TÜRK FEN EĞİTİMİ DERGİSİ
Yıl 3, Sayı 2, Aralık 2006

Journal of
TURKISH SCIENCE EDUCATION
Volume 3, Issue 2, December 2006

http://www.tused.org

Critical Reflective Approach to Teach the Nature of Science: A Rationale and Review of Strategies

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Alındı: 01.04.2005 **Düzeltildi:** 25.09.2006 **Kabul Edildi:** 14.12.2006

ABSTRACT

Today, there is a strong agreement among science educators that science instruction should facilitate the development of an adequate understanding of the nature of science. Despite this agreement, research has showed that science teachers do not possess adequate conceptions about scientific enterprise. Evidence from this research points out that science teachers' views are generally compartmentalized and lacked consistency; features which are expected given that learners are often not provided with opportunities to reflect on and clarify their views about the nature of science (NOS). Towards this end, this paper aims to present and discuss a rationale for preparing reflection-oriented courses for NOS instruction in science teacher education programs. Further, it reviews various approaches and strategies used or offered by research in order to stimulate critical reflective thinking among prospective science teachers about their personal theories on the NOS. The approaches reviewed here include co-operative controversy strategy, action research and inquiry teaching, journal writing, the use of metaphors and proverbs, and critical incidents.

Keywords: *Nature of science, reflection, teacher education*

INTRODUCTION

The impact of science and technology on modern society has been so deep that the print and electronic media often announce the latest advancements in science and technology – human genome project, greenhouse effect, gene transplant, cloning, artificial intelligence, and space station. Our familiarity of these esoteric terms is evidence for power of science and technology in shaping our lives and society. Therefore, the need to promote a society of scientifically literate citizens is regarded as urgent in many countries and is accepted as one of the main goals of science education (Jenkins, 1997). Achieving functional scientific literacy involves providing people with an understanding of science that they can use as they make decisions and engage in debate about scientific and technological issues outside formal education settings (Ryder, 2001). In this sense, educating for scientific literacy entails not only teaching science concepts and theories but also learning about the nature of these concepts and how they function with regard to other beliefs about the physical world (Eichinger, Abell, & Dagher, 1997). In relation to the social dimension, the chief purpose of science teaching is to produce informed citizens – citizens who can take on the responsibility of the social problems related to science.

Questions about the role of science in decision-making and the students' ability to participate in the act of taking decisions are central to an education aiming at democratization. Therefore, the nature of science (NOS) has been the focus of attention in science education circles as a primary component of scientific literacy (Bell & Lederman, 2003; Meichtry, 1999; Tairab, 2001).

Clearly, this objective can only be accomplished by well-educated, informed and knowledgeable science teachers. However, results of intensive research on both pre-service and practising teachers' views of the NOS in the last two decades revealed that science teachers, generally, do not possess adequate conceptions of the NOS (e.g. Abd-El-Khalick & BouJaude 1997; Abell & Smith 1994).

A common conclusion has been that teachers cannot possibly teach what they do not understand (Abd-El-Khalick & Lederman, 1999; Lederman & Zeidler, 1987). Therefore, researchers directed their attentions to science teacher education and various strategies have then been adopted to help science teachers improve their own understanding of the NOS (Monk & Dillon, 2000). However, despite these attempts, the questions concerning the specific content or method of instruction to be included in a science methods course for NOS instruction are still to be solved (Lederman, 1992; Cakir, 2004; Yalvac, 2005).

THE PURPOSE OF THE STUDY

The notion of reflection is one of the most pervasive concepts to influence teacher education, especially in the last two decades. While reflection is not a particularly new idea among educators, its applications in teacher education have brought new dimensions and opportunities for effective teacher learning. To this end, this paper aims to present and discuss a rationale for preparing reflection-oriented courses for NOS instruction in science teacher education programs. Further, it reviews various approaches and strategies used or offered by research in order to stimulate critical reflective thinking among prospective science teachers about their personal theories on the NOS.

METHODOLOGY

Many studies in recent years have focused on developing teachers' and learners' conceptions of science and scientific enterprise. Some of these studies defended and used reflection oriented strategies in their designs. This paper aims to give the reader the rationale behind these studies and presents the most striking approaches and strategies which have been developed in the field. Towards this end, the issues discussed and presented in this paper are drawn from a literature search that examined major international sources of information on teacher education and science education. The review strategy was based on the "best evidence (or practice)" principle of Slavin (1986), which dictates that only the best designed studies be included whenever there are several studies in a particular approach (or strategy).

