

**Teaching and Learning Nature of Science in Elementary Classrooms: Research Based Strategies for
Practical Implementation**

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Abstract: This manuscript is contextualized in previous research on methods to improve elementary students' of ages 5 to 12 conceptions of Nature of Science (NOS). Research based strategies are divided into introductory, inquiry/hands on, and debriefing strategies. In each case the strategies are explicit and reflective, as has been found through previous research to be effective in improving learners' conceptions of NOS. Also included are suggestions for classroom assessment of NOS ideas. Use of children's literature, science notebooks, writing, discussion, and other strategies are shared within each of the categories of introducing NOS ideas, embedded in inquiry, and debriefing strategies. The strategies are research based can be practically implemented in elementary classrooms, and are adjustable for various elementary grade levels. The manuscript discusses the importance of future research to determine even more strategies for practically teaching NOS in elementary classrooms.

Keywords: Nature of Science, Elementary, Teaching Strategies, NOS learning

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1. Introduction

In the United States, the Next Generation Science Standards (NGSS Lead States, 2013) are most referenced as targets for science teaching kindergarten through high school. Though not a main emphasis within the NGSS, other than being in Appendix H, there are aspects of Nature of Science (NOS) for K-6 students embedded throughout the document, such as through connections to NOS that are in the standards. These aspects are: (a) Scientific investigations use a variety of methods (e.g. there is no one scientific method); (b) Scientific knowledge is based on empirical evidence (e.g. requires evidence); (c) Scientific Knowledge is open to revision in light of new evidence (e.g. scientific knowledge is tentative); (d) Science models, laws, mechanisms, and theories explain natural phenomena (e.g. through observations of data and inferences about those observations); (e) Science is a way of knowing (e.g. science is only one way of knowing, and is different from other ways of knowing, such as philosophy, art, etc.); (f) Scientific knowledge assumes an order and consistency in natural systems (e.g. this assumption enables scientists to search for patterns in the data, draw conclusions and develop scientific knowledge; (g) Science is a human endeavor (e.g. though science seeks to be objective, scientists are human and therefore there is an element of subjectivity, scientific knowledge is embedded in human culture, and is also a product of human creativity); and (h) Science addresses questions about the natural and material world (e.g. science cannot answer all questions, such as those that are religious or metaphysical). Though these aspects of NOS are embedded within the NGSS for all Kindergarten through high school grade levels, there are some who question whether elementary (grades kindergarten through sixth grade in the United States, or ages 5-12) students can develop sophisticated understandings of NOS.

Through research, we have found that the use of appropriate teaching strategies enable teachers to help elementary students to improve their conceptions about NOS. In this article we share general research-based teaching strategies that can help teachers improve K-6 students' conceptions of NOS. A review of several studies that focused on improving students' conceptions of NOS shows that students as young as five are able to conceptualize NOS ideas (Authors, 2011). Prior research shows that some NOS aspects, such as observation and inference, creativity, tentativeness, and the empirical NOS are likely more readily

accessible to students than subjectivity or the socio-cultural aspects of NOS possibly because these elements are less abstract. However, school age students are able to improve their understandings of all NOS aspects through instruction (Authors, 2014). Conceptualizing NOS is a component of scientific literacy. A scientifically literate person can ask, find, or determine answers to questions derived from curiosity about everyday experiences; describe and predict natural phenomena; read with understanding articles about science in the popular press and to engage in social conversation about the validity of the conclusions; identify scientific issues underlying national and local decisions and express positions that are scientifically and technologically informed; evaluate the quality of scientific information on the basis of its source and the methods used to generate it; pose and evaluate arguments based on evidence and to apply conclusions from such arguments appropriately (NRC, 1993; 2013). These characteristics of a scientifically literate person are directly related to NOS components.

