.

Variations of Explicit Instruction. Explicit and reflective instruction has been shown to be more effective than implicit instruction but gaps in student learning still exist. “Although there is strong emerging evidence that an explicit approach to the teaching of NOS is more effective than implicit approaches, there has been virtually no research that compares the relative effectiveness of the various explicit approaches” (Lederman, 2007, p. 870). Explicit and reflective instruction can vary in effectiveness according to how NOS is integrated into the science curriculum. For example, is NOS taught within content or in a separate unit? If NOS is taught within content, how are the aspects of NOS related to the content? Does some content lend itself better to NOS instruction?

Khishfe and Lederman (2006) conducted a study to investigate two different explicit approaches in promoting adequate views of NOS. The participants included 42 ninth-grade students split into two groups: an “integrated” and a “nonintegrated” group. The students in the “integrated” group received NOS instruction that was integrated into content instruction. The students in the “nonintegrated” group received NOS instruction through separate

NOS activities that were dispersed throughout the content instruction. The NOS activities in the nonintegrated group addressed aspects of NOS without relating it to the regular content. The results of the study confirmed that both forms of explicit and reflective approach were successful in promoting adequate views of NOS.

The instruction was found to be effective, but not all students progressed in their understanding of NOS, creating the need for more in-depth studies on explicit and reflective discussion. The study highlighted different variations of explicit and reflective instruction that need further investigation in science education research: the “distributed” model, “drip feed” model, and “assembled” model. The “distributed” model involves NOS instruction that is dispersed across a unit of study, providing students with multiple experiences with NOS. The “drip feed” model is very similar but involves short interventions throughout an entire science course. This model was thought to be effective because the NOS discussion took place over a longer period of time allowing the students more robust opportunities to experience the epistemological and conceptual ideas surrounding NOS. The “assembled” model involves teaching NOS separate from content instruction. A mixed model that combines both integrated and nonintegrated instruction was suggested. In this model students participate in an NOS activity separate from content, but then the content instruction is linked to the NOS activity later during instruction. The model intends to ease the student’s ability to scaffold the new ideas pertaining to NOS. The instructional design of

this thesis investigates the effectiveness of a mixed model. A description of the instruction will be discussed in the methods section.

Khishfe (2008) investigated NOS beliefs of 18 seventh-grade students during a three month intervention. All participants were in the same class and taught by the same instructor. Throughout the three month intervention students participated in three inquiry-oriented activities that addressed aspects of NOS within content. Each activity was followed by explicit and reflective discussion. The findings support the belief that an explicit and reflective approach can improve student views of NOS, but suggest that future research focus more closely on the developmental model in which students' views progress.

Seung, Bryan, and Butler (2009) explored an integrated approach in which students learned NOS through four interventions that utilized three instructional approaches: explicit, not context-based; explicit, context-based; and explicit, case-based. The explicit, not context-based involved a NOS activity unrelated to the content currently being taught. The explicit, context-based involved an NOS activity that was more closely related to the content. The explicit, case-based approach involved the use of historical narratives – students participated in two activities in which they read a historical case and in the second activity they developed a historical case. The author's intent was to investigate the assumption that implementing the different instructional approaches would be more beneficial than the explicit approach alone. This study also allowed the authors to compare different variations of explicit instruction. The interventions took place in a middle grades science methods sequence over two semesters.

The study found that the various instructional approaches were successful in promoting adequate views of NOS. Rather than identify one approach as more effective than the others, the authors discussed the strength in using multiple approaches and activities to complement each other. A module approach utilizing multiple approaches can also be effective in demonstrating the relationship between the aspects of NOS. The aspects of NOS are often over-lapping and allowing students to see the interrelatedness within one context can be very powerful. A more in-depth study focusing on the relationship between the aspects of NOS in a single unit of study is needed.

As discussed above, limitations to explicit and reflective discussion exist in promoting adequate student views of NOS. Suggestions for future research include a combined form of explicit instruction utilizing both the “distributed” model and the “assembled” model, a combination of different explicit instructional approaches utilizing context and not-context based activities, and studies that focus on the developmental model of students’ informed conceptions. In a review of research on NOS, Lederman (2007) described research methods as using an “input-output” model. Studies that have identified effective instructional approaches, stressed the significance of naïve views at the start of the study and informed views at the conclusion of the study, but do not provide much insight as to how these views developed. Lederman (2007) suggests that further research must explore the “specific mechanisms of change”. Applying the theory of conceptual change to instruction may provide a closer look at how adequate conceptions of NOS are developed.

Conceptual change

Student conceptions of NOS have been developed over their lifetime and these views are stubborn and difficult to change. “It is highly unlikely that students have come to harbor the well-documented and persistent NOS misconceptions merely by internalizing implicit messages about science embedded in their high school and college science experiences. It is more likely that those students were explicitly taught certain naïve ideas about NOS” (Abd-El-Khalick & Lederman, 2000, p. 1088).

A conceptual change framework is a way to improve student learning of NOS. Posner, Strike, Hewson, and Gertzog (1982) discuss two types of conceptual change: assimilation and accommodation. With assimilation students are able to use their existing conception to make sense of new phenomena. Accommodation refers to the more radical form of conceptual change in which students recognize their concept as inadequate in and the current concept must be replaced or reorganized. Accommodation is necessary in the development of informed views of NOS. Students’ have been exposed to inaccurate representations of scientists and scientific knowledge since the first day of science instruction in schools. These incorrect conceptions of NOS have been strengthened year after year in science classes and thus are very strong, robust, and resistant to change. “Due to years of school science instruction and everyday out-of-school experiences that have consistently conveyed, both explicitly and implicitly, inaccurate and simplistic portrayals of the NOS, students carry deeply held misconceptions that rarely respond to implicit instruction that faithfully

reflects the NOS” (Clough, 2006, pg. 465). In order for students to develop informed views of NOS and experience successful conceptual change, the views need to undergo a radical change – accommodation.

Through a conceptual change framework students will experience four stages:

- 1) Student perceptions of the NOS will be elicited prior to instruction
- 2) These perceptions will be challenged and students will experience dissatisfaction with their views
- 3) More adequate views of NOS will be presented
- 4) Students will experience the informed views of NOS in multiple contexts in order to create more robust and stronger views

Clough (2003) discusses the need for a conceptual change framework as well as explicit instruction that scaffolds back and forth along the decontextualized/contextualized continuum. Decontextualized instruction refers to the use of NOS specific activities to explicitly teach aspects of NOS separate from content. Clough (2003) believes this is critical to the development of adequate conceptions of NOS. The activities introduce NOS in a way that is familiar, concrete, and easy to internalize because it is not complicated by science content. Highly contextualized instruction in which the students experience explicit instruction of NOS within content instruction is also critical in the development of informed conceptions of NOS. The contextualized instruction will provide students with the opportunity to strengthen their understanding of NOS through the exploration of NOS in authentic science. Understanding NOS along the

continuum from decontextualized to contextualized will increase the likelihood that students will find dissatisfaction with their current conceptions thus leading to the development of more informed conceptions of NOS.

Research shows that even with explicit and reflective discussion, naïve views of NOS still exist among students. The lack of research in variations of explicit and reflective discussion creates a need for a study that addresses the unanswered questions of past research as well as the suggestions for future research.

Research in the historical approach discussed the need for explicit instruction within a historical context. This was found to be more effective than the historical approach alone. The study discussed in this thesis investigates explicit instruction within a unit on the history of the theory of plate tectonics. The research also stated that a historical approach must engage the students in active exploration of the progression of knowledge, rather than viewing it in the finished form. Students are provided this opportunity in the study discussed in this thesis.

In addition to suggestions for more effective instruction within the historical approach, suggestions were also made regarding the use of explicit and reflective instruction. Researchers identified the need for further investigation into the variations of explicit and reflective instruction in order to identify the instructional approaches most effective in the development of adequate understandings of NOS.

The purpose of this study is to gain a deeper understanding of student learning of NOS through an integrated/contextualized approach with explicit and reflective discussion. This study is similar to the study conducted by Khishfe and Lederman (2006) in which student learning of NOS was analyzed through two different explicit and reflective approaches: integrated and non-integrated. This study will be looking specifically at the learning of two different groups of students through two different explicit and reflective instructional strategies. Both groups will receive explicit and reflective instruction, but only one group will receive additional activities focused on specific aspects of NOS. This study differs from the study conducted by Khishfe and Lederman (2006) because the group receiving the additional activity on NOS will participate in discussion that connects the NOS activity to the content. Khishfe and Lederman (2006) included NOS activities as part of the instruction, but did not explicitly connect the NOS activity to the content material. The purpose of this study is to investigate if the additional activity on NOS enhances student learning of NOS if it is explicitly tied to the content. Past research has shown that students struggle with transferring the knowledge of NOS to unfamiliar contexts. The additional activity is meant to provide students with a stronger connection to the content and the real work of scientists.

Chapter 3

METHODS

Research Design

The research design of this study is action research. In this study, action research will be defined as

...a form of self-reflective enquiry undertaken by participants in social (including educational) situations in order to improve the rationality and justice of (a) their own social or educational practices, (b) their understanding of these practices, and (c) the situations in which these practices are carried out (as cited in Hopkins, 1993, p.44).

Action research as applied to classroom research can be more specifically defined as "...an act undertaken by teachers, to enhance their own or a colleague's teaching, to test the assumptions of educational theory in practice, or as a means of evaluating and implementing whole school priorities" (Hopkins, 1993, p. 1).

The study was developed with the intent of improving the instruction and enhancing student understanding of NOS.

Two classes will be the focus of this study. One class will serve as the content group and receive instruction using the History of Plate Tectonics Unit (Appendix A). The other class will serve as the content plus group and receive instruction using the History of Plate Tectonics Unit as well as four additional activities focused on an aspect of NOS. Each activity was integrated into a lesson in the History of Plate Tectonics Unit. The instruction will take place over a three week time period and each class will receive 5 hour sessions of instruction each

week. The total teaching time for each group was three weeks equivalent to fifteen hours.

Subjects and Setting

The participants in this study are two seventh grade classes consisting of a total of 64 students (35 males and 29 females) in a 6-8 public middle school in Phoenix, AZ. The average age of the participants is 12-13 years of age. Table 1 contains the demographic information for the two classes.

Table 1

Demographics

Class Period	n	Males	Females	White	Hispanic	Black	Native American	Asian
Content	33	19	14	16	6	6	3	2
Content Plus	31	16	15	18	8	4	0	1

The instruction took place in their general science class that meets five days a week for 68 minutes each day. Seventh grades students had been chosen as the subjects for NOS instruction, because research has shown that the aspects addressed in this study are developmentally appropriate for students of the middle school age (Khishfe, 2008; Khishfe & Lederman, 2006; Lederman, 2007). NOS has also been determined appropriate for students in grades 5-8 according to the NSES (NRC, 1996).

