Evidence-based Strategies for Teaching Nature of Science to Young Children

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ABSTRACT

We provide a research-based model and teaching strategies for teaching nature of science (NOS) to young children (ages 5 to 9). The model describes an iterative teaching cycle that builds from the concrete to the abstract. The authors describe how to embed NOS teaching into existing curricula that do not already include NOS. The authors provide example evidence-based strategies for introducing NOS to young children, for connecting NOS to hands-on and inquiry investigations, and for debriefing the investigations to reinforce NOS connections to science content. The authors include an example of a NOS poster, and a sample list of children's literature for use in introducing and reinforcing NOS conceptions. Recommendations are made for the development of further NOS teaching strategies for young children, and for research that determines the most appropriate strategies, as well as the influence of teaching NOS throughout school careers on student NOS conceptions over time.

KEYWORDS: Nature of Science, Young Children, Teaching Strategies

5-9 Yaş Arası Öğrencilere Bilimin Doğası Öğretimi İçin Delile Dayalı Stratejiler

ÖZET

Bu çalışmada, 5-9 yaş arası öğrencilere bilimin doğasını öğretmek üzere hazırlanan araştırmaya dayalı bir model ve öğretim stratejileri sunulmaktadır. Model, somuttan soyuta doğru devam eden döngüsel bir öğretim modelidir. Bu çalışmada, bilimin doğasını içermeyen öğretim programlarına bilimin doğasının nasıl entegre edilebileceği anlatılmaktadır. Araştırmacılar genç öğrencileri bilimin doğasıyla tanıştırmak için, bilimin doğasını farklı yöntemlerle ilişkilendiren ve bilimin doğası ile öğretim programında yer alan içerik bilgisini birleştiren araştırmaya dayalı örnekler sunmaktadırlar. Aynı zamanda örnek bir bilimin doğası posteri ve öğrencilerin bilimin doğasıyla ilgili kavramlarını güçlendirmek için kullanılabilecek örnek bir okuma listesi de çalışmada sunulmaktadır. Genç öğrencilere bilimin doğasını öğretmek üzere öğretim yöntemleri önerileri, bilimin doğasını öğretmek üzere en uygun öğretim yöntemlerini belirleyecek araştırmalar için öneriler ve bilimin doğası öğretiminin öğrencilerin okul

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gelişimi boyunca bilimin doğası hakkındaki görüşlerinde oluşturacağı etkileri araştırmak üzere öneriler de çalışmada yer almaktadır.

ANAHTAR KELİMELER: Bilimin doğası, Genç öğrenciler, Öğretim yöntemleri

INTRODUCTION

There have previously been questions of whether young children (ages 5-9) could actually conceptualize nature of science (NOS) aspects, yet it is clear from research with these populations in a variety of contexts that young children can indeed, improve their conceptions of NOS toward the accepted views of NOS. For example, Smith, et al (2000) found that elementary students with a teacher who emphasized NOS over the course of their elementary school years improved their NOS conceptions. However, gains in understandings can be made in the short term for young children as well, through classroom science units (Akerson&Volrich, 2006), informal science programs (Akerson& Donnelly, 2010; Quigley, Pongsanon, &Akerson, 2010), and regular classroom teaching over a year (Akerson, Pongsanon, Nargund&Weiland, 2010). These improvements in NOS conceptions have also been made in a variety of teaching contexts, such as urban (Buck, Akerson, Quigley, &Weiland, 2010), suburban at risk schools (Akerson, Pongsanon, Nargund, &Weiland, 2010) and informal science programs (Akerson& Donnelly, 2010; Quigley, Pongsanon, &Akerson, 2010). What exactly are the aspects of NOS that are attainable by young children? Because we are U.S. educators, we consulted the National Science Teachers Association position statement for what should be taught about NOS grades kindergarten through twelfth (NSTA, 2000). These aspects of NOS are that science is tentative but robust, subjective (theory-laden), culturally embedded, creative and imaginative, based on empirical evidence, is a product of observation and inference, and should know the distinction between theory and law. We thought about the kinds of science content that are in the science curricula for young children, and decided to focus our research, and teaching strategies, on improving young children's conceptions of all NOS aspects but the relationship between theory and law because that is not in their science curriculum.

