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Learners' Responses to the Demands of Conceptual Change: Considerations for Effective Nature of Science Instruction

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Abstract. Much has been written about how effective nature of science instruction must have a significant explicit and reflective character. However, while explicitly drawing students' attention to NOS issues is crucial, learning and teaching the NOS are essentially matters of conceptual change. In this article, how people learn and learners' responses to the demands of conceptual change are used to explain how students may exit from instruction with fundamental NOS misconceptions left intact or only slightly altered, despite being explicitly and reflectively attended to more accurate ideas. The purpose of this concept paper is to set within a theoretical framework of learning, and bring some coherence to, what has rapidly become a large body of empirical research regarding effective NOS instruction. Toward these two ends, this article: (1) illustrates how a conceptual change framework can be used to account for learners' responses to NOS instruction and what teachers might do to promote understanding NOS and transferring it to new contexts; (2) characterizes popularly advocated NOS instructional approaches along a continuum marked by increasing connection to the workings of science, and decreased ability to dismiss NOS lessons as extraneous to authentic science; and (3) proposes that NOS instruction would likely be more effective if teachers deliberately scaffolded classroom experiences and students' developing NOS understanding back and forth along the continuum.

1. Introduction

The phrase 'nature of science' (NOS) is often used in referring to issues such as what science is, how it works, the epistemological and ontological foundations of science, how scientists operate as a social group and how society itself both influences and reacts to scientific endeavors. These and many other thoughts regarding the NOS are best informed by contributions from several disciplines including, but not limited to, the history, philosophy, and sociology of science. While some characteristics regarding the NOS are, to an acceptable degree, uncontroversial and have clear implications for school science teaching (Smith et al. 1997; McComas et al. 1998; Eflin et al. 1999), most are contextual with important and complex exceptions. Where consensus does not exist, the key is to convey a plurality of views so that science teachers and students come to understand the importance of the issues and complexities regarding the NOS. Even in NOS matters having widespread agreement, conceptual understanding rather than declarative knowledge should be sought. This is critical as the point of a progressive education, including an understanding of the NOS, is not to indoctrinate, but to educate students about relevant issues, their contextual nature, and reasons for differing perspectives (Matthews 1997).

While major reform documents emphasize the importance of accurately conveying the NOS to students (AAAS 1989; NRC 1996; McComas & Olson 1998), few teachers do so. Despite some evidence to the contrary (Lederman 1986a), science teachers, reflecting their own science education experiences, possess inaccurate and simplistic views of the NOS (Lederman 1992; Abd-El-Khalick & Lederman 2000a) and are generally unaware of the social and cultural construction of scientific thought (Brush 1989). Over 30 years ago Elkana (1970) stated that science teachers' views concerning the NOS trailed contemporary philosophical views by more than two decades, and 15 years later Duschl (1985) wrote about the continuing chasm between developments in the philosophy of science and science education. DeBoer (1991), in his review of the history of science education, argues that the positivist view of the philosophy of science from the last century still informs much classroom practice and pervades most available curriculum materials. Science textbooks, common cookbook laboratory activities, and most audiovisual materials downplay human influences in research, sanitize the processes that eventually result in knowledge, and portray science as a rhetoric of conclusions. Compounding the problem, too often science teachers simply do not consider the NOS an important component of science education (King 1991; Abd-El-Khalick et al. 1998).

The irony of this situation is that despite teachers' intentions, science courses cannot escape conveying an image of the NOS to students. Teachers' language (Dibbs 1982; Benson 1984; Lederman 1986b; Zeidler & Lederman 1989), cookbook laboratory activities, textbooks that report the end products of science without addressing how the knowledge was developed, misuse of important words having special meaning in a science setting, and traditional assessment strategies are just some of the ways students develop conceptions about the NOS. Ever present in science content and science teaching are implicit and explicit messages regarding the NOS. The issue is not whether science teachers will teach about the NOS, only what image will be conveyed to students.

However, the relationship between a teacher's NOS conceptions and classroom practice is not at all straightforward. While the evidence is compelling that simply possessing an accurate understanding of the NOS does not necessarily lead to instruction reflecting that understanding (Lederman

1992), maintaining that no interplay exists between the two is unwarranted (McComas et al. 1998). Apparently, possessing an accurate understanding of the NOS is a necessary, but insufficient condition for effectively teaching it to students. In a sense, this conclusion is not particularly surprising. After all, few would maintain that simply possessing a deep understanding of science content will ensure effective science teaching. Teachers' ideas regarding the purposes of schooling, science education goals, how students learn, effective teaching, classroom management, as well as real and perceived institutional constraints affect what is taught and how it is conveyed. Planning and implementing effective lessons are complex acts, and this applies equally to traditional science content as well as accurately conveying the NOS.

The purpose of this concept paper is to set within a theoretical framework of learning, and bring some coherence to, what has rapidly become a large body of empirical research regarding effective NOS instruction. Toward these two ends, this manuscript: (1) illustrates how a conceptual change framework (Posner et al. 1982; Appleton 1997; Tyson et al. 1997) can be used to account for learners' responses to NOS instruction and what teachers might do to promote understanding the NOS and transferring it to new situations; (2) characterizes popularly advocated NOS instructional approaches along a continuum marked by increasing connection to the workings of science, and decreased ability to dismiss NOS lessons as extraneous to authentic science; and (3) proposes that NOS instruction would likely be more effective if teachers deliberately scaffolded classroom experiences and students' developing NOS understanding back and forth along the continuum. Acknowledging the complexities in conceptual change, including the importance of affective factors (Strike & Posner 1983; West & Pines 1983; Pintrich et al. 1993; Dagher 1994; Demastes et al. 1995), the explanatory framework and recommendations presented here have important implications for NOS instruction and NOS research.

2. Implicit and Explicit/Reflective NOS Instruction

Teachers, including those who possess accurate NOS conceptions, often overlook or downplay the importance of NOS instruction (Duschl & Wright 1989; Abd-El-Khalick et al. 1998; Bell et al. 2000). Those who do seriously consider NOS instruction may believe that if they plan inquiry laboratory activities mirroring the NOS, then those implicit messages will be noted by students. However, research does not support this commonsense view (Lederman 1992; Abd-El-Khalick & Lederman 2000a; Moss et al. 2001; Khishfe & Abd-El-Khalick 2002). Due to years of school science instruction and everyday out-of-school experiences that have consistently conveyed, both explicitly and implicitly, inaccurate and simplistic portrayals of the NOS, students carry deeply held misconceptions that rarely respond to implicit instruction that faithfully reflects the NOS. The expansive, yet inaccurate frameworks students possess regarding the characteristics of science and how it works act as filters that obscure the more faithful implicit NOS messages in authentic inquiry experiences. Students, like scientists, understandably interpret new experiences from a framework consisting of their prior knowledge and experiences.

