An Overview of the Nature of Science for K-12 Science Teachers

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Abstract

Recent publicity has emphasized the concern of American citizens over student performance in the sciences. In an effort to evaluate one aspect of kindergarten through twelfth grade curricula that may have contributed to this situation, a comprehensive review of the literature concerning the nature of science was developed into a philosophical paper. The findings are synthesized into an analysis of the nature of science that provides a broad outline of the subject and related issues. The nature of science is a way of knowing that when balanced with scientific content and processes aids in the development of scientific literacy. Nonetheless, teachers and students are not attaining an adequate level of understanding concerning the nature of science and this impacts their comprehension of science and performance in these subject areas. Many reasons have been given from institutional constraints to lack of resources as to why the nature of science is being excluded from kindergarten through twelfth grade curricula or why it is not completely understood. However, the biggest concern is that the nature of science is being taught implicitly. Teachers need to acquire contemporary views of the nature of science and include it within their objectives and assessment. They also need to teach about the nature of science explicitly and intentionally for it to have greater positive impact.

AN OVERVIEW OF THE NATURE OF SCIENCE

FOR K-12 SCIENCE TEACHERS

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ABSTRACT

Recent publicity has emphasized the concern of American citizens over student performance in the sciences. In an effort to evaluate one aspect of kindergarten through twelfth grade curricula that may have contributed to this situation, a comprehensive review of the literature concerning the nature of science was developed into a philosophical paper. The findings are synthesized into an analysis of the nature of science that provides a broad outline of the subject and related issues. The nature of science is a way of knowing that when balanced with scientific content and processes aids in the development of scientific literacy. Nonetheless, teachers and students are not attaining an adequate level of understanding concerning the nature of science and this impacts their comprehension of science and performance in these subject areas. Many reasons have been given from institutional constraints to lack of resources as to why the nature of science is being excluded from kindergarten through twelfth grade curricula or why it is not completely understood. However, the biggest concern is that the nature of science is being taught implicitly. Teachers need to acquire contemporary views of the nature of science and include it within their objectives and assessment. They also need to teach about the nature of science explicitly and intentionally for it to have greater positive impact.

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PREFACE

Need for Scientific Understanding

Science, including mathematics and technology, needs to be understood and used by all citizens to maintain order within society and to "control" the delicate balance of the universe. Science helps people develop an understanding of the mind and the natural world, which aids them in becoming responsible, effective citizens. An understanding of science not only serves personal and national interests, but supports global interests.

There are a multitude of serious problems and controversies found nationally and globally including: the AIDS epidemic, natural disasters, famine, pollution, nuclear arms development, social disturbances, unchecked population growth, energy crises, war -- the list is long and growing. These problems and controversies are destroying the threads that hold civilization together. However, the fraying can be slowed as many elements of these issues can be successfully addressed through science. The problem lies in the prospect that many people are not properly equipped in regard to science to effectively deal with these issues.

Scientific literacy is achieved through content knowledge, understanding of scientific processes, and a contemporary understanding of the nature of science (NOS). A thorough and complete understanding of these areas elevates scientific literacy. Scientific content, processes, and the NOS are the main components of science and understanding them allows citizens to become firmly grounded in the scientific endeavor. However, a balanced understanding of all three needs to be achieved because the picture is incomplete when an understanding of one of the areas is underdeveloped. Each one of the areas needs to be understood and utilized to attain scientific literacy. This literacy is essential to personal and social decision-making and provides people with the necessary skills to develop solutions to problems that can hinder the evolution of humankind.

Even though society is at a vital juncture, where citizens with a high level of scientific literacy are needed, reports such as the Third International Mathematics and Science Study (as cited in Gibbs & Fox, 1999), are claiming American students are not performing as well as their foreign "counterparts." Additionally, standardized test scores are dropping. Nonetheless, even with these alleged poor performances the United States is a thriving, diverse nation, which is teaming with life and affluence.

In spite of the reality that the United States is prospering, what about its future and the well being of the rest of the world? Imagine where the United States and the world *could* be if everyone had a deeper and more complete understanding of science. What the future holds for individuals, the nation, and the world depends to a considerable degree on the acquisition, distribution, and use of science.