A review of several studies that focused on improving young children's conceptions of NOS shows that students as young as five begin to conceptualize NOS ideas, and older students (e.g. ages 6 to 9) do conceptualize more aspects more readily (Akerson, Buck, Nargund, Pongsanon, &Weiland, 2010). It also shows that some NOS aspects, such as observation and inference, creativity, tentativeness and the empirical NOS are more readily accessible to students than subjectivity or the socio-cultural aspects of NOS. However, these students, especially age 8 and 9, are able to improve their understandings of all NOS aspects through instruction.

So what kinds of strategies are effective with young children? From previous research on what works with older populations we have designed strategies that can be used with young children. In designing NOS instruction for young children we thought that we should use explicit, reflective instruction (Khishfe&Abd-El-Khalick, 2002), and that we should have a mix of contextualized and decontextualized (Clough, 2006) NOS instruction. 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. In other words, the NOS aspects need to be explicitly connected to the science investigations that the students are conducting. We also realized that contextualized and decontextualized NOS instruction is effective in helping adults improve their NOS understandings, and so thought that these strategies could be adapted for young children. In decontextualized NOS instruction the teacher introduces NOS aspects in ways that are not connected to science content. These kinds of activities include black box and puzzle solving activities that enable the teacher to draw attention to NOS aspects using familiar and concrete examples, and provides a foundation upon which more contextualized instruction can occur. Contextualized instruction, then, involves embedding NOS instruction into science content by integrating examples of NOS from history of science, or contemporary science tied to the content being taught. For instance, asking students for examples of observations and inferences and the tentative NOS in connection with an investigation of fossils would be an instance of contextualized NOS instruction. Contextualized NOS instruction would allow for in depth context-specific NOS instruction and illustrate to students that NOS is part of all science, not simply a list of terms to memorize.

In this paper we describe a cycle for teaching NOS that we have developed through evidence of "what works" with young children. We then provide specific examples of teaching strategies to be used within portions of this NOS teaching cycle.

NOS Teaching Trajectory: From Concrete To Abstract

While research has clearly shown that young children can adequately learn NOS, it also suggests that they may not learn all aspects of NOS at the same rate. Akerson and Donnelly (2009) noted that some children in their informal science program still held inadequate views of empirical NOS after instruction. Similarly, Quigley et al. noted that only 3 out of 15 students' understandings of subjectivity improved and noted little improvement in students' understandings of sociocultural NOS. We firmly believe that young children can learn all aspects of NOS (aside, perhaps, from theory versus law), as was demonstrated in Akerson et al. (under review), however, we suggest a trajectory for building students' conceptualizations of NOS. We believe that NOS is likely best taught to young children in such a way that begins with the most concrete concepts (i.e., observation and inference) and slowly builds to those that are more abstract (i.e., subjectivity or social and cultural context). To begin teaching NOS with observations and inferences, students are able to use their five senses to make observations about scientific phenomena. Young children can "see" for themselves that science is based on that which is tangible, and learn the distinction between direct observations and inferences based on those observations. Next, students can learn that science is empirical; it is based on evidence that is collected through observations. Once students have had an opportunity to collect data through observations and inferences, they can then be exposed to the tentative nature of science. Again, experiencing tentative NOS can be quite concrete- children can see that their interpretations of results can change, however it is important that children experience these aspects of NOS for themselves while engaging in inquiry. It is after this first-hand engagement that students may begin to understand some of the more abstract aspects of NOS: creativity, subjectivity, social and cultural context, and theory versus law. Children can understand the use of their imagination and creativity to do science when they are given the freedom to plan, implement, and report on their investigations. Teaching subjectivity, social and cultural context, and theory versus law can be facilitated with the use of children's literature. In the next section, we explicate a proposed iterative cycle for teaching NOS. The first cycle begins with teaching the most concrete aspects of NOS, and slowly builds to include the more abstract concepts. It is important to note that NOS concepts previously taught should be reinforced through each iteration of the cycle.