1.1 Types of research-based teaching strategies

So what kinds of strategies are effective in improving students' conceptions of NOS? In designing NOS instruction for K-12 students, we know from prior research that we should use explicit, reflective instruction (Lederman, 2007). Explicit-reflective NOS instruction draws students' attention directly to the emphasized NOS aspects through teachers' questions and by asking students to reflect on the science investigations in which they were involved; in other words directly connecting students' NOS understandings to the science content. NOS aspects need to be explicitly connected to the science investigations that the students are conducting, thus contextualizing NOS through scientific practices and disciplinary core ideas. Black box activities, where students need to make observations of a hidden item and then infer what is inside, can be used to introduce NOS aspects so students can conceptualize these ideas and then connect them to science content knowledge development. These kinds of activities enable the teacher to draw attention to NOS aspects using familiar and concrete examples, and provide a foundation upon which content-embedded instruction can occur. Using a variety of these activities enables the teacher to draw connections to NOS aspects across different examples so students can see aspects of NOS through various contexts.

Research has shown that teaching K-12 students about NOS aspects can take place as part of regular classroom science instruction, by being connected to science lessons that are already part of the

classroom, through explicit-reflective instruction (Authors, 2014). To begin, it is important to familiarize students with the particular NOS aspects addressed in the lesson, as well as any other science content being covered. To be able to conceptualize NOS students need to be aware of the NOS elements, and these introductory activities highlight these aspects in ways that students can conceptualize these ideas. These introductory activities can include reading children's literature, presenting a short demonstration or inquiry project, or using a K-W-L chart (what we Know, what we Want to know, and what we Learned). Once the concepts have been introduced, research has shown that NOS is best taught through inquiry (Authors, 2010). Following the introductory activity the students should be engaged in a hands-on inquiry activity that enables the teacher and the students to connect the NOS aspects to the investigation. For example, students can make observations and inferences about a toy car as it is pushed across a variety of surfaces. Students record observations and test different surfaces; they can then generate explanations about the scientific phenomena and share their results with one another. They can reflect on how they are making observations and inferences (through their evidence-based explanations), and developing their understanding of the kinds of surfaces on which cars move best. The teacher can lead them to conceptualizing scientific creativity by noticing that they are "creating an understanding of which surfaces cars move best."

Finally, as NOS instruction has been shown to be most effective when taught not only explicitly, but also reflectively (Authors, 2000). Thus, it is imperative to debrief the inquiry so that students can engage in metacognition about their understandings of NOS. Debriefing should include a discussion of NOS aspects present in the inquiry and questioning that allows students to reflect on how science is practiced. For instance, the teacher can either direct the students to think about various NOS aspects present in the inquiry, or ask students to discuss the aspects they noted (with examples) that were present in their inquiry.

Using these strategies of explicitly introducing the NOS within the lessons, teaching the lessons, and debriefing the lessons for students to reflect on aspects of NOS within science practice should not be thought of as something done only once, but as part of all science lessons within the curriculum. A one shot lesson about NOS will have limited, if any, success (Authors, 2006). We describe specific examples of these strategies in subsequent sections of this paper.

2. Embedding NOS Teaching into Existing Curricula

We are aware that in the U.S., most science curricula do not explicitly embed NOS in the lessons. Therefore, the teacher needs to be able to connect NOS to the lessons within the unit, making connections and designing assessments for student understandings. For instance, we have had experience teaching through the FOSS *1-2 Balance and Motion* unit (Full Option Science System [FOSS], 2017). This excellent hands-on kit based unit leads students through many interactive explorations of balance and motion that lead students to understand forces related to what helps things balance, and what puts them into motion. However, the teacher would need to help the students identify the components of the investigations that connect them to NOS, such as their engagement in the tentative NOS in how they are modifying their designs or the empirical NOS through the identification of their ideas of what contributes to items being balanced based on evidence. Similarly, the teacher can connect the creative NOS by asking them to note that as they are creating designs for what contributes to something spinning, they are creating an understanding for what initiates an item to spin (and to spin the longest, for example). Teachers can ask students to make observations of their designs, and inferences for factors that contribute to making things roll (and roll “best”). Furthermore, as an example of the subjective NOS, teachers can also ask students to think about what they have learned about balance and motion that influence how they subsequently design their roller coasters (e.g., that their background knowledge influences how they design their roller coasters). We recommend that the teacher ask students to make records of their science content knowledge as well as their NOS aspect knowledge on worksheets or in science notebooks. In these (and other) ways, the teacher can embed NOS into existing science curricula, enabling them to contextualize their NOS instruction into content that their students will learn in their classrooms, this case literacy content. Below we share some ideas for embedding NOS into existing curricula.