American citizens need to improve upon their scientific literacy. Many understand the content and processes of science, but do not understand the nature of science. The nature of science involves methods, beliefs, and values and is difficult to understand because it is not as concrete as scientific content and processes. Many factors have been identified as reasons why citizens are not achieving this understanding, but the major inference arises from the idea that the nature of science is being taught erroneously or is completely left out of kindergarten through twelfth grade (K-12) curricula. If the United States is to be able to identify and provide effective solutions to scientific and social dilemmas, it must be ensured that the nature of science is an essential part of all science curricula.

INTRODUCTION

Rationale for Research

A need to educate teachers about the nature of science was realized while working with colleagues and pre-service teachers during meetings and mentoring experiences. Those experiences combined with personal uncertainty make it clear that something else needs to be done to inform and educate K-12 educators about major issues and ideas concerning the NOS. The result is a culmination of research and studies which have been synthesized into an overview of the NOS. Although teachers are not provided with everything they need, they are provided with a solid base to work from and build upon.

Statement of Problems

Three main questions have been addressed dealing with the NOS. First, what is the nature of science? This question will be answered by reviewing researched based periodicals and defining the NOS, establishing tenets of the NOS, and identifying the differences between the NOS and science process skills. Secondly, what are the benefits of teaching and understanding goals of the NOS? Lastly, why isn't an adequate understanding of the NOS being achieved, and what can teachers do? Topics used to answer this question include: teacher and student misconceptions, reasons for NOS exclusion, the role of the teacher, and what can teachers do.

RESEARCH APPROACH

This philosophical paper begins by applying a review of the literature to make a case for the appropriate infusion of NOS concepts into K-12 curricula. Special attention was given to research and applicable studies conducted over the NOS and its implications on K-12 education. Rather than performing a research study involving teachers and students, a review of the literature is used. This mode of research is used because of the complexities associated with subject based research such as time constraints, accessibility issues, and quantity and quality of participants. Likewise, many studies have already been conducted with teachers and students and an extensive amount of written material concerning the relationships between teachers/students and the NOS already exists. Nonetheless, few have attempted to collate this research into something close to a metanalysis. The quantity and quality of information concerning the NOS was impressive, but not complete. The research focus was developed because, although a great deal of information has been published, the NOS needed additional consideration and work.

The sources originate from a wide range of publications including research studies, professional journals, books dealing with science and educational issues, and periodicals pertaining to national movements in science and education. Some of the periodicals were written and published nearly half a century apart. Consideration was given to periodicals from five different decades because the NOS is not a new buzzword and has been in the spotlight since the early twentieth century. Although the individual sources may not have made clear and concise connections between the NOS and K-12 education, a collation of these individual studies creates a holistic view of the NOS and education. Once the problems have been outlined and sufficient research has been applied, adequate solutions can be developed and refined.

Scientific Literacy

A major objective of science educators is the preparation of scientifically literate students who understand the concepts, principles, theories, and processes of science.

Furthermore, a goal of science education is for students to have an awareness of the intricate relationships between science, technology, and society (Millar & Osbourne, 1998). Specifically, scientific literacy includes many facets such as citizens being: (a) familiar with the natural world and its unity; (b) having an awareness of the interdependence of science, mathematics, and technology; (c) understanding key components and principles of science; (d) having a capacity for scientific thinking; knowing that science is an human enterprise; and (e) being able to use scientific knowledge for personal and social purposes (American Association for the Advancement of Science [AAAS], 1990).

The United States needs people who are scientifically literate as this literacy serves local and national interests. Engineers, scientists, and science teachers are not the only ones who need to possess scientific literacy. All citizens need to be scientifically literate because the country is only as strong as its weakest link. The United States is a consortium of all people and in order for the country to move forward, all people need to move forward. This progression can be accomplished when every citizen understands and is capable of using the various aspects of scientific literacy.

The components of literacy are not achieved through content knowledge or process skills alone as it also involves a developed and contemporary understanding of the NOS. All citizens need to understand the NOS because it is an essential component of scientific literacy (AAAS, 1990, 1993; National Research Council [NRC], 1996; National Science Teachers Association [NSTA], 1996). Without an understanding of the NOS one cannot become scientifically literate. Being well-rehearsed in scientific content and processes is a necessity, but without an understanding of the framework of science, the usefulness of content and process knowledge is limited. Since all people need to be scientifically literate and an understanding of the NOS is a precursor to literacy, this makes the NOS an important goal of science education (Aikenhead, 1997; Lederman, 1992, 1999; Solomon, Scott, & Duveen, 1996), if not the *major* goal (Matthews, 1994). The need for understanding the NOS is not a new occurrence, as it has been an expected educational outcome since 1907 (Lederman, 1992) and the subject of considerable research during the past half century.