In contrast to the implicit approach, learning and teaching the NOS should be seen as a cognitive objective (Lederman 1998) that is explicitly planned for in a way that draws students' attention to important NOS issues when teaching science (Akindehin 1988; Lederman 1992; Clough 1997, 1998, 2004; McComas 1998; Abd-El-Khalick & Lederman 2000a; Akerson et al. 2000; Bell et al. 2000; Khishfe & Abd-El-Khalick 2002). Explicitly teaching the NOS does not mean lecturing about it, or imposing a particular perspective about the NOS, but it does mean deliberately designing lessons to address particular NOS issues (Lederman 1998; Khishfe & Abd-El-Khalick 2002). Equally important, reflectively teaching the NOS refers to pedagogical approaches that help students make connections between the activities they are experiencing and targeted NOS issues (Khishfe & Abd-El-Khalick 2002), for example, raising questions and creating situations that compel students to consider NOS issues inherent in laboratory activities, readings, and other science education experiences. Research supports the view that NOS instruction is more effective when it has both this explicit and reflective character (Abd-El-Khalick et al. 1998; Abd-El-Khalick & Lederman 2000a; Akerson et al. 2000; Khishfe & Abd-El-Khalick 2002).

In retrospect, the argument that effective NOS instruction must have a significant explicit and reflective emphasis should not have been surprising to science educators. Consider again the teaching of traditional science content. If school science content instruction consisted solely of activities and laboratory work without a teacher intentionally helping students make sense of those experiences, certainly the students' content understanding would compare poorly to that of another group of students whose teacher intentionally engaged them in wrestling with the same science content using the same activities. In teaching both science content and the NOS, discovery learning (i.e. expecting students on their own to generate accepted meaning) is a poor teaching strategy. While the need for explicit and reflective NOS instruction should not be surprising, Khishfe and Abd-El-Khalick (2002) point out that adherents of the implicit approach remain, and thus empirical studies have been, and continue to be, important in laying aside contentions that students will abandon their prior thinking and form accurate ideas about the NOS simply by experiencing science inquiry or other activities that faithfully reflect the NOS.

An important difference exists between the initial development of ideas that make sense to learners, and later efforts to alter those ideas. Examples abound illustrating how children develop ideas to account for their everyday experiences regarding the natural and social world. These ideas, both correct and incorrect, do not necessarily follow from explicit instruction, but once developed may be highly resistant to change. Students' early ideas regarding the NOS are, at least in part, developed in this same way. Implicit experiences regarding what science is and how it works (e.g. extensive experiences with cookbook laboratory activities, textbooks that report the end products of science without addressing how the knowledge was developed, and media portrayals of science and scientists) certainly play a role in learners' developing conceptions of NOS that become deeply held. Mistaken notions of the NOS developed in this way, just like mistaken ideas regarding natural phenomena, resist later implicit and even many explicit attempts to modify those mistaken views. If a child's upbringing consisted entirely of accurate implicit experiences regarding the NOS, they would likely develop a number of accurate NOS ideas. They would, however, also develop mistaken ideas regarding the NOS. Expecting students to generate, on their own, accepted science and NOS ideas does an injustice to fields of study in which brilliant minds have struggled for decades, even centuries, to arrive at our current understandings. This expectation, particularly when students already possess deeply held misconceptions regarding science content and the NOS, also reflects naive views of how people learn.

3. Student Learning and its Implications for Successful NOS Instruction

Fundamental to learning is assiduous mental engagement – selectively taking in and attending to information, and connecting and comparing it to prior knowledge in an attempt to make sense of encounters with the surroundings. However, even when actively engaged in attempting to make sense of instruction, students often interpret and sometimes modify incoming stimuli so that it conforms to what they already believe. Consequently, students' prior knowledge that is at odds with intended learning can be amazingly resistant to change. Driver (1997) argued that:

> Some of the more complicated learning we have to do in life, and a lot of science is like this, involves not adding new information to what we already know, but changing the way we think about the information we already have. It means developing new ways of seeing things.

Conceptual change and teaching for conceptual change are complex processes (Duschl & Hamilton 1998; Guzzetti & Hand 1998 ; Limon & Mason 2002). Posner et al. (1982) suggested four necessary, but insufficient conditions (Strike & Posner 1983, 1992) for conceptual change – dissatisfaction with a currently held idea, and a new conception that is intelligible, plausible and fruitful. However, a number of other issues relevant to conceptual change are important and have been summarized by Tyson et al. (1997) as follows:

1. Some researchers assert that conceptual change refers only to large changes in a learner's conceptual framework, while others argue that it applies to smaller changes as well;
2. Changes in a learner's conceptual framework may occur without extinguishing prior conceptions;
3. Conceptual change has both an evolutionary and revolutionary character;
4. Context is important in shaping and using concepts;
5. Concepts may be domain-specific or more global;
6. The age of a learner is relevant to conceptual change; and
7. The nature of the content has an influence on conceptual change.

They argued for a multidimensional framework that utilizes epistemological, ontological and social/affective perspectives for understanding conceptual change.

Appleton (1997, p. 304) acknowledged the importance of conceptual change perspectives for illuminating learning situations, but argued that they alone "do not provide clear indications as to what learners might do, and in turn, what teachers might do, to facilitate learning." He provided an empirically-based model, consistent with several conceptual change perspectives above and drawn from classroom observations, that emphasizes *learners' responses* to the demands of conceptual change. In doing so, his model is useful in considering the role of the teacher and teaching strategies in anticipating and responding to students' efforts to make sense of experiences they encounter.

Appleton's model captures much that occurs as students bring their existing knowledge and attitudes to a new context and, along with interactions with the new encounter and teacher and lesson cues, strive to create a 'best fit' idea that avoids or reduces cognitive conflict. In his model, three broad pathways follow from this cognitive struggle, but of particular significance is the desire of learners to reach cognitive equilibrium and exit from instruction. Within these three broad pathways, the issues inherent in conceptual change play out.

Ideally, students would exit from instruction only after their deep cognitive effort resulted in understanding that is both an identical fit of the encounter *and* congruent with accepted scientific knowledge. However, students may exit prematurely when the encounter *appears* to them as fitting perfectly with an existing idea, but that idea does not conform to accepted knowledge. A second possible pathway of students' cognitive struggling is an approximate fit of the encounter to an existing idea. Here students may see the fit as close enough and choose to exit from instruction, or seek additional information and reexamine their prior ideas to resolve the matter. A third pathway of students' mental activity is acknowledging an incomplete fit or cognitive conflict leading to a search for information that will resolve the incongruence. Here students use newly gained information and new ways of thinking about information to seek a better fit between their idea and the encounter.