2.1 Introductory activities for teaching NOS

To teach NOS aspects it is necessary for teachers to embed them into existing science curricula that may not contain explicit prompts, instruction, or assessments of students’ NOS understandings. It is certain that most students may not have heard of scientific inferences (however they may have heard of, and be able to connect it to, a reading comprehension skill), or terms like “empirical evidence” and “subjectivity,” or even Nature of Science itself. Therefore these terms need to be introduced to students

initially, in a way that connects to former ideas, or through a science lesson that connects the NOS aspects through investigations. Next we share strategies of class discussions, modeling thinking about NOS, using children's literature, and the use of science notebooks as examples of introductory strategies.

2.2.1 Class Discussion.

To engage students in explicit discussions of NOS, teachers can design a NOS poster that includes the targeted NOS aspects, along with definitions and cartoon drawings, to introduce the NOS terms in a manner that is accessible to elementary students. See the appendix for an example of such a poster that was developed with elementary teachers in a research-based professional development program (Authors, 2009). This poster can support teachers in introducing the NOS terms, as well as to continue to reference the NOS terms throughout subsequent science lessons by referring to the poster at various points in the lesson. To initially use the poster the teacher can hold a conversation with students regarding “the nature of science.” The teacher can ask students, “What do you think science is? What makes science itself, and not called something like math?” The teacher can then allow responses, and states, “The nature of science really is what makes science ‘science.’ It is the characteristics of science that make it unique to itself.” Then the teacher can read each aspect and definition from the poster, and talk about the terms in “kid friendly” language. Of course, this is simply an introduction to the terms, and certainly the students should not be expected to fully conceptualize the ideas. This introduction can come before or after a science investigation. If it comes after a science investigation, we recommend that the teacher use examples from that lesson to reinforce conceptual understanding and label the concept with their scientific terms. If the introduction to NOS comes before a science investigation, the teacher can ask students to think about these aspects as they conduct their investigations. The teacher can then use the poster to ask the students to reflect on their investigation (an example of explicit reflective NOS instruction) as the teacher draws students' attention to the NOS aspects before and after a hands-on investigation.

2.2.2 Modeling thinking about NOS.

From the class discussions section above it is clear that the teacher plays a strong role in emphasizing NOS through interactions with students. The teacher can also use a “think aloud” strategy to model ways to think about NOS in connection within science inquiry lessons, as has been found successful with mathematics lessons (Henjes, 2007). For example, the teacher can model the think-aloud strategy in an

investigation where students explore a mystery material to determine whether it is a solid or a liquid: Oobleck, a material that actually has characteristics of both solids and liquids. The teacher can say, “Well, I think this material has elements of both solids and liquids. It makes it tough to figure out and put it in one category. I am going to think about NOS ideas. Hmm...I can see that I was making observations that the material (Oobleck) takes the shape of its container, which is my empirical evidence! First, I inferred it was a liquid, because a characteristic of a liquid is that it takes the shape of the container. Then, I inferred it was a solid because I couldn’t poke my finger through it and I know solids are hard. Finally, I inferred it may somehow be a solid and a liquid at the same time because it has characteristics of both. I am using the tentative nature of science because I am changing my mind about the evidence. I am also being creative like a scientist because I am creating an understanding of what this stuff is—I think it may be a solid AND a liquid. Now I have to create a new category because it won’t fit in the original categories. This is another example of the tentative and creative nature of science! I knew it had characteristics of a solid AND a liquid because I had background knowledge of solids and liquids, which is my subjectivity coming out. Science is amazing!” The teacher could then point out that scientists created a category for fluids like Oobleck they call “non-Newtonian.”

By reflecting aloud along with the students (the students can also be asked to join in on these reflections and add their own ideas) the teacher thus models thinking about NOS in connection with the content and science investigation that the students just completed. Then, in later investigations the teacher gradually releases the modeling and asks the students to do more of the reflecting aloud and on their own.