NATURE OF SCIENCE INFERENCES

Organization of Research

What is the Nature of Science?

Definition

The nature of science is a way of knowing that includes values, beliefs, methods, and ideas concerning science. It can be the "knowledge about how scientists develop and use scientific knowledge, how they decide which questions to investigate, how they collect and interpret scientific data, and how they decide whether to believe findings in research journals" (Ryder, Leach, & Driver, 1999, p. 201). A different perspective is that the NOS is the "epistemology of science, science as a way of knowing, or the values and beliefs inherent to the development of scientific knowledge" (Abd-El-Khalick, Bell, & Lederman, 1998b, p. 418). The NOS is the who, what, when, how, where, and why that aids in the explanation of the workings of science.

The NOS is a vital part of the framework for science. It involves understanding who is involved in the scientific enterprise and how their relationships with others affect their work and understandings. Likewise, it involves understanding that scientific knowledge is the product of human involvement, imagination, and creativity. The NOS deals with what is involved and how it makes an impact on the situation. Questions asking why, when, and where are fundamental to the NOS, and help to clarify and make results more clear and relevant.

Beliefs about the NOS appear to be comparable, but they are not homogeneous. Abd-El-Khalick and Lederman (2000) reason that beyond general characterizations, there is no consensus amongst philosophers/historians of science, scientists, and science educators on one specific definition of the NOS. Additionally, constitutes of the NOS are equally as debated. Abd-El-Khalick and Lederman further note that this should not be surprising "given the multi-faceted, complex, and dynamic nature of the scientific endeavor" (p. 666). The make-up of the NOS and its definition will change as developments occur in the history, philosophy, and sociology of science. Suchting (1995) agreed that as science expands and our understanding of the universe increase, our views of the NOS are themselves likely to evolve. The NOS is laden with philosophical and theoretical underpinnings, and it cannot be expected that it will or should mean the same thing to everyone. Moreover, the details and structure of the NOS depend on the scientific discipline as each field has its own NOS identity.

Tenets

Educators, scientists, philosophers, sociologists, historians, and scientific organizations have developed lists of tenets. Based upon their experiences and knowledge these groups have fashioned tenets or views concerning science. However, one does not need to concern himself or herself with all tenets, but should instead concentrate on the ones that are applicable to his or her life, occupation, and interests.

Nonetheless, that does not mean one should avoid other tenets, but rather should achieve understanding at the basic level before attempting to move onto more advanced ideas. Once an adequate understanding has been achieved, one should then look to expand his or her knowledge and experiences. It is important to keep growing intellectually, as a more intimate understanding of science allows one to make a greater positive impact on society. Eventually, instead of learning science one can contribute to science by adding research and "knowledge" to the domain.

The tenets held by individuals, groups, and organizations are often debated and disagreed upon. Philosophers have different views of the NOS than practicing scientists and science educators (Alters, 1997; Pomeroy, 1993) because they are exposed to science in different settings and are involved in the scientific endeavor in differing capacities. Smith, Lederman, Bell, McComas, Clough (1997) and Matthews (1994) acknowledge there is not complete agreement on NOS tenets, but insist there is reasonable consensus on many of the basic points. The basic points of these tenets are essentially non-controversial (Lederman, 1999). The lower or basic tenets of the NOS, which Lederman believes to be relevant for K-12 education, state that scientific knowledge is:

1. tentative (subject to change).
2. empirically based (based on/derived from observation of the natural world).
3. subjective (theory-laden).
4. partly the product of human interference, imagination, and creativity.
5. socially and culturally imbedded and involves observations and inferences.
6. a function of relationships between theories and laws.
7. a distinction between observations and inferences.