Whether students quickly exit from instruction, or what path they take in struggling to understand an encounter depends on several factors. Interactions with a teacher and peers, affective factors, context, as well as other issues inherent in conceptual change, may cause learners to reconsider and/or elaborate on the fit of their idea with the encounter. Students will then bring their new perspectives to the encounter under consideration and continue struggling to create an idea that better fits the event. Understanding *a priori* the possible directions students may take during a lesson, and the issues inherent in conceptual change that affect those directions, has significant implications for learning and teaching the NOS. For instance, consider the following broad scenarios regarding NOS instruction that follow respectively from the pathways above:

Scenario 1: Reflecting the first broad pathway of sense-making, students may see new encounters as identical to pre-existing ideas, resulting in reinforcement of already existing knowledge (whether it is right or wrong). Given the prevalence of NOS misconceptions, this scenario best describes the common encounter students have regarding their prior NOS ideas and what occurs in school science. Typical textbooks, lectures, teacher language, prescribed step-by-step activities, and audiovisual materials present a portrayal of science, scientists, and scientific processes that closely match students' previously developed NOS misconceptions. However, students may exit from instruction with their previous ideas unchanged even if, from the teacher's perspective, an experience was designed to confront students' NOS misconceptions. Humans, by their very nature, make sense of experience in light of what they already know. Toward this end, learners attend to aspects of phenomena and other information that fit prior ideas, often unconsciously ignore contrary information, and sometimes modify incoming information so that it also fits what is already known. For this and other reasons, implicit NOS instruction designed to confront students' deep misconceptions regarding the NOS are seemingly interpreted by students, often with little or no difficulty, to fit with their misconceptions, and thus does not result in dissatisfaction with prior ideas.

Scenario 2: On other occasions, reflecting the second broad pathway of cognitive activity, students note that a new encounter approximately fits with preexisting ideas regarding the NOS. Here, if students are not convinced to further examine their thinking, they may accept their vague idea as an adequate answer, and reexamine it only if the context demands them to do so. If a context promoting sufficient dissatisfaction with prior ideas is not created, students can exit from instruction with their fundamental NOS notions unchanged, but with a new idea or "set of ideas for school situations" (Appleton 1993, p. 270). When this occurs, pre-existing NOS ideas have not been abandoned, only slightly modified, or left intact with new schema created that are disconnected from the larger conceptual framework. The latter case aptly describes in-school learning and out-of-school learning where students hold, often unconsciously, contrasting ideas regarding the NOS in these different contexts. This may explain why pre-service elementary teachers in a study by Abd-El-Khalick (2001) conveyed markedly different understanding of the NOS when addressing two science content-specific situations that "share[d] significant similarities in terms of the NOS aspects they invoke" (p. 225).

Scenario 3: Reflecting the third broad pathway of cognitive activity, students may recognize their ideas regarding the NOS are at odds with what is being encountered and attempt to resolve the apparent discrepancy. Assuming important affective issues in conceptual change are addressed, students' on-going failure to reconcile the discrepancy may result in cognitive conflict. However, given the ubiquitous misportrayal of NOS in everyday life and most school settings, a more likely unfortunate outcome is that students will process the information and exit as in scenario 2, not with a deep accurate understanding of particular NOS issues, but with a vague idea of an answer adequate for particular school situations that, as Appleton (1997, p. 307) writes, "will be reexamined only if the context requires this to happen." Creating that context is difficult because students often have an intricately connected system of ideas supporting their misconceptions. Hence, purposeful instructional moves (e.g. questioning, drawing students' attention to features of the encounter they may have missed, and using other students' ideas in discussions) are important for persuading students to reexamine their NOS ideas rather than exit prematurely.

An example illustrating the array of support students often have for their ideas appears in the video *Minds of Our Own* (Annenberg/CPB 1997), where a fifth-grade student wrongly believes that we see because our eyes send out rays that bounce off objects and reflect back to our eyes. The idea likely originated from a television program he watched that explained sight as a result of photons bouncing off objects to a person's eyes where the eyes and brain then work together to create an image. However, when probed further, the student provides several additional reasons supporting his belief. He recalls that bats 'see' by sending out sonar which bounces back to them. He relates a personal experience observing the eyes of his grandmother's cat shining in the dark and says that "they shine so they can see more around them – like a flashlight." As a final pillar of support, he recalls that some fish make artificial light that acts as a lure to other fish. In the same program, two middle school students wrongly believe that humans can see in a totally dark environment. In addition to incorrectly perceiving their personal experiences in dimly lit rooms as being completely dark, one student offers that moles can see and they are underground. The other student adds additional support for her position by recalling a science lesson in school where she learned that eyes adjust to differing light levels. What these examples illustrate is that moving students to a desired understanding of a phenomenon is not merely a matter of presenting the correct explanation for an encounter, nor simply having direct experiences, but rather creating contexts where teachers explicitly help students scaffold between direct experiences and more accurate interpretations of those experiences so that students begin to question the supporting pillars for their ideas.

In addition to elaborate rationales for ideas regarding natural phenomena, students also have extensive frameworks regarding the NOS that may form a formidable fortress resisting implicit, and even particular forms of explicit and reflective NOS instruction designed to challenge those strongly held NOS frameworks. This is not surprising given that knowledge about scientists, science research, scientific knowledge, and other ideas regarding the NOS are intricately linked to in-school and out-of-school experiences. Beginning in elementary school and typically persisting even to postsecondary education, science textbooks, audiovisual materials, laboratory activities and reports, teacher language, and means of assessment all coalesce in portraying common misconceptions about the NOS. Many of these misconceptions fit and are reinforced by out-of-school portrayals of science observed on television, print media (Basalla 1976; Russell 1981), and the internet. Together, these in and out-of-school experiences create a consistent and powerful image of the NOS that resists efforts at conceptual change.

In stressing the importance of learners' prior understandings, their struggles in making sense of a new encounter, the importance of context and affective factors, and the ways students may prematurely exit from instruction having ignored key aspects of that encounter, conceptual change perspectives account for the insufficiency of implicit NOS instruction to engender deep cognitive restructuring. However, the misconceptions students bring to instruction and their network of reasons for holding those views may also defy explicit and reflective NOS instruction. Here Appleton's model is fruitful in raising more precise considerations for encouraging students to continue deep cognitive processing rather than exit prematurely from instruction. It does so by making clear that, for a variety of reasons that include a teacher's purposeful instructional decisions, students' thinking can and perhaps most often will move through the three broad cognitive processes many times before exiting. Appleton (1997, pp. 314–315) suggests that his model has utility in at least four regards:

1. as a post-hoc tool for making sense of students' thinking during a previous lesson;
2. drawing teachers' attention, *a priori*, to the ways students may interpret and act on new encounters. For instance, teachers should be looking for evidence of students' cognitive processes, whether students are exiting, and, if so, their reasons for doing so.
3. helping teachers reflect on a lesson, focus on particular areas of their practice, and consider specific instructional moves that will effectively address particular situations depicted in the model; and
4. developing teaching strategies that will create powerful learning situations for students.

For example, the importance of context, affective factors, and scaffolding within students' zone of proximal development (Vygotsky 1978, 1986; Bruner 1985, 1986) to encourage deep cognitive processing is made apparent in the model, and this has significant value for clarifying potentially important considerations in robust NOS instruction. While prior literature addressing NOS instruction hints at the role of scaffolding (Khishfe & Abd-El-Khalick 2002), it inadequately illuminates specifically what such scaffolding looks like, how it is to be accomplished, the specific role of the teacher in the process, and how all this is linked to how people learn including conceptual change.