Because this is an action research study, I was the instructor of both classes. I am currently pursuing my Masters degree in Curriculum and Instruction with an emphasis in Science Education. As part of the requirements for my

degree, I took a History and Philosophy of Science Education course in the spring of 2010. This course heavily focused on NOS and provided me with the knowledge necessary to instruct students in NOS. A more thorough description of the unit and instruction can be found in the instruction section of the methods.

Assessment

The activities chosen for this study each focus on one aspect of NOS. In order to assess the activities impact on the understanding of NOS, an assessment was created to assess each aspect separately (Appendix B). The assessment will focus on four aspects of NOS: the difference between observation and inference, the tentativeness of scientific knowledge, observations are theory-laden (subjective), and scientific knowledge is the product of inference, creativity, and imagination. Each item on the assessment will focus on one of the four aspects.

Research has found that a multiple-choice assessment alone is not enough to uncover student thinking (Lederman, Wade, & Bell, 1998). NOS consists of abstract concepts and multiple-choice assessments do not provide enough depth into student understanding. Open-ended questions and semi-structured interviews have been found to be a more reliable approach to uncovering misconceptions that may be hidden in student responses. Although research suggests that semi-structured follow-up interviews be paired with a written assessment, interviews were not possible because of the time limitations of the study.

To gain a more in-depth look at student thinking, an explanation with an example was required in addition to a multiple choice question. A 4-part assessment (Appendix B) consisting of multiple choice questions followed by an

explanation was created as the assessment tool. The two-part assessment was based on the formative assessment probes developed by Page Keeley (2005). These probes were developed specifically to illuminate informed conceptions, misconceptions, and incomplete conceptions.

The probes in this book are “enhanced selected response” items. In other words, students must choose from a predetermined list of responses that may match their thinking and justify their reasons for choosing that response. The probes begin with the selected-choice option. The distracters are particularly useful in determining if your own students’ misconceptions match those found in the research (Keeley, 2005, p. 7).

In recent studies, the most commonly used assessment tool was the Views of Nature of Science (VNOS) or variations of the VNOS (Lederman & O’Malley, 1990). These assessment tools were considered but were found to be inappropriate considering the limitations of the study. The VNOS was designed to be used in conjunction with student interviews. The VNOS tool also assesses aspects of NOS which were not addressed in this study. Each item of the VNOS addresses multiple aspects of NOS complicating the use of this assessment tool.

Rather than use an assessment tool already developed, a new assessment was created to fit the specific needs of the study population. The content of the questions was modified to fit the knowledge level of this specific group of students. Content was chosen that would not interfere with the students’ ability to communicate their understanding of NOS. The questions were also modified to match the reading level of the students. The items on the assessment were drawn

from a variety of resources. Some of the items on the questionnaire were based on the VNOS assessment tool used in a study by Khishfe and Lederman (2006). For example, Khishfe and Lederman (2006) used the following question in their study.

#3 The dinosaurs lived millions of years ago.

(d) Scientist agree that about 65 millions of years ago the dinosaurs became extinct. However, scientists disagree about what had caused this to happen. One group of scientists suggests that a huge meteorite hit Earth and caused the extinction. Another group of scientists suggest that violent volcanic eruptions caused the extinction. How is it possible for scientists to reach different conclusions when both groups are using the same data?

(Khishfe & Lederman, 2006, p. 416).

The question was modified in this study to read: Scientists agree that about 65 million years ago the dinosaurs became extinct (all died away). However, scientists disagree about what had caused this to happen. Why do you think they disagree even though they all have the same information?

The assessment tool was shared with outside reviewers to ensure it had content validity. The assessment was then given to both groups to assess student views of NOS. The assessment had four questions and each question focused on one aspect of the NOS. All questions had two parts: the first part consists of a multiple choice question, and the second part required the student to explain their choice. This assessment was administered to all students at the beginning and end

of the study. All students took the assessment during one class period under teacher supervision.

Instruction

In designing this study, I selected two seventh grade classes. One class received the content instruction, while the other class received the content plus activities instruction. For the remainder of this thesis, these groups will be referred to as “content” and “content plus”. The instruction of the content and content plus groups took place immediately following the pre-assessment and spanned a time period of three weeks, or 15 hours. A self-created unit on the History of Plate Tectonics (Appendix A) was used as the basis of instruction. The unit was developed as a project for a graduate level course titled The History and Philosophy of Science Education, and uses a historical approach to teach NOS. The unit has been revised multiple times with input from my graduate advisor, an expert in science education at Arizona State University, to ensure the aspects of NOS are accurately represented. The unit was also revised based on feedback from other graduate students in the History and Philosophy of Science Education course. Revisions based on feedback from the other students in the course and my graduate advisor established content validity.

The curriculum materials available did not have a strong emphasis on the history of the theory of plate tectonics or the significance of NOS. The History of Plate Tectonics Unit was developed with the purpose of accurately representing NOS through a historical approach on the development of the theory of plate tectonics. Studying NOS through a historical approach is appropriate because this

theory of plate tectonics played a significant role in shaping the worldview of earth science. According to Solomon, Duveen, and Scot (1992) a historical approach has many benefits including increased student motivation, enhanced understanding of science content, and an increased awareness of science as a human endeavor. “Tracing the history of science can show how difficult it was for scientific innovators to break through the accepted ideas of their time to reach the conclusions that we currently take for granted” (NRC, 1996, p. 171).

The History of Plate Tectonics was created specifically for a seventh-grade general science classroom and addresses the following standards from the National Science Education Standards (NRC, 1996).

History and Nature of Science: Science has a Human Endeavor, Nature of Science, and History of Science

Earth and Space Science: Structure of the Earth System and Earth’s History

Seven lessons are included in the unit. Each lesson is based on the 5e lesson plan (Bybee et al., 2006) and consists of five parts: engage the learner, explore the concept, explain the concept and define the terms, elaborate on the concept, and evaluate students’ understanding of the concept. Each lesson also includes background information and scripted questions and possible student responses. The lessons are designed to provide explicit and reflective discussion of NOS. A brief description of each lesson is provided in Table 2.

Table 2

History of Plate Tectonics Lesson Overview

Lesson #	Lesson Title	Lesson Overview	NOS Aspects Addressed
1	Matching Coastlines	Students will observe the continents and make inferences based on the shapes of the coastlines.	Difference between observation and inference
2	Searching for Evidence	Students will decide which observations support their inference, and which observations are meaningless.	Observations are theory-laden
3	Explaining the Evidence	Students will to begin to develop an explanation using the evidence collected in lesson 2.	Scientific knowledge is partly the product of imagination, creativity, and inference
4	Location of Earthquakes and Volcanoes	Students will map out earthquakes and volcanoes around the world. This will lead them to change their inference to accommodate the unexpected location of earthquakes and volcanoes.	Scientific knowledge is tentative
5	Sea-floor Spreading	Students will analyze maps that show supporting evidence of seafloor spreading Students will revise their hypothesis about the continents to include more supportive evidence involving tectonic plates and sea-floor spreading.	Scientific knowledge is tentative
6	Convection	Students will explore the idea of convection by watching a demonstration of boiling rice and by conducting an investigation in which they analyze the motion of different water temperatures. Students will continue to strengthen their hypothesis with evidence related to convection and the movement of the plates.	Scientific knowledge is tentative
7	Revising a Theory	Students will write the theory of plate tectonics using the evidence collected throughout the plate tectonics unit. Students will generate new researchable questions and describe the significance of these questions in the future of plate tectonics.	Scientific knowledge is tentative

During the instruction, all students participated in the seven lessons of the History of Plate Tectonics unit in which they studied the development of the theory of plate tectonics and uncovered important themes such as the tentativeness of scientific knowledge, etc. This unit allowed for multiple exposures of the aspects of NOS addressed in this study. The four aspects (difference between observation and inference, the tentativeness of scientific knowledge, observations are theory-laden (subjective), and scientific knowledge is the product of inference, creativity, and imagination) were chosen for the study based on research that has concluded that these ideas are developmentally appropriate for middle school students (Lederman, 2007). The NSES (NRC, 1996) have also included these four aspects as important understandings middle school students should acquire.

The unit was highly contextualized allowing the students to experience NOS through the exploration of an authentic science subject included in the NSES (NRC, 1996): plate tectonics. Each lesson included explicit and reflective instruction. Examples from the history of the development of the theory of plate tectonics were used to contextualize the discussion of the NOS aspects in actual scientific practices. Students were asked to apply NOS aspects to the content. Descriptions of the informed understanding for each aspect of NOS are included in Table 3.

Table 3

Informed Understanding of NOS Aspects

NOS Aspect	Informed Understanding
Difference between observation and inference	<ul style="list-style-type: none"> • Observations are based on the senses • Inferences are conclusions made based on one or more observation
Observations are theory-laden	<ul style="list-style-type: none"> • Observations are guided by inferences, hypotheses, and theories • Inferences, hypotheses, and theories help scientists to interpret data and evidence • Prior knowledge and experiences influence observations
Scientific knowledge is partly the product of imagination, creativity, and inference	<ul style="list-style-type: none"> • Multiple explanations may be inferred from the same evidence/observations • Scientists may explain evidence differently based on different analyses of the same evidence
Scientific knowledge is tentative	<ul style="list-style-type: none"> • Even though an answer may be consistent with evidence, it may never be proven • Science is ongoing and knowledge changes as new information is obtained • As scientists learn more about the world they may change a theory based on new information or seeing information in a new way

In addition to the lessons and activities included in the History of Plate Tectonics Unit, the content plus group participated in four activities emphasizing specific aspects of the NOS. Detailed descriptions of these activities can be found in Table 4. Although the content plus group received additional activities, the length of the intervention was the same for both the content group and the content plus group. While the content plus group participated in generic activities focused on the aspects of NOS, the content group received additional time for reflective

discussion. The activities only required a short period of time, 10-15 minutes, and this time was replaced in the content group with additional dialogue within small groups or whole class. During this time the dialogue occurred between the students with little input from the instructor. The format for the equalized instruction can be seen lessons of the History of Plate Tectonics unit included in Appendix A.

Table 4

NOS Activity Descriptions

NOS Aspects Addressed	NOS Activity	NOS Activity Description
Difference between observation and inference	A “Burning” Question*	Students record observations of a burning “candle”, many of which turn out to be inferences. Candle is actually composed of string cheese with an almond sliver for a wick.
Observations are theory-laden	Perception and Conception: Two Sides of the Same Coin*	Students observe confusing pictures of familiar objects and read ambiguous descriptions of familiar experiences. Students can make little sense of these objects and descriptions until the teacher provides hints.
Scientific knowledge is partly the product of imagination, creativity, and inference	Real Fossils, Real Science**	Students observe a fossil fragment, and infer the shape/type of the dinosaur based on their observations.
Scientific knowledge is tentative	Trailing Fossil Tracks*	Students develop a story to explain patterns of fossil footprints. Their stories change as the teacher reveals more of the footprint-containing strata.