These "seven aspects provide a profile of the scientific enterprise" (Bell, Lederman, & Abd-El-Khalick, 2000, p. 564). Together these tenets help to create a picture of science, but when scattered they serve only as isolated pieces of the puzzle. It is important to realize, although listed separately, the tenets are closely interrelated and should not be examined individually (Bell, Lederman, & Abd-El-Khalick, 2000). The tenets are a package and cannot be disassembled and expected to serve their purpose.

Nature Versus Processes of Science

Although scientific processes and the NOS correspond with each other, it is important to distinguish that they are not one and the same. Processes of science are activities related to the collection, interpretation, and formation of data and conclusions. Further examples of scientific processes include experimentation, observation, and inference. On the other hand, the NOS would be an understanding that observations are based on and/or derived from the natural world and are shaped by ones subjectivity. Although science processes and the NOS overlap, they are distinctly different.

The NOS is tied to many different aspects of science because it is the overall structure that holds science together. Variations in definitions and beliefs coupled with constant changes make it difficult for practicing teachers to keep up with the growth and change of the NOS. Monitoring these changes often gets overlooked as educators attempt to keep pace with the increasing revisions and advances in science content and the field of education. Even with the many benefits that are results of understanding the NOS, teachers do not understand its composition.

What Are the Benefits of Understanding and Teaching Goals of the NOS?

The NOS should be an important and unifying aspect of any science curriculum.

Understanding the NOS is an essential component of becoming scientifically literate; however, a mere familiarity is not enough. Teachers must have the ability to analyze and synthesize their beliefs and values in accordance with others. Likewise, they need to have the ability to act upon and effectively model these processes.

The benefits of holding a contemporary view of the NOS have not been evident because many teachers and students have never consistently worked with and been exposed to adequate understandings. Likewise, even though teachers and students are exposed to adequate conceptions of the NOS, it does not guarantee they will come away with those understandings. Ill-conceived ideas and perspectives perpetuate themselves to the next generation, and unfortunately, many do not even know they hold inadequate ideas. With the various problems and controversies actively debated within scientific circles and public forums, how can people make sense of them?

It is not possible to fully understand issues such as evolution, cloning, gene therapy, animal research practices, experimental procedures/testing and their implications based on just content or process knowledge. People need to understand the "facts" of the situation and the processes used to get there, but they must also understand the nature of the situation. They need to know and understand all three aspects of science.

Science content, processes and the NOS are interrelated and depend on each other to create a holistic view. Without an understanding of all three, the puzzle will be missing a few of its pieces, and the picture will be incomplete. Students need to have appropriate NOS beliefs if they want to take the path to scientific literacy because understanding the NOS is a prerequisite to literacy. Ending up on the wrong route would require students to retrace their steps or find a different way, which would waste time and energy. When students attain a contemporary view of science, they have the ability to pave their own path to scientific literacy. Some do exhibit valid and contemporary perspectives. These people are evidence of the benefits from a well-rounded science education program, which includes the NOS as a central part of its curricula.

Benefits

Throughout history, many have stated that an appropriate understanding of the NOS has cultural, educational, and/or scientific benefits (Klopfer, 1969; Murcia & Schibeci, 1999, Solomon, 1991). Furthermore, understanding the NOS is "crucial to responsible personal decision-making and effective local and global citizenship" (Smith & Scharmann, 1999, p. 495). With an ample understanding of the NOS, people will be capable of making informed decisions. These decisions will be made not just based on the "facts," but instead after intensive deliberation with their own ideas and perspectives.

A contemporary understanding of the NOS helps students to become more competent in science (Matthews, 1998) because their actions in scientific endeavors are influenced by their conceptions of the NOS (Edmundson & Novak, 1993; Songer & Linn, 1991). An assumption from Lederman (1999), and supported by Murcia and Schibeci (1999), is that a clear and informed conception of the NOS will empower students and the public to become more knowledgeable consumers of science who can critically question media reports and advertising based on scientific claims. Moreover, students will one day become journalists, teachers, civil servants, business-people, and politicians; and they will need to conduct tasks which require an acceptable view of the NOS. For example, health officials may need to inform the public on scientific evidence related to a viral outbreak; or a business person may need to describe to his or her clientele the benefits and problems associated with construction materials or engineering structures. Pre-service teachers also suggested NOS activities make science more interesting (Bell, Lederman, & Abd-El-Khalick, 2000). Additionally, it provides background knowledge necessary for critical thinking/problem solving and provides a more authentic context for learning and understanding science knowledge and its progression (Bell, Lederman, & Abd-El-Khalick).