2.2.3 Children’s literature.

Elementary students are accustomed to having stories read to them by the teacher, and children’s literature can be used to teach about NOS and reinforce NOS concepts (Authors, 2010). For example, a teacher can use *The Skull Alphabet Book* (Pallotta & Masiello, 2002) during an activity on fossils. This book cleverly connects the letters of the alphabet to skulls of animals whose names begin with each letter. Through making observations of clues in the text and in the accompanying drawings, the reader infers the animal that the skull belongs to, thus leading directly to a discussion of scientific observation and inference. This kind of book also lends itself to a discussion of the role of empirical evidence in the development of

scientific knowledge because the skulls represent the data source, or empirical evidence, about which we are making observations and inferences.

Indeed, this book also lends itself to a discussion of the subjective NOS, as people are not likely to infer animals with which we are unfamiliar. This can be illustrated by animals in the book that may be unfamiliar to students, such as the Narwhal whale. Students are often familiar with whales, but not often specifically with the Narwhal, and therefore do not infer a whale, which then leads to a discussion regarding the reliable, yet tentative NOS because not all whales have similar characteristics. The teacher can then provide background knowledge regarding the Narwhal whale and discuss with the students how their inferences may change when given more information about this particular whale. This procedure is just like a scientist may change an inference by reconsidering all the evidence they have or when they obtain new evidence. Indeed, this story can also be used to explore scientific creativity as the teacher can lead a discussion of how scientists create an understanding of an animal based on the skull it leaves behind. The students can be led to discuss how scientists infer missing data, skin color and coverings, and still create a reasonable and reliable, but tentative, picture of the animal.

2.2.4 Science notebooks.

Science notebooks are an excellent tool to promote science learning (Morrison, 2005). The teacher can also use science notebooks to aid in their students' understandings of NOS. Students can use these notebooks to record data, ideas, questions, and reflections. These reflections can connect to science disciplinary core ideas as well as to student understandings of NOS aspects. For example, the teacher can ask students to describe in their own words what they believe the NOS aspects mean and then hold a class discussion. Student responses can be listed on chart paper that hangs in front of the room. Students can then be asked to record the terms with the definitions generated by the class in their notebooks, using the chart to guide them with spelling, if needed. Also, if students are not writing yet, teachers or classroom helpers can record the students' ideas in their notebooks, while they are instructed to illustrate their ideas. These notebooks can then be used as an individual assessment of students' conceptions of various NOS aspects.

Teachers can additionally ask students to reflect on the NOS aspects in their science notebooks after investigations, supporting reflective NOS instruction. Indeed, student responses to NOS prompts following investigations can be listed on chart paper in front of the classroom and students can be

instructed to record in their own notebooks ideas with which they agree, or other ideas they have regarding NOS aspects that were present in their investigations. Again, the use of notebooks to emphasize NOS aspects is another example of explicit-reflective NOS instruction.

2.3 Inquiry-based activities

It is critical to engage students in scientific inquiry when teaching NOS, either before or after introducing students to the NOS aspects. If students do not have an opportunity to actually investigate phenomena, it will be difficult for them to connect the terminology to experiences that are similar to the work of scientists. Thus, contextualizing their learning in actual science investigations is important. In the following sections, we describe strategies for emphasizing NOS during activities, including the use of hands-on activities, guided to open inquiries, teacher questioning, observation and inference charts, science notebooks, charts/graphs/classifying, and working in teams.

2.3.1 Hands-on activities.

It has been long known that students must engage in hands-on, minds-on science investigations, as opposed to only learning through teacher demonstration (Flick, 1993). These activities allow students to raise questions, collect data, and make observations and inferences of phenomena. It is through manipulating materials themselves that students can engage in the practices of science, and then later (or even during) reflect on when they were making observations and inferences, how they were being creative like scientists, when they are changing their minds about data or because they collected new data, and how their own or the background knowledge of those in their group influenced their interpretations.