*From Bell (2008)

** From Lederman & Abd-El-Khalick (1998).

The lessons and activities were also presented within a conceptual change framework. The students first discussed their current understanding of scientific knowledge and how it progresses. The students then participated in an activity or lesson in which their understanding of the concept no longer fit. A new explanation of the concept was presented, and students had multiple opportunities to explore this new understanding within the content instruction, the real work of scientists, or other real-life examples. For example, the first lesson on observation vs. inference first required students to observe an image and list their observations. The students discussed their observations in small groups and then shared their definitions with the class. After the definitions were discussed, a new image was presented (ex. a bite was taken from the “candle”) in which students revisited their observations and determined that they were actually inferences. The difference between inference and observation was brought up numerous times throughout the unit. Eventually students were able to quickly correct their classmates when the term “observation” was used incorrectly.

In addition to the model of conceptual change, the content plus group also received explicit instruction that utilized the decontextualized/contextualized continuum as was suggested by Clough (2003). The explicit instruction included the activity (decontextualized) as well as the content (contextualized). Throughout the lesson and discussion, the connections between the activity and the content were referenced and explored multiple times.

Data Collection

Prior to the start of the unit, both classes took an assessment to determine their level of understanding of NOS, and this was evaluated as naïve, informed, or transitional. These labels are consistent with the most recent research on student conceptions of NOS. The assessment had four questions and each question focused on one aspect of the NOS. All questions had two parts: the first part consisted of a multiple choice question, and the second part required the student to explain their choice. If the student chose the correct response for the multiple-choice question and also included a correct explanation, the student was coded as having an informed understanding. If both the multiple choice question and explanation were answered incorrectly, the student was coded as holding a naïve view. A student who answered only one of the two parts correctly was considered to hold a transitional view.

A profile was created for each student consisting of their level of understanding, multiple choice answer, and key sentences from their explanation that were used to code their response. This profile was created for each of the four aspects of NOS. At the completion of the unit, the assessment was administered to the students a second time. The assessment was used to code students as naïve, informed, or transitional using the same analysis described above.

Data Analysis

Two different analyses were conducted in this study. The first was a descriptive analysis, which includes a description of the number of students

possessing each view (naïve, transitional, informed) for each aspect of NOS from pre- to post-instruction. The percentage of students holding each view for each aspect of the NOS was calculated to compare the change in student views. Data for each class was compared from pre- to post-instruction for each aspect of NOS. Student explanations were also examined qualitatively to determine their understanding of NOS. Illustrative quotes will also be provided to give more understanding pertaining to the descriptive data. The second analysis was a 2x2 Repeated Measures ANOVA. The ANOVA was conducted to determine if the change in student views from pre to post-assessment for each group were significant at the .05 level. The ANOVA was also used to determine if the interaction of content plus instruction was significant compared to the gains in learning of the content group.

Both quantitative and qualitative data was used to determine which instructional approach was most effective in promoting accurate conceptions of the NOS. That is, this study will determine if the NOS taught with explicit and reflective discussion with a supporting activity or the NOS taught with explicit and reflective discussion without a supporting activity is better at cultivating student understanding.

Limitations

There were a number of limitations to this study. Limitations applying to the student population included difference in ability and a possible difference in motivation. Although two classes were chosen based on similar achievement data,

differences in ability may have still impacted student scores thus influencing the data analysis. Student motivation may have also been an influential factor. The assessment required short answer explanations. Students who were unmotivated may have written a shorter response that did not provide enough insight to their thinking.

Limitations regarding instruction include time of day, differences due to student dialogue, and interruptions to instructions. The content plus group received instruction in the morning and the content group received instruction during the last class period of the day. These classes were necessary for the study due to similar student populations, but the time of day may have influenced the student's ability to focus. Student dialogue differed between the classes and influenced the direction of discussion and teacher response. Interruptions to classroom instruction such as announcements, fire drills, etc. were impossible to anticipate.

Other limitations such as the inability to conduct student interviews, the lack of an observer, and the possibility of subjective grading provide opportunities for further research. Most research in NOS suggests a pre- and post- assessment paired with semi-structured interviews. Misconceptions of NOS can often be difficult to reveal through the use of a paper-and-pencil assessment. However, because this study is action research the teacher was not able to interview students one-on-one as would be necessary in order to elucidate focused responses free from outside influence. In order to document the equalized instruction time and

consistent instruction and dialogue, an outside observer would be required. Again because of the limitations of action research an outside observer was not available.

Subjective grading has been a concern in past studies of student conceptions of NOS. Prior to grading the assessments, tools were created to lessen the possibility of subjective grading. Table 3, Informed Understandings of NOS Aspects, was created to assist in grading and ensure students were graded consistently. Future research should consider outside reviewers to grade the assessments to ensure interrater reliability.

Chapter 4

RESULTS

Overview

The instruction was presented to two intact classes, not to individual students so the class rather than the student is used as the unit of analysis. Results for each aspect of NOS will be discussed including descriptive data (Tables 5-8) and data from the 2x2 Repeated Measures ANOVA (Table 9).

Descriptive Analysis

Observation vs. Inference. The first aspect of NOS assessed was the difference between observation and inference. Students were asked to read a scenario and identify which of the statements were observations. Students were categorized as informed (I) if they chose the correct multiple-choice answer and displayed an informed level of understanding according to the Informed Understandings Table (Table 3). A student's response was correct if the following ideas were included in the short answer explanation:

Observations are based on the senses

Inferences are conclusions made based on one or more observations

Students who only answered one part of the question correctly were categorized as transitional (T). Students who answered both parts incorrectly were categorized as naïve (N). Students only discussing the definition of observation, even if correct, were marked incorrect.

Prior to instruction sixty-seven percent of the content group and seventy-one percent of the content plus group were found to have naïve views regarding the difference between observation and inference. No students in the content group were categorized as informed and only one student in the content plus group responded with an informed explanation. The percentages can be found in Table 5.

Table 5

Change in Views: Observation vs. Inference

	Content			Content Plus		
	Pre	Post	Δ	Pre	Post	Δ
I	0 (0%)	4 (12%)	4 (12%)	1 (3%)	16 (52%)	15 (48%)
T	11 (33%)	20 (61%)	9 (27%)	8 (26%)	11 (35%)	3 (10%)
N	22 (67 %)	9 (27 %)	-13 (39%)	22 (71%)	4 (13%)	-18 (58%)

Many students incorrectly defined observations as not only describing what you see, but also discussing possible explanations. An explanation from a student in the content plus group can be seen below.

“I chose C (The leaves of the plant are brown because the plant didn’t get enough water) because I thought it was the most specific answer. An observation to me is a specific answer with an answer to why. Joey observed that the plant leaves are brown. To be an observation he needs to say why the leaves are brown. Because they didn’t get enough water. If I observed that my hamster died of starvation because he didn’t get enough food”.

The data from Table 5 shows the content plus group had a greater change in the number of informed students from pre to post-assessment. After instruction twelve percent of the content group was categorized as informed compared to fifty-two percent of the content plus group. The number of informed views in the content plus group had an increase of forty-eight percent while the number of informed views in the content group only increased by twelve percent. This means there was a thirty-six percent difference in the number of informed views pre to post-instruction between the two groups. This is the largest difference (in change of informed views) found for all four aspects of NOS.

Observations are Theory-laden. Observations are theory-laden was the second aspect assessed in the NOS questionnaire. Students read a scenario about discovering planets and were asked to choose the answer that best described how scientific knowledge is discovered. Students were categorized as informed (I) if they answered the multiple-choice part correctly and provided a correct explanation with an example. According the Informed Understandings Table, students were expected to include the one of the following ideas in their response:

Observations are guided by inferences, hypotheses, and theories

Inferences, hypotheses, and theories help scientists interpret data and evidence

Prior knowledge and experiences influence observations

Unlike the results from the Observations vs. Inference question, the majority of the students were categorized as transitional rather than naïve on the

pre-assessment. The number of students categorized as transitional was forty-five percent in the content group and sixty-five percent in the content plus group. The students who were labeled transitional answered the multiple choice part correctly, but the short answer responses reflected an uncertainty regarding how scientific knowledge progresses. Many students discussed the importance of luck in scientific discoveries or the importance of following the scientific method. A response from a student in the content plus group is shown below.

“I believe that C (No, scientists must follow the scientific method in order to make a new discovery) is the answer because the scientists must follow a method to discover new objects.”

Table 6

Change in Views: Observations are Theory-laden

	Content			Content Plus		
	Pre	Post	Δ	Pre	Post	Δ
I	2 (6%)	5 (15%)	3 (9%)	1 (3%)	11 (35%)	10 (32 %)
T	15 (45%)	20 (61%)	5 (15%)	20 (65%)	14 (45%)	-6 (19%)
N	16 (48%)	8 (24%)	-8 (24%)	10 (32%)	6 (19%)	-4 (13%)

In the post-test the majority of the students were again categorized as transitional, sixty-one in the content group compared to forty-five percent in the content plus group. Most of the students were able to select the correct multiple-choice answer, but still struggled with the explanation. Student responses were marked as incorrect if an explanation was not provided which was the case for many of the students. An explanation for this trend is included in the discussion.

This aspect of NOS showed the least amount of change from pre to post-instruction according to the descriptive analysis.

Role of Creativity, Imagination, and Inference. The third aspect of NOS assessed was the role of creativity, imagination, and inference in the construction of scientific knowledge. Students were instructed to read a scenario on the extinction of the dinosaurs and explain why scientists disagree on the reason for the extinction even though they all have the same information. In order to be categorized as informed (I), students must have chosen the correct multiple choice answer and included the following in their short answer explanation

Multiple explanations may be inferred from the same evidence/observations

Students were also instructed to include an example in their response supporting the multiple choice answer they selected. As discussed in the limitations, interviews were not used to probe student responses. Therefore students who did not include an example were considered incorrect. Not enough information was available to confirm their understanding.

The pre-test views for this aspect of NOS were similar to the second aspect of NOS in that the majority of the students were categorized as transitional, fifty-eight percent for the content group and sixty-eight for the content plus group. Many students were able to choose the correct multiple-choice answer, but were not able to explain their choice and support it with an example. Many students, such as the student example below, attempted to construct an explanation using an

example from their everyday life. The use of a non-scientific example illustrates the lack of understanding regarding NOS.

“In my opinion I picked D (Disagreement is normal. Once the scientists talk they will all come to the same conclusion) because once they all come together they will have the same explanation. For an example at school you have a test and you get one answer wrong. You would ask a teacher or student how I got this wrong. Then you will see how you had it wrong, like information or the wrong numbers”.

Table 7

Change in Views: Role of Imagination, Creativity, and Inference

	Content			Content Plus		
	Pre	Post	Δ	Pre	Post	Δ
I	2 (6%)	11 (33%)	9 (27%)	0 (0%)	19 (61%)	19 (61%)
T	19 (58%)	13 (39%)	-6 (18%)	21 (68%)	10 (32%)	-11 (35%)
N	12 (36%)	9 (27%)	-3 (9%)	10 (32%)	2 (6%)	-8 (26%)

On the post-assessment, thirty-three percent of the content group provided an informed response compared to sixty-one in the content plus groups. The students labeled as transitional were able to select the correct multiple choice answer but were not able to explain their thinking thoroughly in the short answer. Not enough information was provided to determine if an informed view was attained. Interviews were not possible so the students were labeled as transitional.