NOS Teaching Cycle

To begin our analysis, we reviewed studies that investigated strategies to teach NOS to young children. Each author reviewed the studies (Akerson&Volrich, 2006); Akerson& Donnelly, 2009; Quigley, Pongsanon&Akerson, 2010; Akerson, Pongsanon, Nargund, &Weiland, under review) separately and coded for strategies that resulted in increased understanding of young children's conceptions of NOS. We then discussed our codes and themes that were revealed through our analysis of the studies. Through our discussion, we found that a pattern of teaching emerged, what we term the "NOS Teaching Cycle." Figure 1 depicts the iterative nature of this cycle, as NOS aspects are introduced, embedded in content, and then reinforced over time. We recommend beginning with more concrete NOS aspects, such as the distinction between observation and inference, and moving toward more abstract, such as the sociocultural NOS as previously introduced aspects are reinforced by continuing to be included in the lessons.

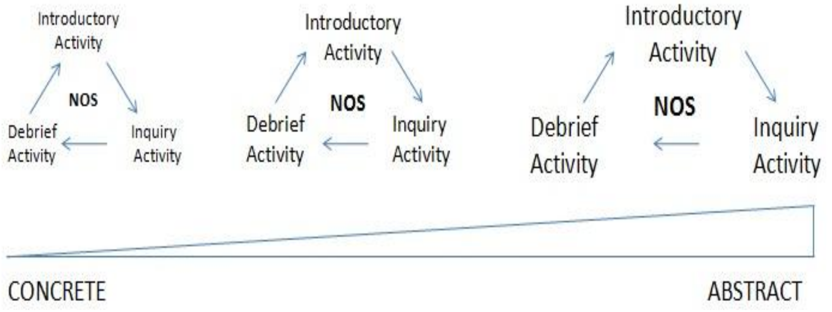

Figure 1. The iterative NOS teaching cycle

Research has shown that what we propose as the NOS Teaching Cycle is an effective way to young children about observations and inferences, tentativeness, subjectivity, creativity and imagination, empirical NOS, and the social and cultural embeddedness. This cycle may be particularly effective with young children as they may need support to connect NOS to their previous knowledge and to their personal experiences, as well to review and reinforce concepts regularly.

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 young children 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 (Akerson& Donnelly, 2009). 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. According to the essential features of inquiry (NRC, 1996), students can begin by engaging in an activity to help answer an investigative question. 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 each surface; 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, and creating an idea of the kinds of surfaces cars move best on. Finally, as NOS instruction has been most effective when taught explicitly and reflectively, it is imperative to debrief the inquiry. Debriefing should include a discussion of NOS aspects present in the inquiry and questioning that allows students to reflect on how science is conducted. 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. We describe specific examples of these strategies in subsequent sections of this paper.

Embedding NOS Teaching into Existing Curricula

We are aware that at least in the U.S., most early childhood science curricula do not 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 *K-2 Balance and Motion* unit (Full Option Science System). 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 how they are modifying their designs as well as their ideas of what contributes to items being balanced based on empirical evidence, as being representative of the tentative NOS. 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). Students can be asked to make observations of their designs, and inferences for factors that contribute to making things roll (and roll "best"). Students can be asked to think about what they have learned about balance and motion that influence how they subsequently design their roller coasters, as an example of the subjective NOS (e.g., that their background knowledge influences how they design their roller coasters). The teacher can 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.

In the sections below we will describe particular strategies that we have used to improve young children's NOS conceptions. We provide examples for each part of the NOS Teaching Cycle.

Introductory Activities as an initial part of the NOS Teaching Cycle

To teach NOS aspects it is necessary for teachers to embed them into existing science curricula that in general, do not naturally contain explicit prompts, instruction, or assessments of students' NOS understandings. It is certain that most children will not have heard of inferences, or terms like "empirical evidence" or "subjectivity," or even Nature of Science itself. Therefore the 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. We will describe various ways a teacher can use explicit NOS instruction to introduce, as well as emphasize, NOS aspects. The strategies we share are the use of class discussions, modeling thinking about NOS, using children's literature, and the use of science notebooks.