For example, during an activity in which students make Play-Doh fossils, the students themselves can actually create the impression of an item as a fossil. Then, students can share these self-made fossils with their peers, who can work to determine which item likely made the fossil impression. Students can be asked whether and how they are being creative during such an investigation. They may certainly agree they are being creative when making the fossil, but they can also be directed to notice that they are being creative like scientists when they are determining what item was likely to have made the impression in a peer's fossil. The teacher can also direct students to notice the kinds of evidence the students are using to make observations and then infer what item was likely used to create the peer's fossil. Teachers can point out that they may not know for sure what item was used to create the impression, yet they can make

reasonable inferences based on their observations of the data and on their background knowledge (subjectivity) of items that could possibly make such impressions. In this way, the teacher is using hands-on investigations to directly connect NOS elements for the students—this is another important example of explicit-reflective NOS instruction.

2.3.2 Guided to open inquiry.

Students should engage in a variety of inquiries from guided (mostly teacher-led) to open (mostly student-led) as they are exploring science and connecting NOS to science content. For example, teachers can use guided inquiries to help students conceptualize how to design and carry out an investigation by planning the investigation along with them. The teacher can use a think-aloud strategy and/or help students connect their investigations to NOS ideas by using the NOS poster described earlier. When students have experience engaging in guided inquiry, the teacher can gradually release student to allow them to design their own science investigations, and with the teacher's permission, carry them out. Then, similar to the guided inquiry, teachers can ask students to think about how and where NOS aspects were present in their work. Further, the teacher can ask students to reflect on these NOS aspects through the use of the NOS poster and/or record their ideas in their science notebooks. If the students are struggling to connect their ideas, the teacher can use a think-aloud strategy to model how to think about NOS ideas in connection with an investigation.

For example, as part of a unit on buoyancy, students can be asked to design an investigation that enables them to determine whether popcorn floats. This inquiry can build on a unit on floating and sinking, and therefore the teacher can facilitate a class discussion surrounding what the students already know about floating and sinking that may influence their inquiry designs. The teacher can also discuss with the students what they know about scientific investigations, for example, the characteristics of a fair test. After the students design an investigation, they can then carry it out, and the teacher can draw their attention to the data through questioning. Some example questions include: Did the popcorn float and sink? Did it matter if they put it in salt water or plain water (for those groups who planned a comparison)? Did it matter if they used popped or unpopped corn (for those who planned a difference)? The teacher can also use the NOS poster to hold a discussion and have students elaborate on how they were scientifically creative in designing the investigation and in interpreting evidence. Students can discuss how they were using their

background knowledge to design the investigation as well as interpret data, and also making observations of what occurred and inferences about whether popcorn floated. The teachers can ask students to notice that their results were tentative because if, for example, they had used salt vs. plain water, or popped vs. unpopped corn they may have had different outcomes. In this way, the students can both design their own scientific inquiry as well as connect NOS elements to the investigation.

2.3.3 Teacher questioning.

Teachers can use questions phrased in ways such that they draw attention to NOS aspects in connection with science investigations, as they do when helping students learn other science content (Harlen, 2015). For example, while students are observing phenomena, the teacher can ask, “What are your observations? Are you able to make any inferences right now based on your observations? Do you think your ideas about what is occurring might change? What might make them change?” These kinds of teacher questions can draw students’ attention to their investigations as well as to how their investigations are connected to NOS. For example, in a unit on inventions the teacher can ask students to design a paper airplane that stays aloft the longest. Students can design airplanes and test them. The teacher can then ask questions such as, “What are your observations about the airplane designs we have so far? Can you make any inferences about what might contribute to keeping the airplanes in the air longer? What changes might you make in your design based on what you see?” Then students can make these changes in their designs, and re-test their airplanes. The teacher can then raise more questions, such as, “So, how did your ideas change after you tested your design? Do you think scientists change their ideas after they conduct investigations? Would you make more changes based on your second test? Do you think you can ever find the “best” design? Why or why not? How have you been creative like a scientist during your investigations of your airplanes?” These questions can be embedded during the time students are investigating, or even raised after the investigation as a debriefing activity. Connecting these questions directly to the tenets of NOS is a further example of explicit reflective NOS instruction.