The content plus group had a percentage change of sixty-one percent in the number of informed views, the most significant change of all four aspects of NOS. The content group only had a percentage change of twenty-seven percent.

This means there was a thirty-four percent difference in the change in the number of informed views from pre- to post-instruction between the two groups.

Tentativeness of Scientific Knowledge . The fourth and final aspect assessed required students to understand and explain the NOS aspect regarding the tentativeness of scientific knowledge. The students were instructed to read a scenario about the possibility of a theory changing over time. A short-answer explanation and example were required in order for a student to be categorized as informed (I). According to the Informed Understandings table, one of the following main ideas should have been included in the student’s response:

Even though an answer may be consistent with evidence, it may never be proven

Science is ongoing and knowledge changes as new information is obtained.

Table 8

Change in Views: Tentativeness of Scientific Knowledge

	Content			Content Plus		
	Pre	Post	Δ	Pre	Post	Δ
I	3 (9%)	14 (42%)	11 (33%)	2 (6%)	19 (61%)	17 (55%)
T	19 (58%)	13 (39%)	-6 (18%)	23 (74%)	9 (29%)	--14 (45%)
N	11 (33%)	6 (18%)	-5 (15%)	6 (19%)	3 (10%)	-3 (10%)

The high trend of transitional views on the pre-test for the previous two aspects is seen also with the aspect pertaining to the tentativeness of scientific knowledge. The majority of students in both groups were categorized as transitional for the pre-assessment, fifty-eight percent in the content group and

seventy-four percent in the content plus group. The students who were categorized as transitional were able to select the correct choice for the multiple-choice, but were not able to provide adequate support in their short answer explanation. A student in the content group provided the following response “I think B (no, although scientific knowledge may change, scientific theories will not change because they have been proven. Once enough evidence is collected a theory is proven) because once a theory is proven it can’t change because it’s already true. Ex. Super bowl 43 Santonio Holmes’ catch in the 4th quarter. They already had a clear view and now they can’t change it.” This is representative of a naïve view of the tentativeness of scientific knowledge.

Forty-two percent of the students in the content group were categorized as informed in the post-assessment, compared to sixty-one percent of the students in the content plus group. Again the content plus group had a more significant change in the number of informed views (fifty-five percent) when compared to the content group (thirty-three percent).

ANOVA Analysis

A 2x2 Repeated Measures ANOVA was used to determine if there was a significant difference from pre to post-instruction between the content and content plus groups. A summary of the ANOVA results can be seen below in Table 9.

Table 9

Summary of ANOVA

Source	Question #1 Significance	Question #2 Significance	Question #3 Significance	Question #4 Significance
Time	.000	.000	.000	.000
Time*intervention	.010	.671	.023	.719

P < .05

According to the results of the ANOVA, both groups had a statistically significant difference at the .05 level from pre to post-instruction for all four aspects of NOS. Both groups had a significance of $p = .000$ for the four aspects of NOS, which means both groups progressed in their understanding of NOS from pre to post-instruction.

Between groups from pre to post-test, there was a significant interaction for two aspects of NOS. According to the results of the ANOVA, the interaction was significant for question 1, “Observation vs Inference” ($p = .010$), and question, “Role of Creativity, Imagination, and Inference” ($p = .023$). There was no significant difference from pre to post-instruction between groups for the other two aspects of NOS, “Observations are Theory-laden” ($p = .671$) and the “Tentativeness of Scientific Knowledge” ($p = .719$).

Similarities exist between the ANOVA data and descriptive analysis which strengthen the reliability of the results for each analysis. According to both analyses, the most significant gains occurred on question 1 and question 3 for the content plus group. The ANOVA showed statistical significance at the .05 level for question 1 and question 3, and according to the descriptive analysis the largest

difference in change (of informed views from pre- to post-) occurred on question 1 (36%) and question 3 (34%).

The descriptive data and ANOVA results also present a similar conclusion for question 2 and question 4. According to the descriptive data for question 2, there was only a 23% difference between the two groups when comparing the change of informed view from pre- to post-assessment. For question 4, there was a 22% difference. This data provides evidence that students in the content plus group had statistically significant gains on two of the four aspects of NOS when compared to the content group. A discussion of the possible explanations for these results can be found in the following chapter.

Chapter 5

DISCUSSION

NOS has received increased attention over the past ten years by science researchers and science educators. It has been identified as a critical aspect in science education and is included in the NSES (NRC, 1996). A developed understanding of the aspects of NOS is critical in the development of scientifically literate students. Research over the past fifty years has shown that naïve views of NOS are held by students of all ages as well as science educators and other adults.

The purpose of this study was to investigate two variations of explicit instruction of NOS with the intent of identifying which of the two is more effective. The question guiding this study was: Is an explicit and reflective approach with supporting activities focused on NOS more effective than an explicit and reflective approach without supporting activities in promoting adequate views of NOS? Three important conclusions were drawn based on the results of this study. Each one will be discussed in depth in the following paragraphs.

The first conclusion relates to the observation that both of the groups, content and content plus, progressed in their understanding of NOS. This suggests that the History of Plate Tectonics Unit was effective in promoting growth in the understanding of the four assessed aspects of NOS. As shown in Table 9, Summary of ANOVA, time was significant at the .05 level, providing evidence

that both groups progressed in their understanding of NOS. The History of Plate Tectonics Unit was designed to explicitly address NOS aspects and both groups were expected to show growth. The results of this study are consistent with literature regarding effective instruction of NOS. Previous research has found that effective instruction of NOS is explicit, historically driven, and includes NOS aspects embedded in content. It is not one approach alone that will positively influence student views, but a combination of effective strategies. Because the History of Plate Tectonics Unit in this study incorporated many of the suggested instructional techniques in the literature review, more evidence exists to suggest that explicit instruction within a historical context with contextualized NOS instruction is successful in developing more adequate conceptions of NOS.

The second finding of this study relates directly to the research question: Is an explicit and reflective approach with supporting activities focused on NOS more effective than an explicit and reflective approach without supporting activities in promoting adequate views of NOS? According to the ANOVA data analysis in Table 9, a statistically significant gain was found for two of the four aspects: the difference between observation and inference and scientific knowledge is partly the product of imagination, creativity, and inference. This data suggest that the explicit and reflective approach with supporting activities may be more effective, but more research is needed.

Three possible explanations exist for the inequitable gains among the aspects of NOS. Previous research has found that some aspects of NOS may be

more accessible than others (Akerson, Abd-El-Khalick, & Lederman, 2000). Aspects such as the difference between observation and inference and the role of creativity, imagination, and inference may appear more easily to students within content instruction than other aspects. Seung, Bryan, and Butler (2009) also discussed the influence of the interrelatedness of aspects. Throughout the instruction of the History of Plate Tectonics Unit the relationship between the difference between observation and inference and scientific knowledge is the product of creativity, imagination, and inference was often emphasized thus the understanding of one aspect reinforced understanding of the other.

A second reason for the differential gains pertains to the NOS specific activities. A clearer connection between the activities and the aspects of NOS may have lead to stronger student conceptions pertaining to the difference between observation and inference and the role of creativity, imagination, and inference. The activities (A “Burning” Questions and Real Fossils, Real Science) may have more clearly portrayed the aspects of NOS and allowed for easier transition into the content than the other two activities.

A third reason for the inequitable gains relates to the assessment tool. Page Keeley (2005) discussed in her book *Uncovering Student Ideas in Science: 25 Formative Assessment Probes*, the challenges of creating an assessment tool that does not provide students with too much information. Many students were able to correctly identify the multiple choice answer in the second, third, and fourth aspects assessed: observations are theory-laden, scientific knowledge is a product

of creativity, imagination, and inference, and the tentativeness of scientific knowledge. Although a significant number of students answered the multiple choice correctly, the short answer responses reflected a naïve understanding. This suggests the possibility that some of the multiple choice questions may have been written in a way that students with naïve views were still able to choose the correct answer. The students seemed to have more difficulty answering the multiple choice part on the first question regarding the difference between observation and inference. This caused the mean pre-assessment score for the first question to be quite a bit lower than the other three aspects. The mean scores for the pre-assessment can be viewed below in Table 10. The minimum possible value was a 1 (naïve) and the maximum valued was a 3 (informed).

Table 10

Mean Scores of Pre-assessment

N	Question #1 Mean	Question #2 Mean	Question #3 Mean	Question #4 Mean
64	1.328	1.641	1.68	1.813

Because the mean scores for the pre-assessment were substantially higher for questions 2, 3, and 4, this may have caused the overall growth to appear lower.

In order to address the issue of validity relating to the multiple choice portion of the assessment, a second ANOVA was run on just the short answer part of the assessment. Each student was assigned a score of 0 or 1; the student received a 0 if their short answer explanation was incorrect and a 1 if their short

answer explanation was correct. The results of the ANOVA are displayed in

Table 11 below.

Table 11

Summary of ANOVA: Short Answer Explanations

Source	Question #1 Significance	Question #2 Significance	Question #3 Significance	Question #4 Significance
Time	.000	.000	.000	.000
Time*intervention	.001	.021	.006	.145

$P < .05$

According to the ANOVA results for the short answer explanations, there was a significant difference at the .05 level between the Content and Content Plus groups for three of the four aspects of NOS: Question 1 ($p=.001$), Question 2 ($p=.021$), and Question 3 ($p=.006$). This data provides further evidence that the multiple choice portion of the assessment may have inflated pre-assessment scores thus influencing the results of the study. According the ANOVA for the short answer, the Content Plus instruction was significantly more effective than the Content instruction for three aspects of NOS: observation vs. inference, observations are theory-laden, and scientific knowledge is partly a product of creativity, imagination, and inference. If this study were to be investigated a second time, a modified assessment tool would be suggested.

The ANOVA data provides evidence that students in the content plus group experienced significant gains when compared to students in the content group for two of the four aspects of NOS. A deeper look into the descriptive data analysis also suggests that the content plus group may have had a slightly higher

increase in overall growth in NOS from pre to post-assessment. Much of the discussion in the results section related to a higher percentage change of informed views for the content plus group compared to the content group. One possible explanation for this is that the activities were successful in enabling students to develop a stronger understanding of NOS. Further research is needed in this area. This data provides some evidence that the explicit and reflective approach with supporting activities may be superior over the explicit and reflective approach without supporting activities.

The third conclusion drawn from this study discusses the percentage of students in both groups who were found to still possess naïve or transitional views at the conclusion of the study. Although both groups progressed in their understanding of NOS, not all students exhibited informed views of the four aspects of NOS at the conclusion of the instruction. The tables found in Chapter 4 display the percentage of students still holding naïve views at the conclusion of the study. This is also consistent with previous research in that students' views are very robust and are resistant to change. Suggestions for further research include a longer instructional period as well as a stronger framework for conceptual change.