Class discussion.We have successfully used a NOS poster that includes the targeted NOS aspects, along with definitions and cartoon drawings, to introduce the NOS terms. This poster (See Figure 2) allows us to (a) introduce the NOS terms, and (b) continue to reference the NOS terms throughout subsequent science lessons. To initially use the poster the teacher holds a conversation with students regarding "the nature of science." The teacher asks students "What do you think science is? What makes science itself, and not called something like math?" The teacher allows responses, and then 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, 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, then the teacher can use examples from that lesson as she explains the terms. If it comes before a science investigation the teacher can ask students to think about these aspects as they conduct their investigations and use the poster to ask the students to reflect on their investigation, a perfect example of explicit reflective NOS instruction.

Modeling thinking about NOS. From the class discussions section above it is clear to see that the teacher plays a strong role in emphasizing NOS through interactions with students. The teacher can use a think aloud strategy to model ways to think about NOS in connection with science activities. For example, again using the NOS poster, and in connection with a science investigation the teacher can model how she thinks about NOS. If we think about an investigation such as students exploring a mystery material to determine whether it is a solid or a liquid, but actually the material has characteristics of both solids and liquids, such as an oobleck, we can illustrate this modeling think-aloud strategy. For example, 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 look at my NOS poster. Hmm. I can see that I was making observations of this material, which was my empirical evidence! First I inferred it was a liquid, because it took the shape of the container. Then I inferred it was a solid because I couldn't poke my finger through it, and then I inferred it was somehow a solid and a liquid at the same time. Because I was changing my mind about the evidence I was using the tentative nature of science. But I was still creative like a scientist because I was creating an understanding of what this stuff is—it is a solid AND a liquid. Now I have to create a new category because it won't fit in the original categories. It is another example of the tentative 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!" By reflecting aloud along with the children (we often ask the children to join in on these reflections and add their own ideas) we are modeling thinking about NOS in connection with the content and science investigation that we have just completed. Then in later investigations the teacher does less of the reflecting and passes it along to the students to do more of the reflecting aloud.

Children's literature. Young students are accustomed to having stories read to them by the teacher. The teacher can capitalize on this strategy by using it to introduce and reinforce NOS aspects. For example, we used *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 name begins 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. Such a 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, it also lends itself to a discussion of the subjective NOS, as we are not likely to infer animals we are unfamiliar with, which often can be illustrated by animals that may be unfamiliar to students as the teacher reads the book, such as the Narwhal whale. Young students are often familiar with whales, but not often specifically with the Narwhal, and therefore do not infer this animal which then leads to a discussion regarding the reliable, yet tentative NOS. The teacher can provide background knowledge regarding the Narwhal whale, and then discuss with the students how now that they have more information regarding different kinds of whales their inferences may change, just like a scientist may change their inferences by reconsidering the evidence they have. 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 lead to discuss how scientists infer missing data, skin color and coverings, and still create a reasonable and reliable, but tentative, picture of the animal.

Science Notebooks. The teacher can also use science notebooks with young children. Students can use these notebooks to record data, ideas, and reflections. These reflections can connect to science content as well as to students' understandings of NOS aspects. For example, the teacher could ask students to describe in their own words what they believe the NOS aspects mean and hold a class discussion. Student responses could be listed on chart paper that hangs in front of the room. Students could then be asked to record the terms with the definitions they agree with in their notebooks, using the chart to guide them with spelling if they need to. Also, if they are not writing yet, teachers or classroom helpers can record the students' ideas in their notebooks, while the students 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. 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 they agree with, or other ideas they had regarding NOS aspects that were present in their investigations.