1- Critical Reflection and the Nature of Science

a- The Notion of Reflection

Especially in the last two decades, the concept of "reflection" has become quite popular among researchers in the field of education. However, the starting point of this journey goes back to the first part of the twentieth century and finds its spirit in the work of Dewey (1933). Having characterized reflection as a specialized form of 'thinking', Dewey describes the reflective thought as "*active, persistent, and careful consideration of any belief or supposed form of knowledge in light of the grounds that support it and the further conclusions to which it tend*" (Dewey, 1933, p.9).

It was Schon's writings (1983; 1987) which have aroused a great deal of interest towards reflection and reflective practice in teacher education (Grimmet, 1988). Schon (1983; 1987), proposed the ideas of reflection *in* and *on* action to extend our thinking about reflective practice. Accordingly, reflection *on-action* involves deliberate inquiry undertaken to resolve problems in teaching; by extension, reflection *in-action* centers on unanticipated moments of insight which lead to re-framing how circumstances are viewed. It has become clear that the quality and content of reflection is significant if meaningful development and learning to occur (Nichols, Tippins, & Wieseman, 1997). The need for reflection "*to be accompanied by confrontation*" (Day, 1993) which will open the doors for critical thinking and conceptual change has become desirable for learning and development. In order to emphasize the importance of revealing ideological aspects of teacher thinking and action "critical reflection" (Bullough & Gitlin, 1991; Carr & Kemmis, 1986) has become the term in use amongst the researchers.

In this orientation, reflection undertaken without a critical perspective is unlikely to address social, historical, or political problems of any educational setting. In the form of an uncritical reflective process, "*… reflection may become nothing more than therapy, a form of disconnected but interesting indwelling*" (Bullough & Gitlin, 1991, p.39). Critical reflection, however, requires reflective thinking which involves a critical examination of one's beliefs and actions in the world understood as historical and social assumptions and choices (Johnston, 1994). In short, *it is essentially concerned with the deconstruction and reconstruction of meaning* (Day, 1993, p.85).

Students are likely to have series of theories, which will probably be incoherent and contradictory (Zeichner, 1986). They are often not aware of their own theories, nor that there are alternatives, until such time as they are overtly challenged (Tann, 1993). The reflection orientation in science teacher education is grounded in the belief that learning to teach science, like learning science itself, is a process of re-evaluating and reforming one's existing theories in the light of perturbing evidence (Abell & Bryan, 1997). It is well-documented that pre-service teachers enter teacher education courses holding ideas, beliefs, and values (Abell & Bryan, 1997; Lainer & Little, 1986) that form their personal theories about science teaching and learning. These pre-existing views are so pervasive that unless directly challenged any attempt to alter is ineffectual (Tann, 1993).

The reflective practice requires the practitioner to "*elicit and identify their personal theories, to explore these by examining their rationale, by problematizing and looking for alternative analyses, then to compare these with peers and with public theories before attempting to re-formulate the theory and test it against further practice*" (Tann, 1993, p.57). Therefore, in becoming reflective science teaching practitioners, it is essential for prospective teachers to develop resources which help them critically examine their views of science teaching and learning and their own educational experiences (Nichols *et al.*, 1997).

To this end, the reflection orientation in science teacher education is characterized by asking students to describe their ideas, beliefs, and values about science teaching and learning and by offering experiences that help them clarify, confront, and possible change in their personal theories.

b-The Nature of Science

Research has demonstrated that teachers' personal understanding of the subject matter they teach exerts a powerful influence on their instructional practice (Brickhouse, 1990; Shulman, 1986). Amongst the fundamental principles shaping teachers' understandings of science are the conceptions they hold about the NOS or their understanding of science as a way of knowing (Hammrich, 1997). The NOS has been defined in many ways throughout the decades dating back to its earliest inception in the

1907 report of the Central Association of Science and Mathematics Teachers which emphasized the scientific method and the processes of science (Hammrich, 1997; Lederman, 1992). The most cited definition of the NOS is that by Lederman and Zeidler (1987) in which they refer to the values and beliefs inherent in scientific knowledge and its development.

Although science does include facts, laws and theories, as a human activity, it is also composed of scientists doing investigations, the attitudes and beliefs these scientists hold, the processes they use, the community within science and so on. Today, few now argue against the proposition that school science experiences should include significant attention to how science works, including how knowledge is created and established (Abd-El-Khalick & Lederman, 2000; Lederman, 1992, McComas *et al.*, 1998; Munby, 1984).