Implications

The findings of this study suggest many implications for the instruction of NOS. In order to address the naïve conceptions of students and science educators, it is critical to address the components of effective instruction of NOS.

Past research has found that explicit and reflective discussion is necessary in promoting informed conceptions of NOS, and this is further supported by the findings of this study. Both approaches investigated in this study, explicit with content and explicit with content plus activities, lead to growth in the understanding of NOS and can be recommended as effective instructional approaches. Explicit instruction does not assume that students will understand NOS simply by participating in activities in which they explore the work of scientists and the ways in which scientific knowledge progresses. Explicit instruction acknowledges that students need to be provided with opportunities to discuss NOS as it applies to the content, work of scientists, and the progression of scientific knowledge.

The findings in this study also support the use of a historical unit in which NOS can be easily integrated. Other content areas may not lend themselves to the exploration of aspects of NOS as easily.

Informed conceptions of NOS rely not only on effective instructional strategies, but also on the views and knowledge of the educators. Despite the inclusion of NOS in the National Science Education Standards (NRC, 1996), change in the standards does not mean change in teacher beliefs and instructional approaches. In order to promote informed conceptions in students, science educators must also have informed conceptions and be motivated to develop these conceptions in students.

NOS activities may be a temporary solution for teachers who currently do not possess informed views of NOS, or are unfamiliar with effective instructional strategies. NOS activities are an easy way for teachers to communicate key aspects of NOS using hands-on strategies. The activities require very little content knowledge which allows all students the opportunity to explore and understand NOS. The learners are free from having to struggle with the complex scientific concepts as they try to internalize NOS.

Future Research

The findings of this study align with previous research in NOS pertaining to the number of students who continue to possess naïve conceptions of NOS after explicit instruction. Future research in student conceptions of NOS should focus more deeply on instructional strategies, context of instruction, frameworks for student learning, and more reliable methods of assessing student growth.

Science researchers stress the importance of explicit instruction, but the different variations of explicit instruction require more research. This study focused on two variations of explicit and reflective instruction, NOS in content and NOS in content plus supporting activities. The study provided some evidence in support of additional activities integrated into content instruction, but research into this specific instructional approach is still needed. A closer look at the development of student conceptions throughout the unit would be beneficial in determining the influence of the activities on NOS conceptions. Pre- and post-assessments are limited in the information they provide. Formative assessments

and student interviews throughout are suggested to more closely monitor the development of student conceptions.

As with any subject in science education, the more exposure the students are provided the better. This study included approximately three weeks of explicit instruction. The findings of this study show that not all students held informed conceptions of NOS at the conclusion of the study. Would a longer intervention lead to a higher percentage of informed views? The length of the intervention as well as the context should be considered. Suggestions for further research include an extended instructional period in which students experience NOS in multiple contexts. NOS should be integrated throughout all content instruction, rather than constrained to one unit. Future studies should investigate the two variations of explicit instruction (content and content plus) throughout a full year of instruction. This would require the development of multiple units to ensure NOS aspects are explicitly taught within a historical context.

The study of student learning through a year of instruction would also provide data regarding the development of informed conceptions of NOS in different contexts. The History of Plate Tectonics Unit aligned closely with the four aspects of NOS addressed in this study. Future research should investigate the following questions: Which other content areas provide an appropriate context in which to teach NOS? Do some contexts lend themselves more nicely than other contexts?

Many frameworks for student learning exist in science education. Frameworks specifically suggested for NOS instruction include the “distributed” model, “assembled” model, “input-output” model, and a framework of conceptual change. This study applied a conceptual change framework to the instruction of the NOS activities, but future research should strengthen the conceptual change model of the instruction. The use of formative assessments and interviews discussed above could track the influence of the conceptual change framework.

The research design of this study, action research, limited the resources available to assess student growth in the understanding of aspects of NOS. A revised and expanded assessment tool, student interviews, and instructional observers would all increase the validity and reliability of the study.

A modified assessment tool is suggested. Some of the questions may have been leading. Many of the students reported that some of the answers sounded “right”, even though they were unfamiliar with the content and aspects of NOS. This is a challenge in the development of multiple choice assessments. Students are programmed to be “smart” test takers and an assessment tool utilizing the multiple choice format is difficult to create. The format of the assessment tool should remain the same, but the multiple choice part of the assessment for the last three aspects should be revised. The assessment tool should then undergo a pilot test to ensure validity and reliability.

This study also illuminated the importance of student interviews. Student interviews would have been useful in determining which students circled the

response because it sounded right, and the students who chose the multiple-choice response because they understood the progression of scientific knowledge. As a classroom teacher, interviews were not possible because of constraints in the classroom. It is strongly suggested that future studies overcome these barriers and pair student interviews with the assessment tool.

The content of the questions in the assessment tool may also need to be modified. The use of the term “theory” may be inappropriate for this assessment tool because the definition of the term was not included in the instruction. Rather than modifying the language of the assessment tool, another option is to incorporate the relationship between hypothesis, theory, and law and the difference between a scientific theory and the common everyday language theory into the History of Plate Tectonics Unit.

Another possible option for the modification of the assessment tool is to use content from the unit in the assessment tool. Would student responses have been different if the questions related directly to the content of the unit? In many of the explanations, students tried to use the example used in the scenario to support their answer, rather than connect the question to experiences within the unit. This may be an issue of transfer of knowledge and calls for further research.

Despite the national push to include NOS in science education, it continues to be omitted or misrepresented in many science classrooms. The findings of this study bring us one step closer to understanding the development of student views of NOS, but many questions still remain. The instruction of NOS

is as complex as the science it represents. NOS remains to be a multifaceted subject reliant on effective instructional strategies, curriculum materials, and knowledge and motivation of science educators. Further research into multiple areas of NOS instruction is needed to close the gaps in students learning.

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APPENDIX A
HISTORY OF PLATE TECTONICS UNIT

Unit Title: Exploring the Nature of Science through Plate Tectonics

Grade: 7th

Subject/Topic Area: Earth Science (Geology): Plate Tectonics

Key Words: continental drift, plate tectonics, plate boundaries, lithosphere, lithospheric plates, convection, evidence, hypothesis, theory

Designed by: Melissa Melville Time Frame: 3 weeks

School District: Kyrene School District School: Centennial Middle School

Brief Summary of Unit: Students will understand and develop the theory of plate tectonics while engaging in activities to strengthen their understanding of the nature of science. Students will be presented with pieces of evidence that support continental drift in the order the evidence was discovered. Students will work as a group to develop hypotheses to support the theory that the continents have moved over time. Students will be required to revise their hypothesis throughout the unit to accommodate new evidence and support the theory that the continents have moved over time. At the end of the unit the students will understand the history behind the development of the theory of plate tectonics: how it started, who was involved, and the supporting and contradicting evidence. Students will also be aware of how this knowledge fits our present day understanding of the plates and the implications this theory holds for science in the future.

Arizona State Standards:

- **S1C1PO1:** Formulate questions based on observations that lead to the development of a hypothesis.
- **S1C1PO3:** Explain the role of a hypothesis in a scientific inquiry.
- **S1C3PO1:** Analyze data obtained in a scientific investigation to identify trends.
- **S1C3PO2:** Form a logical argument about a correlation between variables or sequence of events.

- **S1C3PO3:** Analyze results of data collection in order to accept or reject the hypothesis.
- **S1C3PO6:** Refine hypotheses based on results from investigations.
- **S1C3PO7:** Formulate new questions based on the results of a previous investigation.
- **S1C4PO5:** Communicate the results and conclusions of the investigation.
- **S2C1PO1:** Identify how diverse people and/or cultures, past and present, have made important contributions to scientific innovations.
- **S2C1PO2:** Describe how a major milestone in science or technology has revolutionized the thinking of the time.
- **S2C2PO1:** Describe how science is an ongoing process that changes in response to new information and discoveries.
- **S2C2PO2:** Describe how scientific knowledge is subject to change as new information and/or technology challenges prevailing theories.
- **S6C1PO3:** Explain the following processes involved in the formation of the Earth's structure: Plate Tectonics
- **S6C2PO3:** Analyze the evidence that lithospheric plate movements occur.

Objectives:

***Students will know:**

- Distinction between observation and inference
- Scientific knowledge is subjective (theory-laden)
 - Observations are guided by theories or ideas
- Scientific knowledge is partially based on human inference, imagination, and creativity
 - Multiple explanations may be inferred from the same evidence/observations.
- Scientific knowledge is tentative (subject to change)
 - Even though an answer may be consistent with evidence, it may never be proven.
 - Science is ongoing and knowledge changes as new information is obtained.

***Students will be able to:**

- Explain the theory of plate tectonics with supporting evidence.
- Explain the development of the theory of plate tectonics.
- Create a timeline illustrating the development of the theory of plate tectonics.

Lessons:

Introduction activity: Card Game

- 1. Matching Coastlines (2 60 minute class periods)**
 - a. Observations vs. Inferences (Candle Activity)
 - b. Scientific knowledge is based on observations
- 2. Finding evidence for Continental Drift**
 - a. Observations are theory-laden (Laundry and pictures)
- 3. Explaining the Evidence (Lesson 4: Reconstructing Pangaea and Lesson 5: Writing the Theory of Continental Drift - Not everyone may have this theory)**
 - a. Multiple explanations may be inferred from the same evidence/observations.
 - b. Scientific knowledge is partly a product of human inference, imagination, and creativity (Real Fossils, Real Science)
- 4. New Technology Reveals Location of Earthquakes and Volcanoes**
 - a. Scientific knowledge is tentative
- 5. The Seafloor is Spreading!**
 - a. Scientific knowledge is tentative
- 6. Layers of the Earth and Convection**
- 7. Revising a Theory**
 - a. Scientific knowledge is tentative (Trailing Fossil Tracks)

	1	2	3	4	5	6	7	8	9
S1C1PO1	X	X							
S1C1PO3			X						
S1C3PO1				X		X			
S1C3PO2		X	X			X			
S1C3PO3	X					X	X		
S1C3PO6			X		X	X	X		
S1C3PO7		X		X	X	X	X	X	
S1C4PO5			X		X	X			
S2C1PO1			X		X	X			X
S2C1PO2						X			X
S2C2PO1	X	X	X		X	X	X		X
S2C2PO2	X		X		X	X	X		X
S6C1PO3	X						X	X	X
S6C2PO3	X		X				X	X	

Lesson 1: Matching Coastlines (Observations vs. Inferences)
Experimental: ACTIVITY

Grade Level: 7th

Arizona State Standards:

- **S1C1PO1:** Formulate questions based on observations that lead to the development of a hypothesis.
- **S2C2PO1:** Describe how science is an ongoing process that changes in response to new information and discoveries.
- **S2C2PO2:** Describe how scientific knowledge is subject to change as new information and/or technology challenges prevailing theories.