4. The Decontextualized to Highly Contextualized NOS Continuum

The NOS literature is replete with examples of NOS activities such as discrepant events, puzzle-solving activities (Clough 1997), 'black-box' activities, pictorial gestalt switches, and other activities (Lederman & Abd-El-Khalick 1998) that are often used to explicitly introduce and draw students' attention to important ideas about the NOS. Such NOS activities, readings and discussions, when isolated or tangent from science content and scientists, and whose primary purpose is to directly illustrate important ideas about the NOS, are examples of explicit and reflective *decontextualized* NOS instruction. This approach isolates and emphasizes to students fundamental NOS issues in familiar concrete ways that are not complicated by science content. Explicit and reflective decontextualized NOS instruction is important in that it uses concrete and familiar experiences to introduce complex NOS issues in ways students can begin to understand, thereby creating a foundation for exploring these issues in more contextualized situations. Moreover, these sorts of analogies can play a very important role in addressing several affective issues in conceptual change (Pintrich et al. 1993; Dagher 1994; Tyson et al. 1997).

While explicit decontextualized NOS instruction has a role to play in drawing students' attention to particular NOS issues and initiating deep cognitive processing, Clough and Olson (2001) point out that the above sorts of experiences, even when inserted or embedded between the teaching of science content, become, at best, moderately contextualized for at least two critical reasons. First, such experiences may easily be seen by students and teachers as not reflecting their perceptions of authentic science – how science, as practiced by scientists, is done. This is made evident in efforts to persuade students how decontextualized and moderately decontextualized NOS activities are *like doing science*. This suggests that the activities may easily create two conceptions of the NOS – that illustrated by these sorts of activities and an alternate view associated with their perceptions of authentic science. The ability of learners to hold incongruent perspectives side-by-side for use in different contexts with no awareness of a contradiction is well established (Resnick 1987; Galili & Bar 1992; Mortimer 1995; Tyson et al. 1997). While playing an important role in conceptual change, decontextualized and moderately contextualized NOS experiences create a very limited context in which students must reexamine their existing ideas.

Second, and critical for promoting more widespread and persistent attention to the NOS, teachers likely see explicit decontextualized and even some forms of moderately contextualized NOS experiences as 'add-ons' and rebel against taking instructional time away from teaching science content. This latter concern was noted by some teachers in a study by Abd-El-Khalick et al. (1998) as a reason for not incorporating the NOS into their teaching. Moreover, these sorts of experiences may convey to teachers that effectively teaching the NOS is primarily a matter of having many activities and resources (Abd-El-Khalick et al. 1998). So while explicit/reflective decontextualized NOS teaching is important for drawing students' attention to particular NOS issues and serving as analogies to authentic science, it alone is likely insufficient for developing in students and teachers a deep understanding of the NOS that can be robustly applied in differing content-specific situations. Additionally, the time such experiences take away from traditional content instruction may deter many teachers from addressing the NOS throughout the school year (Lakin & Wellington 1994; Abd-El-Khalick et al. 1998; Clough & Olson 2001). However, as stated earlier, this does not mean that decontextualized NOS activities are not important in effectively teaching the NOS, that students cannot learn much through such experiences, or that the aforementioned authors or others are advocating a solely decontextualized approach to NOS instruction.

At the other end of the continuum, explicit and reflective highly *contextualized* NOS instruction plays a crucial role in NOS instruction by overtly drawing students' attention to important NOS issues *entangled in science content and its development*. Highly contextualized NOS instruction is so tightly bound up in the science content being learned that the two are seamless, and thus conveying how the experience is *like* science is unnecessary. Moreover, at this end of the continuum, efforts to improve students' understanding of the NOS and science content are complementary – each reinforcing the other. The importance of highly contextualized NOS instruction is illustrated in Rudolph and Stewart's (1998) analysis that conceptually understanding evolutionary biology, and science more generally, requires:

> students to become familiar with the metaphysical assumptions and methodological process that Darwin laid out. Theoretical context and scientific practice, in this view, are not just interdependent, but really two views of a single entity. (p. 1085)

The metaphysical and methodological processes of science are often related to the context in which science research is being conducted. This means that sought after NOS understandings may "be relevant to only one specific content area or domain, or they may be relevant across all content areas" (Tyson et al. 1997, p. 402). The contextual metaphysical issues inherent in learning about NOS also mean that epistemological, ontological and social/affective perspectives advocated by Tyson et al. will be important for understanding the conceptual change process in particular contexts.

Inescapably, highly contextualizing the NOS means integrating historical and contemporary science examples that are tied to the fundamental ideas taught in particular science subjects. Such examples (Conant 1957; Klopfer & Cooley 1963; Matthews 1994a; Hagen et al. 1996; Clough 1997, 2004; Abd-El-Khalick 1999; Irwin 2000; Stinner et al. 2003 and many others) illustrate the complexities and challenges individual scientists and the scientific community experience in constructing ideas and determining their fit with empirical evidence. In addition to enhancing understanding of science content, these examples exemplify important epistemological and ontological lessons that are bound up in that content and central to understanding the NOS, and place the science content in a human context. The importance of explicitly contextualizing NOS instruction is also reflected in the research of Driver et al. (1996), Ryder et al. (1999), and Brickhouse et al. (2000) showing that students' perspectives on the NOS are, at least in part, dependent on the science content that frames the discussion. This is also reflected in

Abd-El-Khalick's (2001) noting that the results of his empirical work with preservice elementary teachers indicated that "the context and content in which preservice teachers learned about NOS influence their ability to apply their understandings to novel contexts and content" (p. 229).

The crux of this matter is that as NOS instruction moves from explicit/reflective decontextualized to explicit/reflective highly contextualized, the ease in which students can dismiss a teaching scenario as misrepresenting how authentic science works decreases. This means that students will be less likely to exit from instruction while holding an approximate fit of a NOS encounter to their preexisting ideas. However, because each historical or contemporary example, from the learner's perspective, may be thought of as a new encounter, avoiding the narrow application noted among subjects in Abd-El-Khalick's (2001) study demands that highly contextualized NOS instruction be ubiquitous in a science course.

Table I summarizes several important features in the decontextualized to highly contextualized NOS continuum that will be addressed below, but two deserve special mention here. First, explicit/reflective decontextualized NOS instruction requires students to consider how an activity is like science or what scientists do. Lacking an accurate conception of authentic science research, students understandably often provide naive responses and miss other similarities. Explicit/reflective contextualized NOS instruction uses a more authentic science context and asks students to consider what it illustrates about science and scientists. The value of history of science with explicit/reflective NOS instruction can be inferred in work by Abd-El-Khalick and Lederman (2000b), and is supported more directly in a recent study by Howe (2003). Second, in moving along the continuum toward highly contextualized explicit/reflective NOS instruction, the ease in which science teachers may dismiss NOS education as detracting from science content diminishes. Rather than an 'add-in' activity, NOS instruction is ubiquitous with teaching science content.