In spite of the significant progress toward characterizing science, large disagreement remains amongst the philosophers of science concerning the nature and structure of science (Alters, 1997; Driver, Leach, Millar, & Scott, 1996; Matthews, 1994; McComas *et al.*, 1998). A consideration of the works and approaches of some philosophers and historians of science such as Popper (1979), Kuhn (1970) and Feyerabend (1975) is enough to understand that there is no singularly preferred or informed NOS (Lederman, 1992) and, that there is always likely to be an active debate at the philosophical level (McComas *et al.*, 1998). Having recognized this fact, Lederman (1992) acknowledges that the NOS is as tentative as scientific knowledge itself and, notes that the NOS is neither universal nor stable.

Science education is interested in helping out individuals understand the basics of science in order to promote an effective literacy in science. At this level, there is a significant consensus amongst the philosophers, historians, and sociologists of science regarding certain aspects of the NOS (Abd-El-Khalick, Lederman, Bell, & Schwartz, 2001; McComas *et al.*, 1998; Smith, Lederman, Bell, McComas, & Clough, 1997). For example, there is a consensus on the tentative and revisionary nature of scientific knowledge or the theory-laden nature of scientific observations. Consensus on certain aspects of the NOS has been crucial for science education. Many researchers have seen these aspects as accessible to primary and secondary students and used them in their studies to assess and improve students' understandings of the NOS (Abd-El-Khalick *et al.*, 2001; Good, Cummins, & Lyon, 1999; Moss, Abrams, & Robb, 2001). Furthermore, these NOS aspects have been emphasized in recent science education standards and reform documents such as National Science Education Standards, (NRC, 1996) and, Science in the National Curriculum (England and Wales, 1995).

Teachers' conceptions of the NOS has also been a concern for science educators and researchers over the last thirty years and a wide range of probes and instruments have been developed and used in different studies (See Lederman, Wade & Bell (1998) for a comprehensive assessment of the instruments used in the history of the NOS studies). The results of this intensive research on teachers' understandings have pointed out that science teachers do not possess adequate conceptions of the NOS and similar discouraging findings have been echoed by many researchers in all over the world (Abd-El-Khalick & BouJaude, 1997; Abd-El-Khalick & Lederman, 2000; Abd-El-Khalick *et al.*, 1998; Abell & Smith, 1994; Billeh & Hasan, 1975; Carey & Stauss, 1970; Lederman 1995; Lederman & Zeidler, 1987; Mellado, 1997; Nott & Wellington, 1998; Tsai, 2002).

It is clear that teachers cannot possibly teach what they do not understand. If teachers are to learn how to engage children in conceptual change instruction related to the NOS, they need to further develop their own understanding of the NOS in such a way as to enable them to plan the curriculum and choose appropriate teaching strategies in their classrooms (Bentley & Fleury, 1998). They need to learn ways of guiding and supporting children in considering alternative views and constructing meanings of science. However, it has been well documented that (with few exceptions) undergraduate science courses do not give precedence to the teaching of history and philosophy of science (Abd-El-Khalick & Lederman, 1999; Gallagher, 1991). Science teachers ought to provide students with opportunities to develop their own understanding of nature of science in order to enable them to critically analyze the intertwined relationship between science, technology and society, which is the basic requirement for scientific literacy. Creating such context is a complicated task that requires teachers to revisit their teaching strategies.

2-Linking the "Critical Reflection" Orientation to Nature of Science Instruction

Attempts to enhance science teachers' conceptions of the scientific enterprise started in the early 1960s (Abd-El-Khalick & Lederman, 2000) and intervention studies aimed at improving science teachers' conceptions of the NOS included those by Carey and Stauss (1970), Billeh and Hasan (1975), Ogunniyi (1983), Akindehin (1988), Shapiro (1996) and Akerson *et al*. (2000), amongst many others.