Objectives:

Students will understand

- **Distinction between observation and inference**
- Scientific knowledge is subjective (theory-laden)
 - Observations are guided by theories or ideas
- **Scientific knowledge is partially based on human inference, imagination, and creativity**
 - Multiple explanations may be inferred from the same evidence/observations.
- Scientific knowledge is tentative (subject to change)
 - Even though an answer may be consistent with evidence, it may never be proven.
 - Science is ongoing and knowledge changes as new information is obtained.

Materials:

- Present day world map for each group (political map, not physical map)
- Continent puzzle pieces for each group
- Large whiteboard for each group
- Whiteboard markers and erasers

Engage the Learner (20 minutes):

1. Class discussion - Define observation

<u>Content Plus</u>	<u>Content</u>
<ul style="list-style-type: none">• Teacher lights candle and	<ul style="list-style-type: none">• Pass out a world map to each

<p>students observe (see attached lesson: Observation or Inference: A "Burning" Question)</p> <ul style="list-style-type: none"> • Instruct students to work in groups to record four observations on a piece of notebook paper. Each student should write at least one observation. • Discuss one observation from each group as a class. 	<p>group of students.</p> <ul style="list-style-type: none"> • Ask students to observe the shape of the continents. • Instruct students to work in groups to record four observations on a piece of notebook paper. Each student should write at least one observation. • Discuss one observation from each group as a class.
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Explore the concept:

<u>Content Plus</u>	<u>Content</u>
<ul style="list-style-type: none"> • Teacher reveals composition of candle. • Ask the class to think about the meaning of the word "inference". What is its relationship to observations? Class discussion about observations vs. inferences. Observations lead to inferences. • Which of the statements on the whiteboards are observations? Which are inferences? Students should label each statement on their whiteboards as an observation or inference. • Display the observations and inferences from two groups - do we agree? 	<ul style="list-style-type: none"> • If students do not write, "Coastlines of Africa and South America fit together", ask if this is an observation. Discuss why or why not. • Ask the class to think about the meaning of the word "inference". What is its relationship to observations? Class discussion about observations vs. inferences. Observations lead to inferences. • Which of the statements on the whiteboards are observations? Which are inferences? Students should label each statement on their whiteboards as an observation or inference. • Display the observations and inferences from two groups - do we agree?

Explain the Concept and Define the Terms (20 minutes):

(observation, inference)

1. Students should write the following definitions in their science notebooks. Observation: Information obtained through the use of one or more senses. Inference: A judgment or conclusion made as the result of one or more observations.
2. Discuss the statements as a class. Did each group correctly identify their statements? If you labeled the statement as an inference, write the observation that lead to that inference.
3. Discussion: We often make inferences when we think we are making observations. Recognizing this natural tendency is the first step toward making more accurate observations, an important process skill. Inference is a critical component of much of what we know. We rely not only on what we see, but what we infer. Scientists construct knowledge from observation and inference, not observation alone.

Relate to candle activity

Elaborate on the Concept (20 minutes)

<u>Content</u>	<u>Content Plus</u>
<ul style="list-style-type: none">• Pass out a world map and puzzle pieces to each pair of students.• Students should make observations about the shape of the continents in their science notebooks.	<ul style="list-style-type: none">• Continue discussion• Allow students to ask questions and respond to each other.

- Students should make inferences based on their observations. Students should record the following entry in their notebook: "Why do the coasts of Africa and South America have similar shapes?" They are to write this journal entry as if they were scientists in the 1500's. During the 1500s mapmakers began to notice the matching coastlines and scientists began to offer suggestions as to why Africa and South American appear to have once fit together. Remind

students that at this time this was the only evidence available to support the idea the continents may have once been joined.

- Students discuss their inferences with their group. Together they decide on an explanation to present to the class. Each group should record their explanation on a large whiteboard.
- Each group will present their explanation. Students will be encouraged to question and debate each explanation. This process models the actions of scientists when the idea of the continents once being connected was first suggested.
- The following questions may be used to encourage discussion and debate. If possible guide the students into asking these questions - they are the scientists.
 - a. What is your evidence? (Discuss observation vs. inference again)
 - b. Were the continents always this way? Is it possible the matching coastlines are a coincidence?
 - c. If the students suggest the continents were once together: How do you know? Can you prove this idea? What caused the continents to separate? What causes them to move? Are they still moving? Students will be giving a lot of "I don't know" responses. This is okay. Scientists during this time were not able to offer many explanations as to what caused the continents to separate - this is why many of the suggestions were highly criticized. (Discuss difference between a hypothesis and theory)
 - d. Why might your idea not be accepted? (not able to answer important questions, religious views, stubborn thinking)
 - e. Was the idea that the world was round immediately accepted? Explain.
 - f. What questions could you ask/explore to further support your explanation?
- Brainstorm as a class - What are other possible inferences to explain the matching coastlines of South American and Africa?
 - a. Catastrophists believed rare and rapid events such as a powerful flood tore the continents apart. This idea was

supported by calculations that the Earth was 6,000 years old. This idea existed for almost 200 years, until family histories showed the Earth was a lot older.

Evaluate Students' Understanding of the Concept (20 minutes)

1. Discussion: What is the difference between observation and inference? Why are they so important in science? **Scientific knowledge is partially based on human inference, imagination, and creativity.** It is important to recognize when we are making inferences and to understand that inferences may be incorrect/unaccepted by the scientific community because we do not have enough evidence. **(Discuss candle activity)**
2. Each student will answer questions on worksheet for lesson one.

References:

Bell, R.L. (2008). *Teaching the nature of science through process skills: Activities for grades 3-8*. Boston, MA: Pearson Education, Inc.

Lesson 2: Searching for Evidence Experimental: ACTIVITY

Grade Level: 7th

Arizona State Standards:

- **S1C3PO6:** Refine hypotheses based on results from investigations.
- **S1C4PO5:** Communicate the results and conclusions of the investigation.
- **S2C1PO1:** Identify how diverse people and/or cultures, past and present, have made important contributions to scientific innovations.
- **S2C2PO1:** Describe how science is an ongoing process that changes in response to new information and discoveries.
- **S2C2PO2:** Describe how scientific knowledge is subject to change as new information and/or technology challenges prevailing theories.
- **S6C2PO3:** Analyze the evidence that lithospheric plate movements occur.

Lesson Overview:

Students start to develop the theory of continental drift by researching evidence of fossils of ancient plants and animals and similar mountains and rock layers.

Objectives:

- Distinction between observation and inference
- **Scientific knowledge is subjective (theory-laden)**
 - **Observations are guided by theories or ideas**
- Scientific knowledge is partially based on human inference, imagination, and creativity
 - Multiple explanations may be inferred from the same evidence/observations.
- Scientific knowledge is tentative (subject to change)
 - Even though an answer may be consistent with evidence, it may never be proven.
 - Science is ongoing and knowledge changes as new information is obtained.

Materials:

- [Evidence Cards \(8 total - 1 for each group\)](#)
- [World Map \(Outline of Continents\) worksheet for each student](#)
- Atlas to use as a reference
- Science Notebooks

Engage the Learner:

<u>Content Plus: Perception and Conception: Two Sides of the Same Coin</u>	<u>Content</u>
<ul style="list-style-type: none"> • Show picture of ink blots and ask students to observe • Show outline of dog and discuss importance of having a framework • Read laundry discussion • Explain to students that the passage is about laundry and read again 	<ul style="list-style-type: none"> • Review lesson 1 • Have each group whiteboard their explanation and briefly explain.

- Based on the previous lesson, most of us agree that the continents were once together. Our explanations however are different. (Alfred Wegener thought they drifted apart, biblical flood, etc).
- Where would you begin to look for evidence to support this idea? (Students who believe it is just a coincidence would search for evidence showing the opposite).
- Guide students toward fossil evidence and matching rock layers and mountains.

Explore the concept:

- In the previous lesson students wrote a hypothesis to explain the matching coastlines of Africa and South America. Review these explanations and the possible hypotheses. Ask students
 - "Why are hypotheses, theories, and ideas important in science?" (Possible answers: they guide research, they give us something we can test or investigate)
 - "What kind of information would be helpful to determine how the continents might have fit together in the past?"

- To answer this question it may be helpful for students to look at puzzle pieces. What about the puzzle pieces helped you to fit the pieces together? (shape/outline, image on piece).
- Students should arrive at the idea that more evidence needs to be collected to support the hypothesis that the continents used to be connected such as other matching coastlines, land formations, rock layers, and plant and animal fossils. Have students imagine the classroom torn in two - what evidence would convince people the two halves of the classroom belong together.
- Discuss the meaning of evidence and how it can be supporting or contradicting. Ask students "Do you think it is important to consider contradicting evidence and opposing ideas?" "Can opinions count as evidence?"
- Guide students toward the following idea: "You know that similar animals can be found on South America and Africa such as turtles, snakes, and lizards. You also know that North America and Europe have similar species such as grizzly bears, wolverines, and trees such as beeches and larches. Curious, you decide to look into fossil records to see if the same is true for extinct animals and plants."

Explain the Concept and Define the Terms (supporting evidence and observations)

- Tell students "You have decided to research fossil records in the library".
- Provide each group with an envelope with observations. Each observation represents the findings of other scientists.
- Each student should record observations that are meaningful to their theory in their science notebooks. (Goal is for students to skip over any evidence that is not meaningful).
- You continue your research and collect more evidence. - Students should travel around the room and discuss their findings with other students. The goal is to discover as much evidence as possible and record it in your science notebook.

- Explain to students that they will be defending their inference and trying to convince their colleague that their inference is correct. Will this observation support their idea?
- Not all students may write down the same observations. This is okay - our inferences drive our observations. If they were only looking for evidence for South America and Africa, they may have skipped over evidence relating to the other continents.

Elaborate

- Discussion
 - How many students wrote down the observation about the matching mountains on South America and Africa? Why or why not?
 - How many of you wrote down the opinion from the magazine? Why or why not?
 - How many wrote down about the matching mountains on North American and the Scottish Highlands? Why or why not?

Evaluate

- Discussion: The pictures and passages did not change. But now you have a framework that allows you to interpret data. Without the framework you could not make sense of the data. A primary role of perceptual frameworks is to inform us about what to look for. Context is critical for making sense of what we read or observe. Models and theories are incredibly powerful because they help scientists interpret their observations by providing the big picture and by helping them decide which details to pay attention to and which to ignore. **Only use certain parts for control**
- Notebook Entry
 - How did you decide which pieces of information to record in your science notebook? How did you decide which information to ignore?
 - Inferences, hypotheses, and theories
 - Guide observations
 - Tell us what to look for

- Provide a framework that allows us to make sense of data and observations
- Help scientists interpret their observations by providing the big picture
- Example: If you inferred that South America and Africa were once together, you probably wrote down the evidence that included South America and Africa.

References:

Bell, R.L. (2008). *Teaching the nature of science through process skills: Activities for grades 3-8*. Boston, MA: Pearson Education, Inc.

Lesson 3: Explaining the Evidence Experimental: ACTIVITY

Grade Level: 7th

Arizona State Standards:

- **S1C3PO1:** Analyze data obtained in a scientific investigation to identify trends.
- **S1C3PO7:** Formulate new questions based on the results of a previous investigation.