4.1. EXAMPLES OF HIGHLY CONTEXTUALIZED NOS INSTRUCTION

Highly contextualized explicit/reflective NOS instruction may take several forms. Content readings and teacher talk, so ubiquitous in science education, must be examined for their portrayal of the NOS. In all contexts where teachers talk to students, they must be aware that their use of language conveys images about the NOS (Munby 1976; Zeidler & Lederman 1989). Significant language such as "law", "hypothesis", "theory", and "prove" need to be accurately used when teaching content, and students made apparent of their importance. For example, students' naive empiricist views are likely influenced by statements such as "What did the data tell us?" or "What does the data show?" Because data does not *tell*

Table I. Important features in the decontextualized to highly contextualized explicit nature of science continuum

Explicit decontextualized NOS				Explicit highly contextualized NOS
Connection to science content	None	*Embedded* in, but still distinct, from science content		Seamless
Connection to authentic science	How is this activity/reading like science or what scientists do?			How is this authentic incident/NOSissue illustrated in prior NOS and lab activities?
Exemplar Activities	Black box activities Gestalt switches Puzzle solving	Decontextualized activities linked to science content	Inquiry science content activities linked to NOS	Drawing students' attention to NOS issues in authentic historical and Contemporary science incidents, and using the words of scientists accurately conveying what science is like (e.g. using Medawar's "Is the Scientific Paper a Fraud?")

'Outs' students have to exit without deep conceptual change	These activities are not science	The science content is much different than the NOS activities	Scientists have better equipment Scientists are smarter Scientists have more experience Scientists have more resources Scientists have large teams	The historical or contemporary incident is incomplete or not accurate. The particular scientist's perspective is not representative of all science or scientists. Students misinterpreting the historical or contemporary incident
Ease in which teachers may dismiss NOS instruction as detracting from science content	Easy			Difficult

scientists what to think, when teaching science content, the NOS can seamlessly be incorporated by alternatively making explicit statements like, "Note that the data is not telling the scientists what to think. Instead, scientists have to *develop* ideas that will *account for* the data." This important shift in language while teaching science content creates opportunities to pose fruitful questions such as, "How does the need to make sense of data account for disagreements among scientists and the inventive character of science?".

While teaching science content, seamlessly addressing the human side of science, epistemological and ontological assumptions underlying knowledge, difficulties in making sense of data, and justification for conclusions are crucial for explicitly and contextually addressing the NOS. A long advocated strategy to accomplish this has been integrating the history of science alongside the teaching of content (Conant 1957; Klopfer & Cooley 1963; Klopfer 1969; Russell 1981; AAAS 1990; Bybee et al. 1991; Matthews 1994b; Eichman 1996; Hagen et al. 1996; Monk & Osborne 1997; Stinner et al. 2003). Advocated approaches range from extensive and elaborate historical case studies (Conant 1957; Klopfer 1964; Matthews 1994a), significant historical components (Rutherford et al. 1970; Cassidy et al. 2002; Lin & Chen 2002), addressing misleading textbook accounts of science content (Rudge 2000), historical short stories (Solomon et al. 1992; Hagen et al. 1996; Clough 1997; Leach et al. 2003; Tao 2003), to 5–10 minutes oral historical vignettes reflecting the lives of famous scientists (Wandersee 1992). Heilbron (2002) also argues for the use of history of science, and he provides three examples illustrating how these need not be in such depth that they detract from the science content. He writes:

> Finally, wherever possible the case studies should carry epistemological or methodological lessons and dangle ties to humanistic subject matter. But never should the primary purpose of the cases be the teaching of history. (p. 330)

Contemporary science stories (Clough 1997; Shibley 2003) can powerfully contextualize the NOS through: (1) their extant nature illustrating current science in the making (Latour 1987); (2) avoiding the difficulties students sometimes display in empathizing with perspectives no longer accepted by the scientific community (Solomon et al. 1992); and (3) sensitizing students to NOS issues embedded in media reports of science that students will encounter the remainder of their lives. Each of these benefits create contexts that, with explicit attention to the NOS, encourages students to reexamine their prior ideas regarding how science and scientists work. For instance, several years ago, the media reported that scientists had *found* the sixth and final quark – the top quark. A local newspaper carried a story including information from the Associated Press and the New York Times.

Within the article the following statements appeared, and in a relevant chemistry or physics setting, the questions in italics would initiate highly contextualized NOS discussions:

Physicist: “We're not claiming discovery, but it's the first direct evidence of the top quark.”

NOS *Question: In what sense might this still evolving situation be thought of as a discovery? In what sense does the word “discovery” not capture the complexity of the process?*

Spokesperson: “The search began 17 years ago, and the team continues to search for more evidence to verify the top quark's existence.”

NOS *Question: What is encouraging physicists to search so long for the top quark's existence?*

Physicist: The exciting thing is that this is the final piece of matter as we know it, as predicted by cosmology and the Standard Model of particle physics. It's the final piece of that puzzle.

Journalist: “Without the top quark, the Standard Model – a widely held theory of what makes up matter – would collapse, forcing scientists to rethink three decades of research.”

Journalist: “Five quarks had already been discovered. Since they're believed to come in pairs, scientists believed a sixth, or top quark, must exist.”

NOS *Question: What do the three statements above imply about the role of theories in science?*

Journalist: “Scientists didn't actually see it but found evidence that it exists from patterns created by experiments ...”

NOS *Question: What does this statement imply about observation, evidence, and inference in science? How are each of these influenced by theory?*

Physicist: “Though the discovery is reassuring to physicists, it raises another more mysterious question ...”

NOS *Question: How does this statement illustrate that scientific knowledge is both a product and a process?*

These important issues in the NOS – discovery vs. invention, the role of theories, the nature of evidence, scientists' commitment to prior work, and the role of scientific knowledge in further research – are brought to life in a highly contextualized and relevant contemporary context that encourages the deep processing and cognitive restructuring essential for conceptual change regarding NOS issues.

While the story above is not closely connected to science content commonly taught in secondary school, a more recent episode showing science in the making involves a science topic that is significantly addressed in secondary school physical science and physics courses – gravity. In this still unfolding story described in the October 2003 issue of *Discover* magazine (Folger 2003), *Pioneer* 10 and 11 space probes launched in 1972 and 1973, respectively appear to be slowing down the further they travel away from our sun, as if the gravitational attraction between the sun and the probes is *increasing* with distance. Two other probes may be behaving the same way, and astronomers have known for some time that in other galaxies studied, stars and gas move faster than predicted by accepted laws of nature. To make the calculations agree with observation, the existence of dark matter – invisible matter – has been postulated. The article nicely describes attempts underway to detect dark matter and the considerable difficulties scientists have in setting up such an experiment and interpreting data that would throw light on the issue. Within the article the following statements appear that, like the quark story above, can initiate highly contextualized NOS discussions:

Astronomer: Something was exerting a force on the spacecraft that we didn't understand. We thought we'd be able to explain it in terms of forces generated by the spacecraft. And I really thought eventually it would go away as we got farther and farther from the sun. But it did not go away.