Ultimately, the NOS provides grounding for science and the overlying benefit of it is that it acts as the glue that binds the infrastructure of science. Without the glue the structure is incomplete, unstable, and defective. The benefits of understanding the NOS are many and prolific, but if there are so many, why are science educators and their students not attaining these understandings?

Teachers and students must be able to internalize and articulate the NOS. Not only should they be aware of it, they should be able to understand the NOS. For instance, it must be understood that science is tentative and changes occur as new technology, techniques, experiments, and modes of thought are created and accepted. Additionally, science is not based solely on observations, but instead involves a combination of inferences and observations.

Why Isn't an Adequate Understanding of the NOS Being Achieved by Teachers and Students and What Can Teachers Do?

Teacher and Student Misconceptions

Unfortunately, regardless of the amount of importance placed on the NOS and established tenets, it is evident teachers and students are not attaining an adequate and contemporary understanding. This is not a recent phenomenon, but has plagued science education since the distinction of the NOS as an educational outcome. Numerous studies and research have been conducted which assert that teachers do not possess contemporary views regarding the NOS (Abell & Smith, 1994; Aguirre, Hagerty, & Linder, 1990; Kimball, 1967-68; King, 1991; Koulaidis & Ogborn, 1995; Pomeroy, 1993). Likewise, students are not attaining an adequate understanding of the NOS (Aikenhead, 1973; Mackay, 1971; Ryan & Aikenhead, 1992; Wilson, 1954). The high priority of teacher and student achievement in understanding the NOS, coupled with the idea that it is not being achieved, opens the door for debate and controversy.

There are many ongoing debates concerning the NOS and its part in science education. The relationship between teacher understanding of the NOS and how it impacts classroom practice has been actively researched through classroom experiences, teacher and student interviews, case studies, and surveys. Through this type of research it has been identified that teacher understanding and its effect on classroom practice is a complex issue (Lederman & Druger, 1985; Lederman & Zeidler, 1987) and teachers' views do not necessarily influence classroom practice (Lederman, 1992, 1999; Mellado, 1997). This revelation intensifies debate and intrigues educators. The disclosure that what teachers say and model does not necessarily translate into student understanding and/or acceptance has attracted additional involvement and research.

Reasons for Exclusion

Many researchers have spent decades trying to determine why the NOS is excluded from science curricula. Although this issue is complicated, an assortment of explanations has been identified. Teachers do not include the NOS within their instruction because of curriculum and institutional constraints (Brickhouse, 1990;

Lederman & Zeidler, 1987). With the implementation of content standards, benchmarks, and critical objectives teachers feel they have little room for anything else. Likewise, some teachers do not have control over what is taught and teach what they are told to. Other constraints experienced by teachers involve pressure to cover content (Duschl & Wright, 1989) and time constraints (Bell, Lederman, & Abd-El-Khalick, 2000). Many have difficulty getting through everything they have to cover or feel they need to cover, let alone include the NOS. With the continued push to involve students with as much content as possible, teachers do not set aside the time to include the NOS within their instructional strategies.

Conversely, some who want to incorporate the NOS cannot do so because of the lack of resources for teaching and assessing understandings of it (Bell, Lederman, & Abd-El-Khalick, 2000). A problem that affects many classrooms, regardless of the subject area and students, is classroom management (Lantz & Kass, 1987; Lederman, 1995). Due to the sizes and structure of classes, teachers feel they do not have the ability to effectively incorporate values and beliefs concerning science within the curriculum.

Educators are also concerned about student abilities, needs, attitudes, and/or motivation (Duschl & Wright, 1989). Teachers are afraid the abstract nature of the NOS will be too much for students to understand or due to a lack of motivation students will not completely participate. Furthermore, some believe students lack the cognitive capacity to comprehend, understand, and associate the various tenets with science content and processes.