Science educators have proposed different strategies for teaching and learning the NOS. Some advocate the essence of teaching the NOS through scientific content and process skill instruction, labeled as implicit approach. Some of them (e.g., Matthews, 1996) advocate teaching the NOS through historical cases of scientific knowledge. Some others (e.g., Abd-El-Khalick & Lederman 1998; Akerson et al., 2000) believe teaching the NOS can only be achieved with explicit NOS instruction. Generally speaking, these attempts employed one of two general approaches. The first approach was implicit and suggested that "*an understanding of the NOS is a learning outcome that can be facilitated through process skill instruction, science content coursework, and 'doing science'*" (Abd-El-Khalick & Lederman, 1999). Such an approach was employed by researchers such as Scharmann and Harris (1992) and Palmquist and Finley (1997). Abd-El-Khalick and Lederman (1998) and Akerson *et al.* (2000) pointed out that two interrelated assumptions seemed to underlie the implicit approach and compromise its effectiveness. The first assumption depicted attaining an understanding of the NOS to be an affective as compared to a cognitive learning outcome. They reported that this first assumption entailed a second one that learning about the NOS would result as a by-product of engagement in science process-skills instruction or science-based activities that lacked any explicit references or reflective components related to the NOS. However, they argued;

> *… the NOS as an "enterprise", if you will, is a reflective endeavour. The varying images of science that have been constructed throughout the history of the scientific enterprise are, by and large, the result of collective endeavours of historians of science, philosophers of science, sociologists of science, scientists turned historians and philosophers, and reflective scientists. Within a certain time frame, various aspects that are taken to be representative of the scientific enterprise reflect the collective attempts of those individuals to reconstruct the history and activities of science in an attempt to understand its workings. The endeavour to delineate various aspects of the NOS is not a matter of merely reading the "book of science" or going through it motions, but rather a matter of putting questions to that book and reflecting on that practice.*
>
> (Abd-El-Khalick & Lederman, 2000; p.691)

Their argument was not against the use of scientific activities to enhance science teachers' understandings of the NOS. They claimed that even though any attempt to foster better understandings of the NOS amongst science teachers should be framed within the context of the content and activities of science, these attempts, nevertheless, should be explicit and reflective. Since it has been reflective efforts lying at the heart of our efforts to accumulate knowledge in science, any attempt to assess and learn about this knowledge has to be reflective as well.

Despite various attempts to improve science teachers' understandings of the NOS, both explicit and implicit, results have showed that much is still desired and alternative ways have to be considered. However, as emerging literature points out (Abd-El-Khalick & Lederman, 1999, 2000; Akerson *et al.*, 2000; Dickinson, 1999), inclusion of reflective components to the explicit approaches will bring a certain degree of success to the attempts to enhance science teachers' understandings of the NOS. It is essential that teachers be provided with conceptual frameworks that would help them to construct better understandings of certain aspects of the NOS (Abd-El-Khalick & Lederman, 2000).

Rather than being static the NOS is dynamic and evolving (Suchting, 1995). Instead of teaching history of science or making the tenets static and compartmentalized by simplifying the NOS; teaching for understanding in NOS should incorporate a variety of contexts and reflective practices. What needed is to invent and improve strategies which stimulate science teachers to elicit and identify their personal theories about scientific enterprise, to explore these by examining their rationale, by problematizing and looking for alternative ideas. At the foundations of this approach lies the critical examination and confrontation of personal theories and beliefs.

In the following section, some significant strategies and activities used and or offered by the literature which can stimulate critical reflective thinking in learning about the NOS will be reviewed.

3. Strategies to Stimulate Critical Reflective Thinking

There are various strategies in the literature, which have come to be identified as contributing to reflection such as the use of action research, critical incidents, and writing for journals. While each of these strategies and approaches has a particular focus and orientation, they all encourage teachers to return to their own personal theories and focus on what these mean to them.

Study of personal epistemology focuses on how the individual develops conceptions of knowledge and knowing. King and Kitchener (1994) suggested that a three level of cognitive processing was necessary to account for the behavior of adults who are engaged in ill-structured problems. First level is labeled as "cognition", second level is about "monitoring" progress when one is dealing with task in level one, and at the third level, labeled "epistemic cognition", individuals consider "the limits of knowledge, the certainty of knowing, and the criteria for knowing". Epistemic cognition allows the monitoring of problem types and the evaluation of proposed solutions. King and Kitchener (1994) argue that epistemic cognition is the foundation of critical thinking when individuals are faced with ill-structured problems. These problems require making judgments based on the strength of available evidence and adequacy of argument. They articulated a model of the development of epistemic cognition, which they called "Reflective Judgment Model". They identified seven distinct but developmentally related set of stages in development of reflective thinking. These seven stages can be summarized into three major periods: the pre-reflective (stages 1 to 3), the quasi-reflective (stages 4 and 5), and the reflective (stages 6 and 7). People in pre-reflective period believe that knowledge is gained through authority figure and first hand observation, rather than, through the evaluation of evidence. They believe their knowledge is absolutely correct with complete certainty. People in quasi-reflective period recognize that knowledge claims contain element of uncertainty, citing missing information or method of acquiring the evidence. Although they use the evidence, they do not understand how evidence demands a conclusion and therefore tend to view judgments as highly personal. People who reason with reflective thinking accept that knowledge claims cannot be made with certainty; they make judgments that are most reasonable after evaluating available data. They actively construct their decisions and evaluate knowledge claims in relation to the context in which they were generated to determine their validity. They are also ready to reevaluate the adequacy of their decisions as new data or methodology is available (King & Kitchener, 1994).