Lesson Overview:

Students develop a theory to explain their evidence from lesson 2.

Objectives:

- Distinction between observation and inference
- Scientific knowledge is subjective (theory-laden)
 - Observations are guided by theories or ideas
- **Scientific knowledge is partially based on human inference, imagination, and creativity**
 - **Multiple explanations may be inferred from the same evidence/observations.**
- Scientific knowledge is tentative (subject to change)
 - Even though an answer may be consistent with evidence, it may never be proven.
 - Science is ongoing and knowledge changes as new information is obtained.

Materials:

- World map for each student
- Colored pencils
- Evidence from lesson 2
- Whiteboard for each group

Engage the Learner:

- Tell students "You begin to realize that fossils of many different species have been found on different continents. Intrigued by this finding you decide to map out the findings of different fossils".

Explore

- Students should map out each piece of evidence. Each map should have a map key. The map key should include a symbol/picture for each piece of evidence. (Alternative: stickers/stamps?).
- Display the list of evidence the students may have discovered:
 - Matching Coastlines
 - Mesosaurus fossils
 - Glossopteris fossils
 - Megascolecina fossils
 - Cynognathus fossils
 - Lystrosaurus fossils
 - Mountains
 - Glacier marks
 - Coal

Explain the Concept and Define the Terms:

<u>Content Plus (Real Fossils, Real Science)</u>	<u>Content (Extra time for discussion)</u>
<ul style="list-style-type: none">• Give each pair of students a fossil fragment.• Ask students to trace the outline of their fossil fragment on a separate sheet of colored construction paper. Cut out the tracing and discard of it.• Using it as a stencil, trace the fossil onto another sheet of paper.• Using a different color pencil instruct students to complete their fossil drawing of an organism from which, they believe, the fossil fragment has come. (this will be considered their inference and should be connected to the explanation they will infer	<ul style="list-style-type: none">• Have each group briefly describe three pieces of evidence they believe is significant.• What could explain the evidence of similar fossils and landforms on different continents? Students should discuss this in groups. (Land bridges that sunk over time, continents drifted, continents were torn apart by a flood, coincidence)

based on the evidence collected in lesson 2)	
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Elaborate on the Concept

- Students should write out a thorough explanation on the whiteboards explaining the evidence.

Content Plus	Content
<ul style="list-style-type: none"> • Present fossil stencil and completed organism. Explain the organism's diet, habitat, and other information inferred from the fossil fragment. • Discussion: Students made inferences about the complete organism based on careful observations of the original fossil fragment and their prior knowledge (knowledge of dinosaurs, habitat, diet, etc.) Students eventually came up with several plausible explanations; similar to the explanations created to explain the evidence of continental separation. Usually students will narrow down the possibilities to a single preferred explanation, but the evidence is not conclusive. This process works in terms of producing explanations that fit the evidence, even if scientists can't prove that such explanations are "true". 	<ul style="list-style-type: none"> • Have each group present their whiteboard. • Discussion: Students eventually came up with several plausible explanations to explain the evidence of continental separation. Usually students will narrow down the possibilities to a single preferred explanation, but the evidence is not conclusive. This process works in terms of producing explanations that fit the evidence, even if scientists can't prove that such explanations are "true".

Evaluate Students' Understanding of the Concept.

Class Discussion:

- Why are the explanations different? Do we really know what happened? Will we ever know what really happened? How do scientists know so much about things they cannot directly observe?

Journal Entry:

- Did everyone in the class come up with the same explanation/inference?
 - Although the class was looking at the same evidence, groups came up with different explanations.
- Why did the inferences differ if everyone was looking at the same evidence?
 - Multiple explanations can be inferred from the same evidence.
- How do scientists know so much about things they cannot directly observe?
 - Scientific knowledge is partly a product of human inference, imagination, and creativity.
 - Science involves the invention of explanations, and this requires a lot of creativity by scientists.
 - Even though scientists may be looking at the same observations and evidence, their imagination and creativity may cause them to create a different explanation than other scientists.

References:

Lederman, N.G. & Abd-El-Khalick, F. (1998). Avoiding de-natured science: Activities that promote understandings of the nature of science. In W.F. McComas (Ed.), *The nature of science and science education: Rationales and strategies*. (pp. 83-126). Dordrecht, The Netherlands: Kluwer.

Lesson 4: New Technology Reveals the Location of Earthquakes and Volcanoes

Grade Level: 7th

Arizona State Standards:

- **S1C3PO1:** Analyze data obtained in a scientific investigation to identify trends.
- **S1C3PO2:** Form a logical argument about a correlation between variables or sequence of events.
- **S1C3PO3:** Analyze results of data collection in order to accept or reject the hypothesis.
- **S1C3PO6:** Refine hypotheses based on results from investigations.
- **S1C3PO7:** Formulate new questions based on the results of a previous investigation.
- **S1C4PO5:** Communicate the results and conclusions of the investigation.
- **S2C1PO1:** Identify how diverse people and/or cultures, past and present, have made important contributions to scientific innovations.
- **S2C1PO2:** Describe how a major milestone in science or technology has revolutionized the thinking of the time.
- **S2C2PO1:** Describe how science is an ongoing process that changes in response to new information and discoveries.
- **S2C2PO2:** Describe how scientific knowledge is subject to change as new information and/or technology challenges prevailing theories.

Lesson Overview:

Students will research earthquakes and volcanoes around the world. Students will map the location of earthquakes and volcanoes and use this information to identify plate boundaries.

Objectives:

- Distinction between observation and inference
- Scientific knowledge is subjective (theory-laden)
 - Observations are guided by theories or ideas

- Scientific knowledge is partially based on human inference, imagination, and creativity
 - Multiple explanations may be inferred from the same evidence/observations.
- Scientific knowledge is tentative (subject to change)
 - Even though an answer may be consistent with evidence, it may never be proven.
 - Science is ongoing and knowledge changes as new information is obtained.

Materials:

- Laptop (or books) for each group
- Outline map for each student
- 2 different colored pencils for each student

Engage the Learner:

- Review the previous lesson. As a class discuss all present scientific information and the ideas to explain this evidence.
- Explain to the students that it is now the 1920's and new seismology equipment has improved scientists' abilities to locate earthquakes and volcanoes. Students are to take on the role of a seismologist (scientist who studies earthquakes) and map the location of different earthquakes and volcanoes around the world.

Explore the concept:

- Each group should research fifteen earthquakes and fifteen volcanoes and record the following information: Location (country location and coordinates), date, and magnitude. Suggest the following website to students: National Earthquake Information Center <http://earthquake.usgs.gov/regional/neic/>
- Each student should label the location of the earthquakes (green) and the volcanoes (red) on their world map.

Explain the Concept and Define the Terms (lithospheric plates

- Ask students, "What do you notice about the location of the earthquakes and volcanoes?" Students may notice that earthquakes and volcanoes occur all over the world, but many occur in the oceans. Why is this?
- Discuss the location of mid-ocean ridges. What does this tell you?

- Introduce the term "lithospheric plates"

Elaborate on the Concept

- Using their maps, students should work with another person in class to identify the plate boundaries. Each student should map the other students finding on their map.
- Ask, "What information do you need to locate the specific plate boundaries?"
- Pass out puzzle pieces of the plates to the students.
- Ask, "How do these plates compare to the plates you drew on your map?"

Evaluate Students' Understanding of the Concept

- Notebook Entry: List 3 observations relating to earthquakes and volcanoes.

Earthquakes key: <http://pubs.usgs.gov/gip/dynamic/zones.html>

Lesson 5: Seafloor Spreading

Grade Level: 7th

Arizona State Standards:

- **S1C3PO3:** Analyze results of data collection in order to accept or reject the hypothesis.
- **S1C3PO6:** Refine hypotheses based on results from investigations.
- **S1C3PO7:** Formulate new questions based on the results of a previous investigation.
- **S2C2PO1:** Describe how science is an ongoing process that changes in response to new information and discoveries.
- **S2C2PO2:** Describe how scientific knowledge is subject to change as new information and/or technology challenges prevailing theories.
- **S6C1PO3:** Explain the following processes involved in the formation of the Earth's structure: Plate Tectonics
- **S6C2PO3:** Analyze the evidence that lithospheric plate movements occur.

Lesson Overview:

Students will analyze maps that show supporting evidence of seafloor spreading. Working in groups, students will piece together the following evidence to create the idea of seafloor spreading: 1) at or near the crest of the ridge, the rocks are very young, and they become progressively older away from the ridge crest; 2) the youngest rocks at the ridge crest always have present-day (normal) polarity; and 3) stripes of rock parallel to the ridge crest altered in magnetic polarity, suggesting that the Earth's magnetic field has flip-flopped many times.

Objectives:

- Distinction between observation and inference
- Scientific knowledge is subjective (theory-laden)
 - Observations are guided by theories or ideas
- Scientific knowledge is partially based on human inference, imagination, and creativity

- Multiple explanations may be inferred from the same evidence/observations.
- Scientific knowledge is tentative (subject to change)
 - Even though an answer may be consistent with evidence, it may never be proven.
 - Science is ongoing and knowledge changes as new information is obtained.

Materials:

- Science notebooks
- Online maps and visuals
 - http://www.ngdc.noaa.gov/mgg/ocean_age/data/2008/ngdc-generated_images/whole_world/2008_age_of_oceans_plates.pdf
 - <http://pubs.usgs.gov/gip/dynamic/stripes.html>

Engage the Learner:

- Discuss previous lesson and new scientific information available.
- Explain to students that new technology has allowed scientists to collect data on the age of the ocean floor and map the age of the oceanic lithosphere. Here are the findings:
- Show map "Age of Oceanic Lithosphere"
http://www.ngdc.noaa.gov/mgg/ocean_age/data/2008/ngdc-generated_images/whole_world/2008_age_of_oceans_plates.pdf
- Students should whiteboard 5 observations of the map. Students should see that oceanic lithosphere is youngest at the plate boundaries and gets progressively older as you move away.
- Discuss observations as a class. Record significant observations in science notebook. At this point scientists are beginning to develop the idea of seafloor spreading.

Explore the concept:

- Explain to students that further investigation has produced the following new scientific information.
- Discuss the visual found on the following website:
<http://pubs.usgs.gov/gip/dynamic/stripes.html>
- The idea of magnetic striping may be difficult for some students to understand. It would be helpful to discuss the information on the

webpage as well as the following notes from the timeline: 1950's: Scientists using magnetic instruments adapted from airborne devices developed during World War II to detect submarines, began recognizing odd magnetic variations across the ocean floor. The bottom layer of the ocean is composed of hardened magma known as basalt, which contains magnetic minerals. When the basalt cools and hardens, these minerals line up with Earth's magnetic field, which periodically reverses its polarity. The basalt showed that new seafloor must be constantly produced at each mid-ocean ridge, from which it spreads out to both sides.