A bigger problem lies in teacher understanding, as many do not include the NOS within their curriculum because of their own discomfort in understanding it (Bell, Lederman, & Abd-El-Khalick, 2000). Teachers realize they have inadequate and outdated perspectives, and due to these deficiencies, choose not to teach what they themselves do not know. Young or inexperienced teachers also leave out NOS teachings (Brickhouse & Bodner, 1992). They are new to the field, and with the weight of their various duties and many responsibilities, they fail to embed the NOS within the curriculum. Many reasons have been expressed why teachers do not include the NOS within their curriculum; however, one of the more important justifications is that teachers believe students will learn about it implicitly.

Implicit Versus Explicit Teaching

Studies that have researched teacher and student conceptions of the NOS have focused on implicit and explicit teaching approaches. These approaches are drastically different, but the differences are not measured by what type of activity is used. Instead the discrimination between the two "lies in the extent to which learners are provided...with the conceptual tools...that would enable them to think about and reflect on the activities in which they are engaged" (Abd-El-Khalick & Lederman, 2000, p. 690).

Implicit.

Implicit learning refers to an understanding of the NOS facilitated through process skill instruction, science content coursework, and "doing" science. In other words, it is assumed students learn about science simply by going through the motions. The understanding of the NOS through implicit means is considered to be a by-product of engagement in science-based activities (Abd-El-Khalick & Lederman, 2000) and is designated as an affective goal (Riley, 1979). Teachers expect students to learn information as a consequence of instruction or as a result of changes in the learning environment, despite the absence of direct reference to the NOS. Examples of implicit teaching include laboratory tasks, group work, lecture, project tasks, and performance of scientific activities with no reflection on the nature of the activity.

Explicit.

Explicit teaching is diametrically opposed to implicit teaching and utilizes reflective practices while conducting experiments, project tasks, lectures, and discussions. It is the utilization of elements from history and philosophy of science and/or instruction geared towards the various aspects of the NOS (Abd-El-Khalick & Lederman, 2000). Explicit teaching of the NOS can be traced back to the early 1900's (Abd-El-Khalick, Bell, & Lederman, 1998b) and requires the outcome to be planned, instead of a side effect (Akindehin, 1988). Moreover, it is a cognitive outcome. Simply stated, explicit teaching refers to the direct teaching of concepts involving the NOS.

Explicit teaching; however, does not mean didactic teaching. An example of explicit teaching would involve showing a video and using it to initiate a discussion about the ways in which scientific ideas came to be accepted in and outside of scientific communities (Ryder, Leach, & Driver, 1999). Another example would involve giving students partial trilobite fossils and instructing them to draw the entire organism. Upon completion of the drawings, students would participate in a discussion as to how observations and inferences play a role in the development of science and scientific ideas. Regardless of the lesson used, explicit teaching requires direct connections to the NOS and opportunities for reflection.

Implications of studies.

Studies have been conducted in regard to explicit and implicit approaches to teaching, and their results are clear. Some research indicates explicit teaching of the NOS does help students gain contemporary views concerning the NOS (Abd-El-Khalick & Lederman, 2000). On the other hand, there is no experimental support for the assumption that implicit teaching of the NOS helps teachers and students acquire adequate conceptions of it.

Studies conducted in the late sixties and early seventies focusing on the effectiveness of hands-on and inquiry based curriculum indicated the NOS cannot be learned implicitly (Durkee, 1974; Tamir, 1972; Trent, 1965). These studies looked at classrooms in which teachers allowed students to "do" science, but made no direct connections to the NOS. Hence, upon checking for understanding of the NOS it was found the students had inadequate conceptions. Additionally, studies conducted by Haukos and Penrick (1985), Scharmann and Harris (1992), and Spears and Zollman (1997) with the intent of improving conceptions of the NOS using implicit measures showed no significant gains in student understanding of the NOS. However, studies that utilized explicit measures did indicate significant improvement in participant understanding of the NOS (Akindehin, 1988; Billeh & Hasan, 1975; Jones, 1969; Lavach, 1969). Students who were allowed to reflect and were given direct connections to the NOS showed growth in comprehension of the NOS. Conceptual change research also supports explicit approaches are necessary to address misconceptions students hold from both implicit and explicit instruction (Strike & Posner, 1992).

Many possibilities have been suggested as the reasons why teachers do not teach about the NOS within their classrooms. These explanations range from time constraints to lack of resources. Realizing that understanding the NOS is a goal of science education and is needed in order to achieve scientific literacy, what can be done to encourage teachers and students to develop adequate and sufficient conceptions of it?