2.3.4 Observation and inference charts.

Teachers can ask students to record observations and inferences of phenomena on a chart or in their notebooks. These observations and inferences can be reported to the class for discussion. We have seen teachers successfully use an observation and inference chart that students can use in many different

investigations (Authors, 2009). This chart consists of two columns. In one column, students list the observations they are making, and in the next column they make complementary inferences. For example, during an investigation to determine whether Oobleck is a solid or a liquid, students can list their observations (e.g., it is green, it doesn't pour, it takes the shape of its container) and their inferences of those observations (e.g. it is a solid, it is a liquid, it is both). In this way, the teacher facilitates explicit-reflective NOS instruction as the students make distinctions between observations and inferences during a hands-on investigation.

2.3.5 Science notebooks.

Some ways to incorporate science notebooks into NOS instruction have already been discussed, however they can also be used to help students reflect on both science content and NOS during and after a scientific investigation (Morrison, 2005). The teacher can provide students writing prompts to encourage them to reflect on their content knowledge as well as their NOS understandings. Following a class discussion about the same topic, the teacher can ask students to write using prompts such as, "Did anyone make any observations or inferences in this investigation? [allow discussion] Please record those in your notebooks." Or "What was your empirical evidence in this investigation?" Or "How were you creative like a scientist in this investigation?"

During investigations students can record data as the teacher points out the importance of collecting empirical evidence in the development of scientific understandings. For instance, in a unit on electric circuits, students can draw and write their initial ideas for how to light a bulb using a battery and a wire. As they investigate the problem the teacher can be ask students to record other ideas they try, and finally, different ways they are able to light the bulb. Teacher can ask students to reflect in their notebook recordings how their ideas changed as they collected more data regarding how to light a bulb. Students can reflect on their writings for how they were being scientifically creative their investigations, and for instances of where they were using observations and inferences in their explorations. Further, they can record their ideas of where NOS aspects were present in their investigations on how to light a bulb. In this unit on electric circuits, for example, students can continue to record and reflect on their changing ideas as the teacher helps them to understand the importance of evidence, the role of observation and inference, and

the tentative NOS as their ideas develop through investigations. This example of explicit reflective NOS instruction suggests how teachers to continue emphasizing NOS using science notebooks with students.

2.3.6 Charts/graphs/classifying.

As is common with scientific investigations, teacher can ask students to use charts, graphs, and methods of classifying data to represent their scientific observations (Bowen & Roth, 2005). The teacher can help students see that they need to actually collect, organize, and analyze data to make scientific claims. For example, during an investigation on what makes the best roller coasters, students can collect data on how far toy cars travel across the floor based on the height of the ramp. With the teacher's help, they can chart the height of the ramp and the distances the car traveled, and also graph this relationship. The teacher can draw students' attention to the importance of collecting and representing this data so they can make better inferences for what contributed to the distance the car traveled. Students can then use this information to design their roller coaster, further illustrating the role of background knowledge, or subjectivity, in the development of scientific knowledge. Teachers can use explicit and reflection instruction to direct students to notice that they are being scientifically creative in designing, carrying out, recording, and interpreting the data that then influences how they design their roller coasters.

2.3.7 Work in teams.

When students work in teams they can share and discuss ideas about science and aspects of NOS (Flick, 1993). Having students work together in teams also allows the teacher to draw their attention to the fact that all students in their group have different knowledge bases they bring to the discussion, and therefore their viewpoints about the investigations may be slightly different. This difference in understanding can be explicitly and reflectively discussed as part of the subjective NOS. Further, it can allow the students (and scientists) to look at data and investigations differently and more holistically than if just one person were investigating a phenomenon. Through sharing ideas in "research teams," students can recognize the tentative NOS—because they may hear one of their peers interpreting data in a different way, they may also see a difference in the data and change their own ideas. Working in teams can also help students see science as being creative as they create various understandings of their scientific investigations in teams—from designing, carrying out, interpreting, and reporting their results, students can see that they are being creative like scientists.