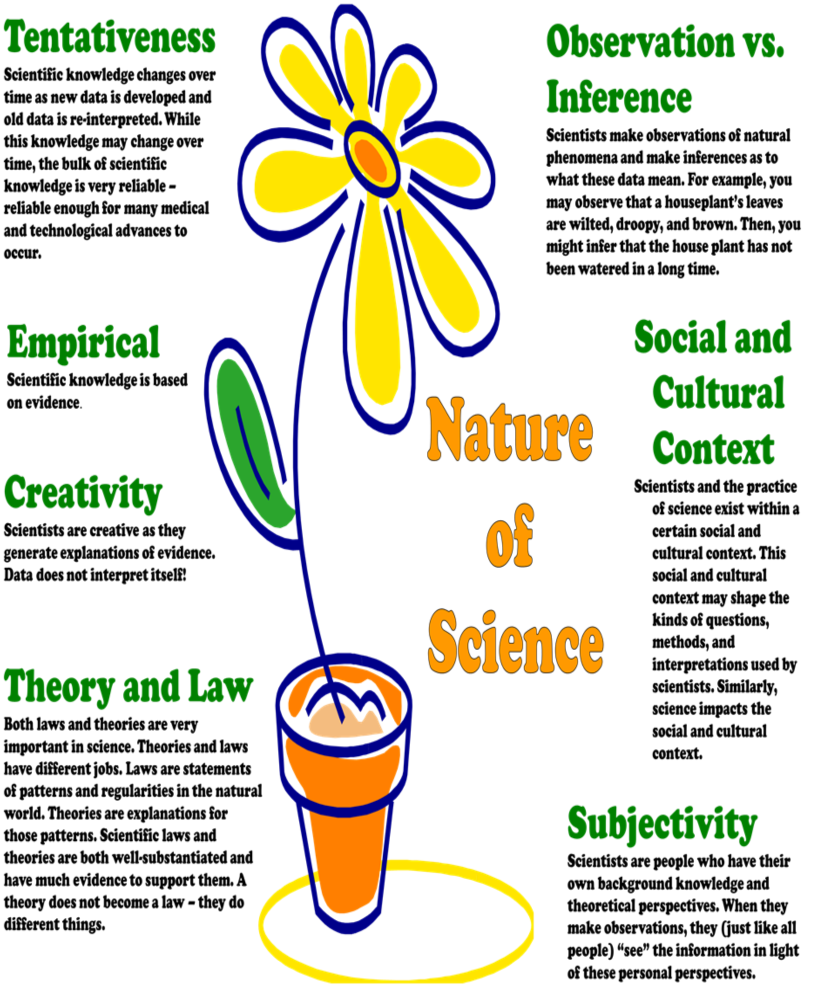

Figure 2. NOS Poster that can be used to introduce or reinforce NOS aspects

Inquiry Based Activities

If students had not engaged in scientific inquiry prior to learning about NOS, it is definitely important to engage them after introducing students to the NOS aspects. If they have no opportunity to actually investigate phenomena then it will be difficult for them to connect the terminology to experiences, and thus contextualizing their learning in actual science investigations is important. In this section 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.

Hands on. The science investigations need to be what students engage in, not what teachers engage in via demonstration. These activities need to be hands-on for the students in terms of the students raising questions, collecting data, and making observations and inferences of phenomena. It is through manipulating materials themselves that students can engage in the practice of science, and then later (or even during) reflect on when they were making observations, when they were making inferences, how they were being creative like scientists, when they changed their minds about data, or because they collected new data, and how the background knowledge of those in their groups influenced their interpretations. For example, during an activity in which students make Play-Doh fossils, the students actually create the impressions of an item in a fossil. Then they share these with their peers, who have 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 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. They can also be drawn to notice that they do 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. In this way the teacher is using hands-on investigations to directly connect NOS elements for the students.

Guided to Open. Students should engage in a variety of inquiries from guided to open 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 then use a think-aloud strategy, or help students connect their investigations to NOS ideas by using the NOS poster. When students have experience engaging in guided inquiry the teacher can have them design their own science investigation and with the teacher's permission, carry it out. Then, similar to the guided inquiry, students can be asked to think about how and where NOS aspects were present in their work, and also asked to reflect on these NOS aspects through the use of the NOS poster, or record their ideas in their science notebooks. If the students are struggling to connect their ideas, teachers could 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 could be asked to design an investigation that enables them to determine whether popcorn floats. This inquiry into floating and sinking could build on the unit they had been exploring, and therefore the teacher can orchestrate 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—e.g., help them design fair tests. After the students design an investigation, they can then carry it out, and the teacher can draw their attention to the data—e.g. 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 could also hold a discussion, using the NOS poster, to have students elaborate on how they were scientifically creative in designing the investigation, as well as interpreting evidence. They could discuss how they were using their background knowledge to design the investigation as well as interpret data, and also made observations of what occurred and inferences as to whether popcorn floated. They could be drawn to notice that their results were tentative because if they had used salt vs. plain water, or popped vs. unpopped corn they may have had different outcomes. In this way the students are both designing their own scientific inquiry as well as connecting NOS elements to the investigation.