Role of the Teacher

Teachers have to be responsible for disseminating knowledge about the NOS because they are the main intermediaries of science curriculum (Lederman, 1999). An initial step is for teachers to recognize the significance of the NOS and how it relates to science teaching. Teachers must learn about and understand the NOS because they cannot teach what they do not know. Educators need to understand the NOS so they can model appropriate behaviors and attitudes (Duschl, 1990) because students are not going to be able to attain a realistic view of the NOS if their teachers cannot model one.

Teachers' understandings, interests, and attitudes influence student learning to a great degree. Research by Palmquist and Finley (1997) and supported by Brickhouse (1990) indicates teachers' views significantly affect the teaching of the NOS. If teacher understanding increases, there is a greater probability with appropriate approaches, student understanding will follow. Nevertheless, understanding the NOS is not enough, as teachers need to apply their views in order to have effective NOS instruction (Abd-El-Khalick & Lederman, 2000).

What Can Teachers Do?

Many science educators have already been exposed to NOS practices and suggestions, but exposure is not enough. Teachers need to become involved with and engaged in activities which help them develop realistic conceptions of the NOS. A conscious effort needs to be made to utilize the NOS within all science classrooms and for all students to gain understandings of it.

Teachers can attain an understanding of the NOS through continuing education, research, experimentation, and reading of research. Teachers need to attend and participate in professional developmental activities, which focus on an understanding of the NOS. In addition, teachers should study history and philosophy of science to "enrich their understanding of the nature of science by contributing to a better understanding of the social and cultural influences affecting this discipline" (Murcia & Schibeci, 1999, p. 1139).

Once teachers understand and internalize the NOS, it is necessary for them to accept that the NOS is an important instructional objective (Lederman & Latz, 1995). Teachers must include the NOS in their objectives and assessments because instructional intentions significantly affect what occurs in the classroom. These objectives should be structured as cognitive instructional outcomes (Bell, Lederman, & Abd-El-Khalick, 2000). Teachers also need to acquire the ability to transform their beliefs into classroom practice. They need to have a wide variety of pedagogical routines and approaches concerning organization and management of instruction because that is a prerequisite for any efforts to promote student understanding of the NOS (Lederman, 1999). Teachers need to focus on specific approaches which they are comfortable with, as those approaches will help to transfer knowledge into classroom practice. Additionally, teachers need to address the NOS explicitly and intentionally within their teachings as direct connections of the NOS foster adequate conceptions about science.

SUMMARY

All citizens need to have scientific literacy if humankind expects to solve the critical issues of our time both locally and globally. Currently, students from the United

States are purported to be performing below students from foreign countries. We need to do better, and we can do better. A step in the right direction would be ensuring a balanced curriculum that involves science content, process skills, and the NOS. A great deal of emphasis has been placed on content and process skills, but attention to the nature of science has been inadequate. All three of these areas need to be addressed if students are to attain scientific literacy.

The NOS is a way of knowing, an epistemology, but not the only way. A specific definition of the NOS, or what it exactly entails, is not completely agreed upon. The need for more attention to the NOS and the prospect that many disagree on various aspects of it, lead to debate both privately and publicly. However, there are basic components of the NOS that are agreed upon. These basic tenets have been found to be significant for K-12 instruction.

An understanding of the NOS has many benefits. The greatest asset of a contemporary view of the NOS involves the ability to become scientifically literate. Additionally, an understanding has educational, cultural, and pedagogical benefits. Unfortunately, even with what is at stake, teachers and students are not attaining an adequate and complete understanding of the NOS.

A great deal of research has been conducted and published which has looked at factors which impede teacher and student understanding of the NOS. The research has shown the issue is extremely complex and it has been difficult to isolate specific factors that impede the acquisition of the NOS. However, the aspect that has shown to have the most relevance is how the NOS is actually taught.

Implicit teaching of the NOS has been unproductive whereas explicit teaching has shown to be a more effective teaching approach. Statistics, case studies, and reports all indicate that explicit teaching of the NOS is more effective because it directly makes connections to science and provides opportunities for reflection. Nevertheless, before too much emphasis is placed on how teachers should teach about the NOS, it must be assured that they realize and accept the significance of it. Teachers need to become educated or re-educated about the NOS. Once teachers acquire a contemporary view of the NOS, they need to develop the means to teach and assess it. When teachers effectively assimilate the NOS into their curriculum, student outcomes should become apparent.