The following are some examples of strategies to induce critical reflective thinking in order to foster NOS instruction used in the literature. While some of them are offered for teachers in certain development levels (pre-service or in-service), most of them can be used in any educational level by slight modifications.

a-Critical Incidents as Stimulators of Critical Reflective Thinking

In their study, Nott and Wellington (1998) argued the use of critical incidents as a means of probing and developing teachers' views of science in in-service teacher education. They define a critical incident as *"an event which makes a teacher decide on a course of action which involves some kind of explanation of the scientific enterprise"* (p.581) and believe that part of the incidents' criticality is that they evoke responses from the teacher which provide an insight into the teacher's view of science.

These events are often stimulated by pupils saying and doing things regarding the nature of scientific enterprise but they may also arise through the action of the teacher, particularly when a demonstration goes wrong (for the list and description of the critical incidents they have used, see Nott & Wellington, 1998). Therefore, by using critical incidents which are rooted in classroom experience, an environment which stimulates and encourage discussion and reflection can be created, and through this reflection, learning and learning how to teach about the NOS can be facilitated.

Although they have used this approach in in-service teacher education, a similar approach could be used in pre-service teacher education. One way to that could be the use of student teachers' school experiences in their student teaching phase. These experiences and critical incidents could be stimulators of discussions and reflections and then they can be translated into more academic discourse.

Another way could be the use of classroom cases as a reflective tool for helping prospective teachers construct and re-construct their knowledge about science. As new images of the complexity of teaching emerge, educational cases *"provide a tool through which instructional practices can be viewed as inextricably connected with meaning and context"* (Nichols *et al*. 1997, p.85). As a reflective tool, classroom cases can be used to detect and examine problematic areas about the learning and learning how to teach about the NOS. Prospective teachers can be encouraged to think of solutions from multiple perspectives, and by doing that they can be aware of their personal theories about scientific endeavour. These cases also provide a useful environment for exchanging ideas which promote learning.

b-Action Research And Inquiry Teaching

The teachers' understandings of what science is and how students learn science in schools have formed a consistent system of beliefs for guiding classroom activities (Brickhouse, 1990, p.60). Therefore, teachers' understandings of scientific inquiry are of particular importance because it can influence decisions about what is taught and how it is taught.

Meichtry (1999) offers an action research strategy to enhance prospective science teachers' understandings of scientific enterprise. Meichtry used this strategy with a mixed group of college and graduate students seeking teacher certification in elementary science teaching. Accordingly, *"real"* science experiences aiming to enhance pre-service elementary science teachers' conceptions of science are used by engaging them with scientific experiments where students are in complete control. Students, working alone or in groups of 2-4, conduct a scientific investigation in which they are responsible from the development of a research question which interests them to the formulation of a hypothesis, the design of an experiment, the collection and recording of data, the interpretation of results, and the drawing of conclusions based on their results.

According to Meichtry, there are two reasons to engage student teachers with such research experiments. First, these experiments help student teachers to experience and understand the actual processes of scientific investigation. Second, and more importantly, these experiments give opportunity to students discuss and reflect on the various aspects of science and scientific enquiry. Meichtry, reporting on the results of such an action research approach, stated that the experience of actually using the processes of science to research a question had developed a greater understanding of the NOS of virtually every student.

Cakir (2004) designed an exemplary inquiry based module to engage prospective science teachers as learners for developing knowledge and skills addressed in teaching standards such as: (a) teachers of science plan, guide and facilitate learning in an inquiry-based science program; (b) teachers of science develop communities of science learners that reflect the intellectual rigor of scientific inquiry and the attitudes and social values conducive to science learning (NRC, 1996). He reported that prospective teachers' understandings of scientific inquiry and their abilities to do inquiry were enhanced. Initially, they viewed scientific inquiry as the posing of questions and investigation of them in order to learn the truths of science. They viewed science as a way of understanding nature and the world around them through use of the scientific method. They also viewed observation, exploration, and experimentation as a crucial part of this process. Science was also seen as a tool to solve problems in our world and help us in our everyday lives. Prospective teachers began to recognize the elements of scientific inquiry and importance of data-driven evidence and use of models in science. Prospective science teachers demonstrated more informed understandings of several aspects of scientific inquiry and the nature of science after the module.