Journalist: For Michael Martin Nieto, a theoretical physicist at Los Alamos National Laboratory... it reveals that there might be something wrong with our understanding of gravity, the most pervasive force in the universe.

Physicist 1: [Dark matter] is a fudge factor.

Journalist: While the overwhelming majority of astronomers believe in the existence of dark matter, a handful of heretics have begun to question the wisdom of believing in something that no one has ever seen.

Physicist 2: I think the scientific community *should* give [my new idea – Modified Newtonian Dynamics] a hard time. If you really want to shake the principles, it shouldn't be an easy matter.

Journalist: [Physicist 2] also acknowledges that [his idea] has a serious flaw: It has no connection to any deeper theory.

Physicist 3: We infer that dark matter exists only because we think we understand gravity on these scales. If we have the perfect theory of gravity, then the data oblige us to believe that there is unseen matter. On the other hand, we don't have any tests of our theory on those scales except these kinds of data.

Physicist 1: Seriously, if God came down and said, 'OK now, bet your soul and tell me what's causing the *Pioneer* effect,' I'd say a

> systematic error. ...I want *Pioneer* to be different. Who wouldn't? Of course, I'd love it to be something new. I'd love it. I'd definitely go out and stick my tongue out at my enemies. But that's different than saying I believe it is."

This contemporary story has even greater power when associated with the nineteenth century episode where scientists noted that observations of Uranus' orbit departed significantly from that predicted by Newton's gravitational law. While some scientists at the time speculated that the inverse-square law might not apply at the distance of Uranus, most scientists, noting the enormous success of the Newtonian framework in other affairs, expected the anomaly to be accounted for without abandoning or modifying Newton's law. In 1835, years after the anomaly in Uranus' orbit was first recognized, the return of Halley's comet sparked the idea that celestial bodies beyond Uranus might exert a force on the planet large enough to explain the planet's orbital discrepancy. This confidence, rather than seeing the anomaly as falsifying a well-supported idea, was key in the prediction and discovery of Neptune in 1846.

Here again, important NOS issues such as discovery vs. invention, the role of theories in interpreting data and setting up experiments, the nature of evidence, scientists' commitment to prior work, the role of ad-hoc ideas, the manner in which anomalies are interpreted and handled, the conservative reaction most scientists have towards ideas that challenge fundamental knowledge, and the expectation that robust scientific knowledge should connect with more encompassing ideas – are brought to life in a highly contextualized contemporary context that is tightly bound to content taught at the secondary school level.

As a third example, 10 years ago *The Milwaukee Journal* published a story (Bednarek 1993) relating how Thomas Brock, in the mid 1960s, reported on a bacterium flourishing in the hot springs of Yellowstone National Park, and placed that information in the public domain through the American Type Culture Collection. This knowledge, a product of basic or pure research, later became useful in unanticipated ways. In the 1980s, the bacterium was used by a biotechnology company to isolate the Taq polymerase enzyme which was then used in the PCR process. The Taq polymerase enzyme was patented in 1989 and later sold to a pharmaceutical company for $300 million. At the time of the article's publication, a legal battle involving PCR and the Taq enzyme was underway. This story can be profitably incorporated alongside study of bacteria, genetics, and other relevant biology topics to illustrate the relationship between basic science, applied science, technology, and society (Clough 1997, 2004).

These examples illustrate that carefully selected contemporary stories involving science, introduced alongside relevant science topics, unifies the

NOS, science content, and contemporary media portrayals of science and scientists, creating a context that further encourages students to reexamine prior understandings, and diminishes the ease with which they can exit from instruction holding opposing in-school and out-of-school perspectives of NOS. This, in turn, may help students accurately interpret NOS ideas in historical stories. Furthermore, when integrated with relevant science topics, these explicit and contextualized contemporary science short stories, like relevant historical stories, do not push the science content into a secondary role.

Highly contextualized NOS instruction can also occur in common inquiry laboratory experiences. One example provided by Clough (1997) has students maintain a personal journal throughout their inquiry process. Student entries are to include: (1) their science ideas entertained privately and those made public; (2) discussions with others; (3) experiments considered and abandoned as well as those carried to their end; (4) data collected, ignored and eventually reported; (5) where ideas originated; and (6) other thoughts and feelings regarding the overall inquiry experience. When the time comes to report the results of the inquiry, students and their laboratory colleagues are asked to follow the traditional time-honored approach appearing in scientific journals. Afterwards, a class discussion occurs comparing personal accounts of the experience to that appearing in the formal report. If the activity stopped here, it would be moderately contextualized, as students have plenty of room to exit without believing authentic science is similar to their experience. Hence, to create a more highly contextualized NOS learning experience, students can be assigned abridged (and, if necessary, modified for the reading level of the students) portions of Peter Medawar's (1963) "Is The Scientific Paper a Fraud?" Doing so places their classroom experience in a context that previously did not exist. Whereas prior to the Medawar reading they could have easily exited from instruction while harboring many reasons for how authentic research does not have the private and public character of their in-school experience, a Nobel Laureate's account of private and public science makes doing so more difficult.

As a final example, years ago I showed a videotape regarding genetics, genetic engineering and the implications for society to my introductory high school biology students. In addition to stopping the tape periodically to pose science content questions, I also focused students' attention to NOS issues in comments by scientists and other situations involving authentic science appearing in the video. For instance, one scientist compared doing science to composing music, and I stopped the video and asked, "How is doing science like composing music?" and followed that discussion with, "How is doing science different than composing music?"

The key is that in all these explicit and highly contextualized examples, an important flip has occurred. Rather than asking students how what they are doing is like authentic science, the role of the teacher is to ask questions and draw students' attention to how the authentic historical, contemporary, or scientist's account of science is similar to or different from decontextualized and moderately contextualized NOS activities (e.g. black box, puzzle solving, NOS reading, inquiry labs, etc.) experienced in school science courses. This also illustrates that effective NOS instruction will scaffold in both directions along the continuum.

5. The Importance of Deliberately Scaffolding Along the Decontextualized/Contextualized Continuum

Despite the need for highly contextualized explicit/reflective NOS instruction, explicit/reflective decontextualized and moderately contextualized NOS experiences also play a crucial role in effectively conveying the NOS and setting up students to profit from highly contextualized NOS instruction. For instance, students' prior ideas regarding science content and the NOS will play a large role in their efforts to make sense of new experiences. Because their prior notions of the NOS are filled with misconceptions, they will likely attend to aspects of NOS stories that fit their prior ideas, unknowingly modify other aspects to fit their prior ideas, ignore other aspects that do not fit their prior understandings (Abd-El-Khalick & Lederman 2000b; Tao 2003), and exit from instruction. Students interpreting science stories in idiosyncratic ways, and focusing on aspects of stories that fit their misconceptions was noted in a study by Tao (2003):

> Since most students drew on the science stories for justifications of their views, the way they interpreted the science stories was crucial. Students' peer interactions showed that most of them were not fully aware of the overall theme of the stories; instead they attended to certain aspects that appealed to them and appeared to confirm and reinforce their inadequate views. (p. 167)

Just as importantly, students struggling to understand new science content are likely to miss or downplay intended NOS teachings in highly contextualized situations (Leach et al. 2003), even if they are explicit, without having first been introduced to key NOS ideas in less complex situations.