2.4 Debriefing activities

After engaging in an inquiry-based activity, debriefing is a key component in aiding students to develop appropriate understandings about NOS concepts. Research indicates that NOS instruction is most effective when it is explicit and reflective, and debriefing is the perfect way for students to reflect on their NOS ideas (Abd-El-Khalick & Lederman, 2000; Authors, 2000). There are a number of ways to engage in explicit, reflective instruction after an inquiry-based activity that targets NOS. Here we discuss the activities that were found to be effective with students: class discussion, the use of NOS terminology, visual aids, science journals, and children's literature.

2.4.1 Class discussion.

One way to engage in explicit-reflective instruction is to facilitate class discussion about the inquiry activity. Authors (2010a) asked students how their models of bridges demonstrated subjective NOS, and noted that one student indicated he thought that "scientists do not always come up with the same idea." Authors (2011) asked students to identify how they were thinking like scientists during their inquiry investigations and made explicit reference to specific NOS aspects. For example, after students made their own model fossils using clay and then made observations and inferences about each others' fossils, Authors (2010) asked students how they were being creative and "whether scientists were creative while doing their work" (p. 15). Authors (2010) also engaged in a "double debrief" process in which we read written responses from each week's debrief, identified any misconceptions, and then orally debriefed the activity again at the beginning of the next activity. This "double debrief" promoted explicit-reflective NOS instruction by allowing us to reteach and address any misconceptions the students still held.

2.4.2 NOS terminology.

Including NOS terminology during class discussion can reinforce concepts and models the use of NOS language for students (Authors, 2011). It is important to refer specifically to the investigation when engaging students in discussion, for example, "Where do we see scientific tentativeness illustrated in our investigation?" These discussions can be facilitated to eventually increase the students' responsibility for identifying aspects of NOS independently by asking a more open-ended question, "Which NOS aspects do you see illustrated in our investigation?" If students would then state, for example, "tentativeness," the teacher can ask, "Where is an example of scientific tentativeness in your investigation?" A student may

respond, “We changed our minds about what these (jumping) beans were. We saw them move, and then figured out there had to be something alive and moving in them.” Authors (2006) debriefed every NOS activity with an even more open-ended prompt: “How is this like what scientists do?” to promote students’ understanding of science practices as well as NOS aspects.

2.4.3 Visual aids.

The use of visual aids to support students understanding of NOS can be effective (Authors, 2009) As noted previously, a NOS poster can be placed in the classroom for the teacher and students to refer to throughout the science lesson or unit. The teacher can use the poster to explicitly identify aspects of NOS throughout debriefing (reflection) discussions, first by providing examples to the students to model how notice NOS in their work, and later by asking students to describe the NOS aspects evident in their investigations on their own. The students can refer to such a poster while engaging in science lessons, or while recording data in their science notebooks. A reduced copy of the poster can be inserted into the students’ science notebook or reference.

2.4.4 Science notebooks.

Science notebooks can be used to debrief NOS activities in a fashion similar to how they are used during introductory and inquiry activities. Students can respond to journal prompts, for example, “What observations did you make during your investigation? What inferences did you make?” Science notebooks can be used to formatively assess students’ understandings of NOS, thereby informing the teacher’s instruction and allowing the teacher to reinforce concepts throughout subsequent inquiry lessons. Additionally, science notebooks can be used to summatively assess not only understandings of individual aspects of NOS but also a holistic view of NOS. For example, by asking students to draw/write a response to the question, “How were we acting like scientists?” students have the opportunity to share in their notebooks their thoughts related to all aspects of NOS.

2.4.5 Children’s literature.

Finally, the use of children’s literature can reinforce NOS aspects that are evident in students’ investigations, as well as provide an interdisciplinary connection to literacy (Authors, 2014). During an activity that emphasizes observations and inferences, students can determine what might be inside an opaque sealed bottle. Students can make various observations, and come back together as a group to