Teacher questioning. Teachers can use questions phrased in ways such that they draw attention to NOS aspects in connection with science investigations. For example, while students are observing phenomena, the teacher can ask “What are your observations? Are you able to make any inferences right now? 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 students could be asked to design the paper airplane that stays aloft the longest. Students could design airplanes and test them. The teacher could 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 could make these changes in their designs, and re-test their airplanes. The teacher could raise more questions “So, how did your ideas change after you tested your design? Do you think scientists change their ideas after they make 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 (see below).

Observation and inference charts. Students can be asked 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 successfully used an observation and inference chart that students can use in many different investigations. This chart consists of two columns. In one column they list the observations they are making, and in the next column they make complimentary inferences. For example, during an investigation to determine whether Oobleck is a solid or a liquid, students would 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 is facilitating the students in making distinctions between observations and inferences during a hands-on investigation. (See Figure 3 for an example of the chart.)

Science notebooks.We have used science notebooks to help students reflect on both science content as well as NOS during and after their investigations. In encouraging young students to reflect on their content knowledge as well as their NOS understandings the teacher should provide writing prompts, possibly following a class discussion about the same topic, such as "did anyone making 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 they can be recording 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 example, of how to light a bulb using a battery and a wire. As they investigate the problem they can be asked to record other ideas they try, and finally, different ways they are able to light the bulb. They can be asked to reflect on their notebook recordings for how their ideas changed as they collected more data regarding how to light a bulb. They can be asked to 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. They can be asked to recording ideas of where NOS aspects were present in their investigations on how to light a bulb. In this unit on electric circuits, for example, they 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.

Charts/graphs/classifying. As is common with scientific investigations, students can be asked to use charts, graphs, and methods of classifying data to represent their scientific explorations. 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 could collect data for how far toy cars travel across the floor depending on the height of the ramp. With the teacher's help they could chart the height of the ramp and the distances the car traveled, and also graph this relationship. The teacher could draw their attention to the importance of collecting and representing this data so they could make better inferences for what contributed to the distance the car traveled. They could then use this information to design their roller coaster, further illustrating the role of background knowledge, or subjectivity in the development of scientific knowledge. Students could be directed 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.

Work in teams. In every case of working with young children in science we have had the students work on their investigations in teams. We have found that they share and discuss ideas about science as well as NOS aspects in teams. 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 that they bring to the problem, and therefore their viewpoints about the investigations may be slightly different. This difference in understandings can be pointed out as part of the subjective NOS, and that it can allow the students (and scientists) to look at data and investigations differently and in a more full fashion than if just one person were investigating. In addition, 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.

Debriefing Activities

After engaging in an inquiry-based activity, debriefing is a key component of the NOS Teaching Cycle. Research indicates that NOS instruction is most effective when it is explicit and reflective (Abd-El-Khalick& Lederman, 2000; Akerson, Abd-El-Khalick, & Lederman, 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 young children: class discussion, the use of NOS terminology, visual aids, science journals, and children's literature.

Class discussion. One way to engage in explicit reflective instruction is to facilitate class discussion about the inquiry activity. Quigley et al. (2010) asked students to how their models of bridges demonstrated subjective NOS, and noted that one student replied, "Scientists do not always come up with the same idea." Akerson and Donnelly (2009) asked students to identify how they were acting like scientists during their inquiry investigations and made explicit reference to specific NOS aspects. For example, after students made their own models fossils using clay and making observations and inferences about each others' fossils, Akerson and Donnelly asked students how they were being creative and "whether scientists were creative while doing their work" (p. 15). Akerson and Donnelly also engaged in a "double debrief" process in which they 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 allowed them to reteach and address any misconceptions still held by the students.

NOS terminology. Including NOS terminology during class discussion can reinforce concepts and models the use of NOS language for the students. Akerson et al. (under review) found that it was important to refer specifically to the investigation when in engaging student in discussion, for example, "Where do we see scientific tentativeness illustrated in our investigation?" They noted that these discussions can be facilitated to eventually increase the students' responsibility for identifying aspects of NOS 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," one could say "Where is an example of scientific tentativeness?" In the case of Akerson et al, a student responded with "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." Akerson and Volrich (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 process skills.