5.1. THE VALUE OF EXPLICIT DECONTEXTUALIZED NOS ACTIVITIES

Hence, explicit and reflective decontextualized NOS activities, readings, and multimedia play an important role in introducing and emphasizing to students fundamental NOS issues in familiar concrete ways that are not obstructed by unfamiliar science content, or historical stories that they can easily misinterpret. In addition to preparing students to benefit from more contextualized NOS instruction, such activities also raise students' interest in the NOS and communicate the importance that will be placed on it for the remainder of a course. For instance, black box activities are perennial favorites of teachers and students for the curiosity and challenge they engender. While students may show little initial interest in NOS issues, Meyling (1997) reports that two-thirds of the students in his study who actually experienced explicit instruction regarding how scientific knowledge comes to be accepted showed further interest in such learning. Discrepant events, common puzzle-solving activities (Clough 1997), 'black-box' activities, pictorial gestalt switches, and other activities suggested by Lederman and Abd-El-Khalick (1998) introduce important ideas about the NOS in ways students enjoy. Such analogies are important for satisfying both the cognitive and affective demands of conceptual change (Pintrich et al. 1993; Dagher 1994; Tyson et al. 1997).

While students have many misconceptions about authentic science research and will struggle in making some important connections between decontextualized NOS activities and science, the ease in which students can engage in such activities makes them valuable for scaffolding to moderately and highly contextualized NOS experiences. The activities above, if revisited alongside and explicitly linked to science content instruction and school laboratory experiences, now take on a moderately contextualized status. For instance, the popular tube activity and other black box activities suggested by Lederman and Abd-El-Khalick (1998) can be moderately contextualized when reintroducing them alongside teaching about the model of the atom. Effective highly contextualized NOS instruction could then result by introducing the alpha-particle bombardment experimental work of Geiger and Marsden, the months Rutherford pondered the data and its inconsistency with Thomson's plum-pudding model, and linking these historical occurrences to students' prior work with black box activities.

5.2. THE VALUE OF EXPLICIT MODERATELY CONTEXTUALIZED NOS ACTIVITIES

Inquiry laboratory activities in which students design procedures, wrestle with data, and report their work for peer review provide many opportunities for contexualizing NOS instruction to varying degrees. However, the ubiquitous nature of cookbook activities and highly structured lab reports warrants a gradual move towards more student decision-making that will, in time, better reflect issues in authentic science (Colburn & Clough 1997).

Early in the school year, teachers might simply have students decide how to convey the results of their laboratory work. This means deciding what to include in the report, whether or not to use data tables and graphs, and the order to present the information. Lacking prior experience making these sorts of decisions, students will likely ask for clarification. Rather than directly answering such requests, teachers should ask students questions like, "What would a reader need to know to follow your work and resulting conclusions?", "How might you present your data in a way that is easiest for the reader to grasp?" and "How do individual scientists and research teams decide what to include in their manuscripts for publication?" Classroom discussion regarding students' approaches, the pros and cons of each, and how this process mirrors scientists' preparation of reports should occur. This process deeply engages students in the content illustrated in the lab experience while also explicitly teaching the NOS in a moderately contextualized manner.

In following laboratory work, procedures can be rewritten so that they do not convey to students what is 'supposed to happen.' Clough (1997, p. 197) suggests that in preparing students for NOS lessons in laboratory activities throughout the school year, "Student skepticism should be directed back to the laboratory procedure, evidence accumulated, and interpretations made." As the school year progresses, more student decision-making should be promoted by having them decide how to go about investigating laboratory research questions and raising researchable questions of their own (Clough 2004). Colburn and Clough (1997) encourage the use of post-laboratory discussions where teachers ask questions such as, "What were you investigating?", "What were your results?", "Why do you think the lab procedure was set up in this particular way?", "What interpretations can be made about the data?" and "What have you learned from doing the activity?" Effective use of students' responses and referring back to their lab results prepares students for NOS questions such as, "What does your struggle to make sense of the lab results indicate about scientific data?", "Why would scientists looking at data have to go through the same struggle?" and "What does this experience illustrate about the nature of scientific research?"

The reason these sorts of experiences fall short of highly contextualized NOS instruction is illustrated again by the ways students can dismiss these experiences as not truly representing authentic science, and hence, exit from instruction with an approximate fit to desired outcomes. For example, students can easily maintain that real scientists are smarter, have more experience, possess better equipment and resources, and have larger research teams. To help students see that their personal laboratory experiences and difficulties interpreting results are similar to those of authentic scientists, teachers ought to periodically incorporate historically based empirical work (Matthews 1994a; Allchin et al. 1999) and explicitly scaffold the relevant NOS issues in those episodes to students' other laboratory inquiry experiences.

6. Conclusion and Implications

The crucial role of explicit NOS instruction that draws students' attention to particular NOS ideas has been made abundantly clear in the literature (Akindehin 1988; Hagen et al. 1996; MacDonald 1996; Clough 1997, 1998; Bell et al. 1998; Lederman 1998; Abd-El-Khalick & Lederman 2000a; Akerson et al. 2000), but several significant reasons exist for also explicitly stressing instruction that scaffolds back and forth along the decontextualized/contextualized NOS continuum. First, when tied to how students learn, awareness of the continuum can be useful in understanding why students may exit from explicit and reflective NOS instruction not having learned what was intended. Second, understanding the interplay of NOS instruction along the continuum can encourage short- and long-term NOS lesson planning that will more likely promote a rich understanding of the NOS. Third, science teacher educators can use the continuum in conveying to preservice and inservice teachers: (a) the role of decontextualized, moderately contextualized, and highly contextualized NOS instruction in effective NOS instruction; (b) the need to scaffold back and forth between these three broad categories of NOS instruction; and (c) the crucial importance of explicit and reflective NOS instruction, but the need to also address the decontextualized/contextualized NOS continuum. Fourth, attention to the continuum may be useful to researchers attempting to understand teachers' NOS implementation practices and their effects on students. Finally, thoughtful consideration of the continuum has utility in persuading teachers that consistently teaching the NOS need not detract from, and will likely promote, science content learning.