The process of identifying, understanding, and effectively including NOS within K-12 curricula will not be easy. The problems are not simple and cannot be corrected overnight. Many steps will be taken forward and backward before solutions can be constructed. However, solutions must be made if we expect to evolve locally, nationally, and globally. Instead of asking if it is possible, we should be demonstrating the effective infusion of the NOS into K-12 curricula.

DISCUSSION

Educational Implications

The NOS continues to be an important educational outcome within science education, but research continues to show teachers and students are not attaining an adequate understanding of it. If students are not exhibiting adequate understandings of the NOS they cannot become scientifically literate because an understanding of the NOS is a significant requirement to becoming scientifically literate. If all citizens do not attain scientific literacy, humankind cannot reach its potential. Without scientific literacy people create boundaries and limitations for themselves and others, but if they achieve scientific literacy their potential is infinite.

Studies have been conducted which attempted to explain why teachers and students are not acquiring an accepted view of the NOS. Whether it is from lack of experience, institutional constraints, classroom management issues, etc., the NOS is being left out or taught inadequately in schools. However, that does not mean it cannot be addressed and taught appropriately in schools.

Educators need to continue and enhance their understanding of the NOS. Likewise, they need to make conscious and explicit efforts to include it within their curricula. If teachers do not take a stand the cycle of inadequate views concerning the NOS will continue. Although it is an individual effort, if teachers do not collectively teach about the NOS, the overall effect will be obsolete. The cycle must be broken if we are to become a scientifically literate society and enjoy the benefits of this literacy.

Recommendations

What Needs to be Done and Who is Involved?

The changes that need to occur will not be easy or completed quickly. Instead the process will be challenging and may take time. The more people and organizations involved the more productive the process will be. Teachers have many responsibilities within this change, but without the assistance and guidance from colleges, universities, scientists, philosophers, and historians, the process will be incomplete.

Responsibilities of Teachers

In order to be able to portray and model acceptable NOS beliefs there are various steps teachers can take. First and foremost, teachers need to understand the NOS. They can educate themselves by reading about and researching current perspectives on the

NOS and further involving themselves in scientific experimentation. Additionally, they can further their education through graduate work and professional development. This will help teachers stay current with the changes and modifications within science and education.

Once teachers have attained an adequate understanding, they need to specifically include the NOS within their instruction and assessment. Likewise, they must develop the strategies needed to incorporate the NOS within their classes. Science and the NOS should be addressed intentionally and explicitly, as it encourages teachers to "develop and validate strategies that facilitate the translation of contemporary views of the nature of science into explicit classroom instruction" (Bell, Lederman, & Abd-El-Khalick, 1998a, p. 1060). Only when explicit and continued efforts are made will the teaching and understanding of the NOS become successful.

Responsibilities of Universities/Colleges

The lack of understanding of the NOS could be improved if more attention was devoted to the NOS at all levels of education. Teachers are not the only ones who need to improve upon their understanding of the NOS and how to teach about it. Colleges and universities need to do a better job of preparing their graduates. They need to expose all of their science education teaching candidates to the NOS and provide them with a starting point. Undergraduate and graduate programs need to infuse the NOS within their curriculum and explicitly teach about it. This needs to be done within content *and* teacher education courses. It should not be the teachers' sole responsibility to completely educate themselves about the NOS. They do not have the means and resources which colleges and universities have at their disposal to successfully immerse themselves within the NOS. After being exposed and having the opportunity to develop an adequate understanding concerning the NOS, graduates would then be prepared for future changes. With time and experience teachers could build upon the solid foundation which their undergraduate and graduate programs provided them.

Areas in Need of Further Research

More research needs to be conducted to help educators assess the connection between teacher knowledge and classroom practice regarding the NOS. Other areas of research, which could further the inclusion of the NOS into K-12 educational settings, include additional work on why teachers do not attain adequate views, reasons which impede student understanding of NOS activities, and factors preventing teachers from including the NOS within their curriculum. This research could strengthen and broaden the existing knowledge in such a fashion that more effective solutions could be created which would help solve science and specifically NOS problems.

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