Visual aids. The use of visual aids to support students understanding of NOS was also used by Akerson et al. As the instructor, the first author created a poster that used child-friendly language to define aspects of NOS. This poster was placed in the classroom so that students could refer to throughout their science instruction. The instructor used the poster to identify aspects of NOS throughout debriefing discussions, first by providing examples to the students to model how notice NOS in their work, and later asking students to describe NOS aspects evident in their investigations on their own.

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 your instruction and allowing you to reinforce concepts throughout subsequent inquiry lessons. Additionally, science notebooks can be used to summatively assess not only individual aspects of NOS but also a holistic view of NOS. For example, but asking students to draw/write a response to the question, "How were we acting like scientists?" students have the opportunity to share their thoughts related to all aspects of NOS.

Children's Literature. Finally, the use of children's literature can not only reinforce NOS evident in students' investigations, but it can also provide an interdisciplinary connection to language arts. (SeeTable 1 for a sampling of children's books that connect to NOS aspects). Children's books can be used throughout the NOS Teaching Cycle. During an activity that emphasized observations and inferences, Akerson et al. engaged the students in an activity that required them to determine what might be inside a sealed bottle. Students made various observations, and when they came back together as a group they discussed the inferences they made and the observations that lead them to those inferences. They concluded with the book Seven Blind Mice (Young) and students were able to note observations and inferences within the story, as well as the role of subjectivity. For instance, one student said "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 student agreed, stating "You need background knowledge to make inferences." Akerson and Donnelly 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.

DISCUSSION

In this paper we presented a research-based model for "what works" in teaching young children about NOS. The NOS teaching cycle that we presented came from strategies we have successfully used with K-3 students in improving their NOS conceptions. The iterative cycle that starts with the concrete and moves toward the abstract enables teachers to use explicit strategies that introduce NOS aspects, reinforce them through scientific investigations, and then debriefs these NOS aspects after the investigation, has been shown to improve young students' conceptions of NOS aspects. This cycle is 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 connected to the content. While we know that the strategies we have described in this paper have worked with the K-3 students we have taught, we are not suggesting that these are the only strategies that can be effective, nor even that they are the best strategies, as of course, not all teaching strategies have been tried and researched with K-3 students. We suggest using these strategies as a starting point for exploring further what kinds of teaching helps young children best conceptualize NOS aspects. It is entirely possible, and indeed probable, that there are many different strategies that can be used to approach teaching NOS to young children.

We recommend that future research explore the kinds of strategies that can best be used to improve young children's understandings of NOS aspects. Research should explore the kinds of NOS instruction that enables students to conceptualize NOS aspects from the concrete to the abstract, in ways that subsequent teachers can build on and refine student thinking regarding NOS. Future research can also explore whether helping young children conceptualize NOS aspects influences their science content knowledge, as well as their perceptions of science as a field of study they are comfortable with and are willing to pursue throughout their K-12 education (and beyond).

Table1. *List of children's books and how they might be used to teach and emphasize NOS aspects*

Title and Author	**NOS Aspects**	**Points of Discussion**
June 29, 1999 By David Wiesner	creativity, observation & inference tentativeness	Student designs and carries out her own investigation. Student changes interpretations as she collects more data and makes more observations and inferences.
What are Scientists? By Rita Golden Gelman, Susan Kovacs Buxbaun	Subjectivity	Students can see that there are many different types of scientists, all with different background knowledge, but all do investigations of some sort.
Seven Blind Mice By Ed Young	observation & inference tentativeness creativity social & cultural context	Observations are made by different mice who then make different inferences. Last mouse creates an understanding from all data previously collected, changing interpretations based on all data. Inferences are of items within a cultural context.
Earth Mobiles as Explained by Professor Xargle By Jeanne Willis and Tony Ross *Earthlets as Explained by Professor Xargle* By Jeanne Willis and Tony Ross	observation & inference subjectivity social and cultural context creativity tentativeness	Alien scientist makes observations and inferences of earth. Inferences are based on his subjective view and through his own cultural lens Alien creates an understanding of earth based on these observations and inferences, but students can be lead to notice that the alien may change his interpretation with new evidence, or reinterpretation of existing evidence.
The Extinct Alphabet Book By Jerry Pallotta and Ralph Masiello	observation & inference creativity tentativeness empirical	Students make observations of extinct animals and infer the animal. They "create" an interpretation of the animal from the empirical evidence. They can be lead to notice that scientists are never 100% certain about