- Students should add the recent discovery of magnetic striping to their notebooks: the youngest rocks at the ridge crest always have present-day (normal) polarity, and stripes of rock parallel to the ridge crest altered in magnetic polarity, suggesting that the Earth's magnetic field has flip-flopped many times

Explain the Concept and Define the Terms (seafloor spreading, magnetic striping)

- What inference can we make based on this information?
- Discuss the term "seafloor spreading": occurs at [mid-ocean ridges](#), where new [oceanic crust](#) is formed through [volcanic activity](#) and then gradually moves away from the ridge. Students should record this definition in their notebooks.
- Ask students, "How is this idea supported by the new scientific information we discovered today?" Students should record this information in their notebook.

Elaborate on the Concept

- Ask students to review the explanation they recorded in their notebooks.
- How does this new information fit with the explanation? Can your theory accommodate these new findings? Why or why not? What does this mean? Students should come to the conclusion that the theory needs to be revised to accommodate the new scientific information.
- Create a new explanation that accommodates the new information.
- Discussion:

Evaluate Students' Understanding of the Concept

Journal Entry

- How have your ideas changed regarding the explanation for the position of the continents?
- What was responsible for these changes?
- How did these changes affect your theory?

Lesson 6: Convection

Grade Level: 7th

Arizona State Standards:

- **S1C3PO7:** Formulate new questions based on the results of a previous investigation.
- **S6C1PO3:** Explain the following processes involved in the formation of the Earth's structure: Plate Tectonics
- **S6C2PO3:** Analyze the evidence that lithospheric plate movements occur.

Lesson Overview:

Students will explore the idea of convection by watching a demonstration of boiling rice and by conducting an investigation in which they analyze the motion of different water temperatures.

Objectives:

- Distinction between observation and inference
- Scientific knowledge is subjective (theory-laden)
 - Observations are guided by theories or ideas
- Scientific knowledge is partially based on human inference, imagination, and creativity
 - Multiple explanations may be inferred from the same evidence/observations.
- Scientific knowledge is tentative (subject to change)
 - Even though an answer may be consistent with evidence, it may never be proven.
 - Science is ongoing and knowledge changes as new information is obtained.

Materials:

- Teacher: hot plate, pot, water, rice
- For each student group (Note: this lab is a variation of a lab in the *SEPUP Issues and Earth Science curriculum: Activity 46: Convection Currents*. If materials are not available the following activity may be supplemented: <http://www.pcids.org/share/sci8/labs/concurlab.htm>)

- Supply of warm water
- Supply of cold water
- 2 plastic cups
- 1 plastic syringe
- 1 plastic cup with circular depression
- 1 small vial with 2-holed cap
- 1 bottle of red food coloring

Engage the Learner:

- Ask students to respond to the following question in their science notebooks, "If evidence shows the sea-floor is spreading, why is the Earth not changing in size?"
- Discuss with the class Hutton's idea the movement of earth are similar to a conveyor belt - show students an image of a conveyor belt to help them understand the cyclical motion of a conveyor belt.
- Have students research Harry Hess. Ask students the following questions:
 - Who is Harry Hess?
 - What ideas did he propose?
 - How do his ideas fit with your theory of continental movement?
 - What questions do you have about his ideas?

Explore the concept:

- Teacher demonstration: Boil rice. Ask students to record their observations before the water boils, while the water boils, and after the water has cooled.

Explain the Concept and Define the Terms (convection)

- Ask students to explain the motion of the rice.
- Relate this motion to the idea of convection: the circular movement of materials caused by a temperature difference.
- Students draw and label a scale drawing of the layers of the Earth.

Elaborate on the Concept

- Provide students with the following materials: warm water, cold water, 2 plastic cups, 1 plastic syringe, 1 plastic cup with circular depression, 1 small vial with 2-holed cap, and 1 bottle of red food coloring. Note: this lab is a variation of a lab in the *SEPUP Issues and Earth Science curriculum: Activity 46: Convection Currents*. If materials are not available the following activity may be supplemented: <http://www.pcds.org/share/sci8/labs/concurlab.htm>
- Students should follow the procedures from Activity 46: Convection Currents

Evaluate Students' Understanding of the Concept

- Students should respond to the following question in their science notebook:
 - What do you think is necessary for a convection current to form?
 - Imagine that hotter magma is lying beneath an area of cooler magma deep in the mantle. What do you predict will happen? Be as specific as you can and explain your reasoning.
 - What do scientist believe causes plates to move.
- Students should generate three questions they still have about the movement of the plates. (such as how many convection cells exist? Where and how do they originate? What is their structure? Do other planets have similar processes?)

References:

<http://pubs.usgs.gov/gip/dynamic/unanswered.html>

Lesson 7: Revising a Theory

Grade Level: 7th

Arizona State Standards:

- **S2C1PO1:** Identify how diverse people and/or cultures, past and present, have made important contributions to scientific innovations.
- **S2C1PO2:** Describe how a major milestone in science or technology has revolutionized the thinking of the time.
- **S2C2PO1:** Describe how science is an ongoing process that changes in response to new information and discoveries.
- **S2C2PO2:** Describe how scientific knowledge is subject to change as new information and/or technology challenges prevailing theories.
- **S6C1PO3:** Explain the following processes involved in the formation of the Earth's structure: Plate Tectonics

Lesson Overview:

Students will write the theory of plate tectonics using the evidence collected throughout the plate tectonics unit. Students will generate new researchable questions and describe the significance of these questions in the future of plate tectonics.

Objectives:

- Distinction between observation and inference
- Scientific knowledge is subjective (theory-laden)
 - Observations are guided by theories or ideas
- Scientific knowledge is partially based on human inference, imagination, and creativity
 - Multiple explanations may be inferred from the same evidence/observations.
- Scientific knowledge is tentative (subject to change)
 - Even though an answer may be consistent with evidence, it may never be proven.
 - Science is ongoing and knowledge changes as new information is obtained.

Materials:

- Science notebooks

Engage the Learner:

Content Plus (Trailing Fossil Tracks)	Content
<ul style="list-style-type: none">• Display one small part of the fossil tracks image. Students should record observations and inferences.• Display a larger area of the picture. Students should add to their observations and revise their inferences.• Continue displaying larger sections of the fossil tracks.• Have students discuss the observations from the plate tectonics unit and how when we put them together we were able to form inferences.	<ul style="list-style-type: none">• Ask students to whiteboard the most significant piece of evidence they uncovered in the plate tectonics unit. Students should explain the significance of this piece of evidence.• Each group will present their whiteboard. Students should be encouraged to ask questions if the ideas on the whiteboard are not clear.• Have students discuss the observations from the plate tectonics unit and how when we put them together we were able to form inferences.

Explore the concept:

- After groups have presented discuss other evidence that may have not been discussed.
- Students should review their notebook entries throughout the plate tectonics unit.

Explain the Concept and Define the Terms (plates, theory of plate tectonics)

- Class discussion:
 - How have our ideas changed?
 - What information do we have now that was not available to Alfred Wegener?
 - Do you think Alfred Wegener's ideas would have been more widely accepted if he had this information available to him? Why or why not? Why was his idea of continental drift criticized? Would this information satisfy those criticisms?

Elaborate on the Concept

- Review the definition of plates.
- Students will now whiteboard the theory of plate tectonics in groups. They should be encouraged to be as thorough as possible including all available evidence and reasoning.
- Groups will compare and contrast the whiteboards. Three similarities and three differences should be recorded.
- Groups will participate in a gallery walk in which they walk around the room analyzing each board and draw a star on the board they believe has the most scientific theory.

Evaluate Students' Understanding of the Concept

- Have students create a Venn Diagram in which they compare/contrast the theory of continental drift and the theory of plate tectonics.
- On the back of the Venn Diagram students should write their theory of plate tectonics and explain how this theory was developed.
 - Did their ideas change from Lesson 1 to Lesson 9?
 - How did their ideas change?
 - What caused your ideas to change?
 - How was new evidence discovered?
 - How did they accommodate new evidence?
 - Were their ideas accepted by the class? Why or why not?
 - Were they accepting of others ideas?
 - Would it be easier or more difficult to develop the theory of plate tectonics on your own?

- Relate your answers to the work of Alfred Wegener. How did he revolutionize thinking during that time?
- Exit slip: Students will record three unanswered questions on the theory of plate tectonics.

References:

Bell, R.L. (2008). *Teaching the nature of science through process skills: Activities for grades 3-8*. Boston, MA: Pearson Education, Inc.

APPENDIX B
NOS ASSESSMENT

The Classroom Plant

Directions:

Read the scenario and choose the best answer.

It's Joey's turn to water the classroom plant for the week. When he goes to water the plant he notices the leaves are brown and the soil is dry. It was Monica's responsibility to water the plant last week. Joey turns to Monica and says, "The leaves are brown because you didn't give the plant enough water!"

Which of these is/are an observation?

- A. The leaves of the plant are brown.
- B. The plant didn't get enough water.
- C. The leaves of the plant are brown because the plant didn't get enough water.
- D. Both *A* and *B* are observations.
- E. I don't have enough information to answer this question.

Please explain your thinking below. Use an example to explain your answer.

Discovering Planets

Directions:

Read the scenario and choose the best answer.

Monica and Joey are looking at the sky during the night to see planets. Monica sees an object she can't identify using her star chart, which indicates planets. She wonders if she made a new discovery. She says to Joey, "I think I found a planet, and that's how scientists discover new planets. They observe the night sky and get lucky and find a new planet".

Do you agree with Monica?

- A. Yes, scientists see what they expect to see. Monica wanted to see a planet and she did.
- B. Yes, scientists depend on luck to make major discoveries.
- C. No, scientists must follow the scientific method in order to make a new discovery.
- D. No, scientists are guided by a theory or idea and their knowledge of the topic influences their observations.
- E. I don't have enough information to answer this question.

Please explain your thinking below. Use an example to explain your answer.

Extinction of the Dinosaurs

Directions:

Read the scenario and choose the best answer.

Scientists agree that about 65 million years ago the dinosaurs became extinct (all died away). However, scientists disagree about what had caused this to happen.

Why do you think they disagree even though they all have the same information?

- A. Scientists may explain evidence differently based on different analyses of the same evidence.
- B. Some of the scientists have analyzed the evidence incorrectly.
- C. Every scientist should arrive at the same explanation if they have the same information.
- D. Disagreement is normal. Once the scientists talk they will all come to the same conclusion.
- E. I don't have enough information to answer this question.

Please explain your thinking below. Use an example to explain your answer.

Theories

Directions:

Read the scenario and choose the best answer.

Monica is learning about hypotheses, theories, and laws in science class. The teacher asks Monica if a theory can every change.

What should Monica say? Can a theory change?

- A. No, scientific theories are based on facts. Facts are certain and will never change.
- B. No, although scientific knowledge may change, scientific theories will not change because they have been proven. Once enough evidence is collected a theory is proven.
- C. Yes, as technology improves we change our theories.
- D. Yes, as scientists learn more about the world they may change a theory based on new information or seeing information in a new way.
- E. I don't have enough information to answer this question.

Please explain your thinking below. Use an example to explain your answer.