discuss the inferences they made and the observations that lead them to those inferences. This lesson can be concluded with the book *Seven Blind Mice* (Young, 1993) and students can note observations and inferences, as well as the role of subjectivity. This book's storyline lends itself well to a discussion about observation and inferences given it is about seven blind mice who use their sense of touch to determine the nature of a "something" that if they could see, they would know was an elephant. For instance, a student might say, "They bring their data together and compare it. They heard the other mice's inferences so they had more background knowledge and had different ideas." Another may student agree, stating, "You need background knowledge to make inferences." Authors (2010) also used literature to draw connections to specific aspects of NOS in the investigation. For example, after making observations and inferences about skulls, they read *The Skull Alphabet Book* and asked the students "to make observations of the skulls and the surroundings in the book to infer the kind of animals that would have such a skull" (p. 9). In this case, the book provided students with contextual information (where skulls may be found) that the classroom investigation could not offer. In this way, the book served to support their understanding of the investigation, and allowed for explicit reflective NOS instruction.

3. Discussion

In this paper, we presented research-based ideas for "what works" in teaching elementary students about NOS. Again, we recommend emphasizing NOS explicitly through repeated instruction using the methods we describe in this paper, as through research, these strategies have been found to improve elementary students' ideas about NOS. We recommend teaching in a cyclic fashion, using introductory activities, NOS instruction embedded in hands-on inquiries, and debriefing activities for most, if not all, science lessons.

These strategies were developed through research on effective practices to help elementary students improve their NOS conceptions. Though there have been questions regarding whether elementary students are capable of developing appropriate conceptions of NOS aspects, research shows that through appropriate instruction elementary students can, and do, develop sophisticated understandings of NOS as young as five years old (Authors, 2010). Indeed, child psychology researchers such as Metz (1995; 2004) and Carey (1986; Carey & Smith, 1993) have long indicated that children are able to develop sophisticated understandings of many science concepts given appropriate instruction.

The explicit-reflective strategies that introduce NOS aspects, reinforce them through scientific investigations, and then debrief these NOS aspects after the investigation, have been shown to improve elementary students' conceptions of NOS aspects (Authors, 2014). These strategies can be repeated throughout different science investigations and science content areas, allowing the teacher to continue emphasizing NOS aspects that students are familiar with while introducing new NOS aspects that are logically connected to the content. While research suggests that the strategies described in this paper have worked with elementary students, we are not purporting that these are the only strategies that can be effective, as we know that it is critical to plan your instruction based on the unique needs of students. We suggest using these strategies as a starting point for exploring further the kinds of instructional strategies and approaches that best help elementary students conceptualize NOS. We imagine that there are many different strategies that can be used to effectively teach NOS to elementary students.

Yet it is rarely the case that we see NOS embedded in science lessons in elementary classrooms. Of course, coupled with research on effective strategies is also research on how to best prepare elementary teachers to teach about NOS. That is a subject for a different paper, but it is clear, once teachers are convinced that elementary students are capable of learning sophisticated understandings about science and NOS, and have strategies to do so, the elementary students can, and do, develop appropriate understandings of both science content and NOS.

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Appendix: Sample of poster to be used with science lessons to introduce and debrief NOS aspects.

Tentativeness

Scientific knowledge changes over time as new data is developed and old data is re-interpreted. While this knowledge may change over time, the bulk of scientific knowledge is very reliable - reliable enough for many medical and technological advances to occur.

Empirical

Scientific knowledge is based on evidence.

Creativity

Scientists are creative as they generate explanations of evidence. Data does not interpret itself!

Theory and Law

Both laws and theories are very important in science. Theories and laws have different jobs. Laws are statements of patterns and regularities in the natural world. Theories are explanations for those patterns. Scientific laws and theories are both well-substantiated and have much evidence to support them. A theory does not become a law - they do different things.



Observation vs. Inference

Scientists make observations of natural phenomena and make inferences as to what these data mean. For example, you may observe that a houseplant's leaves are wilted, droopy, and brown. Then, you might infer that the house plant has not been watered in a long time.

Social and Cultural Context

Scientists and the practice of science exist within a certain social and cultural context. This social and cultural context may shape the kinds of questions, methods, and interpretations used by scientists. Similarly, science impacts the social and cultural context.

Subjectivity

Scientists are people who have their own background knowledge and theoretical perspectives. When they make observations, they (just like all people) "see" the information in light of these personal perspectives.