		an extinct animal, but base their interpretations on evidence.
What Do You Do With A Tail Like This? By Steve Jenkins and Robin Page *Actual Size* By Steve Jenkins	observation & inference tentativeness subjectivity social/ cultural context empirical	In these books students observe pictures of parts of animals and infer either what the tail is used for, or the animal itself. They can see how their inferences changed sometimes when the page was turned. They can see that the partial pictures are evidence, just like scientists don't always have all the evidence. They can see that their own subjectivity influences their inferences, just as it would a scientist. They can be lead to see that scientists would not infer an animal, or a tail of an animal, that was not in existence in their social/cultural context.
What Makes Day and Night By Franklyn M. Branley and Arthur Dorros	observation & inference subjectivity	Students can see the kinds of observations and inferences scientists made to interpret the causes of day and night, and movement of earth, moon, and sun. Students can see the importance of background knowledge on inferences.

REFERENCES

Akerson, V. L., &Volrich, M. L. (2006). Teaching nature of science explicitly in a first grade classroom. *Journal of Research in Science Teaching, 43,* 377-394.

Akerson, V. L., & Donnelly, L. A. (2010). Teaching nature of science to K-2 students: What understandings can they attain? *International Journal of Science Education, 32,* 97-124.

Akerson, V. L., Pongsanon, K., Nargund, V., &Weiland, I (2010, April). *Teaching nature of science in a third grade classroom: An assessment of strategies and student knowledge.* Paper presented at the annual meeting of the National Association for Research in Science Teaching.

Branley, F., &Dorros, A. (1986). *What makes day and night? (Let's-read-and-find-out science 2).* New York: Collins.

Buck, G. A., Akerson, V. L., Quigley, C., &Weiland, I (2010). *Teaching nature of science to second-grade, urban, low SES, African American girls: What understandings did they attain?* Paper proposed for National Association for Research in Science Teaching.

Clough, M. P. (2006). Learner's responses to the demands of conceptual change: Considerations for effective nature of science instruction. *International Journal of Science Education, 15,* 463-494.

Gelman, R. G., &Buxbaun, S. K. (1992). *What are scientists?* New York: Scholastic.

Jenkins, S. (2004). *Actual size.* New York: Houghton Mifflin.

Khishfe, R., &Abd-El-Khalick, F. S. (20020. Influence of explicit and reflective versus implicit inquiry-oriented instruction on sixth graders' views of nature of science. *Journal of Research in Science Teaching, 39,* 551-578.

National Research Council. (1996). National Science Education Standards. Retrieved September 8, 2008 from http://www.nap.edu/readingroom/books/nses/

National Science Teachers Association. (2000). *NSTA position statement: The nature of science.*

Retrieved March 18, 2003, from http://www.nsta.org/159&psid=22

Page, R., & Jenkins, S. (2008). *What do you do with a tail like this?* New York: Sandpiper.

Pallotta, J., &Masiello, R. (1993). *The Extinct Alphabet Book.* Watertown, MA: Charlesbridge.

Pallotta, J, &Masiello, R. (2002). *The Skull Alphabet Book.* Watertown, MA: Charlesbridge.

Quigley, C., Pongsanon, K., &Akerson, V. L. (2010, June, on line). If we teach them, they can learn: Young students' views of nature of science during an informal science education program. *Journal of Science Teacher Education.*

Wiesner, D. (1995). *June 29, 1999.* New York: Clarion.

Willis, J., & Ross, T. (1992). *Earth Mobiles, as explained by Professor Xargle.* New York: Puffin Books.

Willis, J., & Ross, T. (1994). *Earthlets explained by Professor Xargle (2nd ed).* New York: Puffin Books.