Despite a wide variety of efforts aimed at encouraging teachers to devote explicit attention to NOS instruction, results have, for the most part, been disappointing. Teachers generally appear unconvinced of the need to emphasize the NOS as a cognitive objective (Abd-El-Khalick et al. 1998; Lederman 1998), and likely see NOS instruction as detracting from their primary mission of teaching science content. Lakin and Wellington (1994) point out that NOS instruction appears to be contrary to "expectations held of science and science teaching in schools, not only by teachers and pupils but also those perceived as being held by parents and society"

(p. 186). However, the marginal results of commonly advocated NOS instructional strategies likely reflect, at least in part, a lack of attention to the important interplay along the decontextualized/contextualized NOS instruction continuum. Science teachers balk at extensive explicit decontextualized NOS activities, seeing them as taking time from science content instruction. For the same reason, they also resist extensive history of science case studies. Our preliminary efforts emphasizing to teachers the roles of explicit/implicit and decontextualized/contextualized NOS instruction (Clough & Olson 2001) has produced some encouraging results. Four of six teachers participating in a study following such a course implemented the NOS both decontextually and contextually consistently throughout the academic year (Olson & Clough 2001). Moreover, both secondary and college science teachers have expressed interest in current efforts now underway at creating short historical narratives that teach science content while also drawing students' attention to important NOS ideas (Clough & Olson 2004). While needing further study, perhaps teachers are willing to consistently teach the NOS if it is entangled within the science content traditionally taught in science courses, thus not taking significant time away from that instruction. If so, emphasizing the decontextualized/contextualized NOS continuum takes on added significance.

Attention to *both* the implicit/explicit and decontextualized/contextualized continua provides an useful framework for promoting effective and consistent NOS instruction, and conceptualizing and reporting research studies addressing the NOS and science education (Olson & Clough 2001). Figure 1 illustrates how in prior work (Olson et al. 2003), we have placed the decontextualized/contextualized and explicit/implicit continua on a horizontal and vertical axis, respectively to map the general emphasis of teachers' NOS instruction after an intervening treatment. The implicit/explicit and decontextualized/contextualized graphic representation may also be used for mapping over time the specific type, instances, sequence, and scaffolding of NOS instruction. Attention to the two continua may also be useful for helping preservice and inservice teachers: (a) understand the role of, and interplay among, explicit, implicit, decontextualized, moderately contextualized and highly contextualized NOS instruction; (b) attend to both continua in lesson planning and sequencing of lessons; and (c) map their own NOS implementation practices.

Attention to the decontextualized/contextualized continuum and its potentially critical role in NOS instruction, unfortunately, demands a much deeper understanding of the NOS than is common among classroom teachers. The highly contextualized NOS instruction examples provided in this paper make clear that teachers must understand and notice such issues entangled in science content and its development, and then effectively

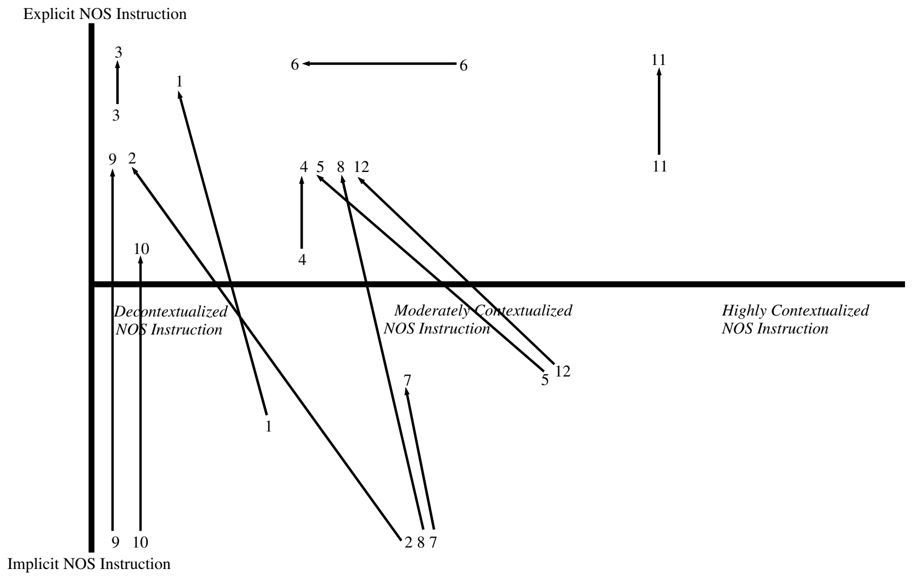

Figure 1. Explicit/implicit and decontextualized/contextualized map for conveying movement in teachers' primary NOS implementation practices (Olson et al. 2003).

incorporate it with content instruction. Tobin and Garnett (1988) determined that lack of deep content understanding inhibited teachers from asking questions that effectively helped students see the problem with their thinking and move towards more robust understandings. Windschitl (2002) presents compelling arguments that effective science teaching requires a much deeper understanding of science content, how students learn, and pedagogy than does traditional science teaching. The importance of effectively contextualizing and scaffolding experiences to help students grapple with and understand difficult ideas (Metz 1995) is critical for effective NOS instruction and adds an additional requirement to the complex and, at times, unpredictable character of teaching about the NOS. Such instruction requires from teachers a deep understanding of NOS content, NOS pedagogical content knowledge, and general pedagogy skills. Whether such understanding and skills can be promoted and implemented widely remains to be seen.

While this paper has focused primarily on NOS instructional examples appropriate for secondary science settings, Kafai and Gilliland-Swetland's (2001) study of 4th and 5th grade students in an urban setting suggests that with attention to particular limitations, integrating highly contextualized NOS experiences has fruitful outcomes for elementary children. Stinner et al. (2003) argue that science stories conveyed to young children should avoid the logical operations and mathematics for natural phenomena and instead concentrate on natural history – those individuals who described and classified what they observed. However, Metz (1995, p. 121) writes, "Research that examines the possibilities in children's thinking with judicious scaffolding is much more relevant to the determination of the possibilities of instruction." To what extent highly contextualized NOS instruction can be used with elementary children remains to be seen.

A conceptual change framework helps make sense of the difficulties students often have developing robust understandings of the NOS that can be applied in a variety of settings. In doing so, it explains the importance of explicit and reflective NOS instruction, but also raises additional issues to consider in effective NOS instruction. The decontextualized/contextualized NOS continuum developed in this paper, and the scaffolding along that continuum, emphasizes the importance of context and may be useful for understanding why students, despite explicit and reflective NOS instruction, can exit from instruction with their fundamental NOS notions unchanged. As argued earlier, decontextualized and moderately contextualized NOS experiences can be easily seen as disparate from authentic science. But the significance of highly contextualized NOS experiences can just as easily be dismissed because students and teachers interpret them using their inadequate prior knowledge. Conceptual development and change, and teaching for these ends, are immensely complex. Appleton's model draws teachers' attention to students' reasons for exiting from instruction, and makes explicit that the teachers' role is to accurately assess students' reasons for exiting and determine if and how students' exiting is to be redirected. More explicit attention to scaffolding along the decontextualized/contextualized NOS continuum may be critical in this effort to promote continued cognitive restructuring that, over time, will result in students' exiting from instruction with a robust understanding of the complex NOS.

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