From a similar action research perspective, Trumbull and Slack (1991) reported on the use of structured interviewing assignments in a pre-service secondary science teacher education program in order to increase students' abilities for reflection. These interviews were intended to elicit the interviewee's ways of thinking about and making sense of a particular phenomenon, which, in their case, was student teachers' pedagogical understanding. In this strategy, students developed the interview protocol and conducted interviews with individuals from different ages (with their fellows, and students older and younger than a collage student). Then students presented their findings as reports and in their journals and discussed them with their peers. This was an on-going learning process and Trumbull and Slack reported that pre-service teachers began to reflect on some aspects of their work in this process.

Hewson and Hewson's (1989) work was similar to that of Trumbull and Slack, and they too reported a success in identifying different conceptions of prospective science teachers about science teaching (including different components of the conception, such as the NOS).

It is possible to use a similar structured interviewing strategy in learning and learning how to teach about the NOS by assigning student teachers to develop, conduct and analyze interviews with different individuals about the NOS. It is very likely that this process will help prospective science teachers reflect upon their own conceptions about the NOS.

The current practice of science teaching indicates that research on the essentials of implementing inquiry into science classrooms is still needed (Songer, Lee, & Mcdonald, 2003). Limited numbers of studies report attempts to assist prospective elementary teachers in developing an understanding of scientific inquiry. For example, after implementing inquiry-based science teaching in their program Zembal-Saul, Starr, & Krajcik (2002) suggested that students developed a better understanding of the importance of cognitive engagement through the use of prediction, discussion, inquiry activities, and questioning. Mulnix & Penhale (1997) successfully used the collaborative model to simulate the activities of scientists when conducting research projects and communicating findings with peers.

c-Co-operative Controversy Strategy

One of the strategies to facilitate teacher candidates' understanding of the NOS is co-operative controversy strategy. This strategy sees conceptual understanding as an interactive process involving person-in-conservation, and learning as the process by which individuals are introduced to an alternative perspective (Hammrich, 1997). Accordingly, learning science involves being "*confronted with the ideas and practices of the science community*" (p.145) and "*making these ideas and practices meaningful on an individual level"* (p.146).

Co-operative controversy is an instructional strategy designed to actively engage a person in a debate of two opposing sides of a controversial issue. Conflicts over conceptions within the NOS are inevitable but these conflicts can provide a positive experience and increase learning (Hammrich, 1997).

When any controversial issue, such as the NOS, is approached, there is a choosing-of-sides behavior, where the learner takes a position on the issue. In the co-operative controversy strategy, individual conceptions are challenged by other conceptions. This creates a conflict and this conflict causes uncertainty and a desire for more information. The uncertainty resulting from conflict leads to a search for more information and a desire to find out where individual conceptions come from. This is referred as *active reflection* in which "*individuals may change their conceptions based on the conceptions of others several times while always reflecting back on their own conception*" (Hammrich, 1997, p.144).

In Hammrich's study, each pair of teacher candidates was given the written description that describes one of the two opposing sides. Teacher candidates were asked to read, discuss, and write a persuasive document defending the position given. Then, two pairs, with opposing sides, engaged in the co-operative controversy strategy by presenting their side to the other pair and defending their position. Teacher candidates were encouraged to ask questions for clarification of any point that they did not understand. After the discussion, two pairs were asked to reverse roles by taking the opposite side to read and defend. The goal of the role reversal was for each pair to elaborate on what members of the other pair had said previously.

By using this strategy, Hammrich reported a significant success in improving the conceptions of prospective teachers. She claimed that the best indicator of the value of the co-operative controversy strategy is student reflections of the strategy culled from reflections in their journals.

> *Before we began the co-operative controversy activity, I was not real sure what my conception was of science… By debating two views of the nature of science, I was better able to reflect upon my own conception* (Student reflection)

> *The activity forced me to critically think and reflect upon what I actually considered to be the nature of science.*(Student reflection)
>
> (cited from Hammrich, 1997, p.148)

Above all, what the co-operative controversy strategy does show is that prospective science teachers "*must be provided with opportunities to explore, examine, reflect, and be challenged about their conceptions of science and other controversial issues*" (Hammrich, 1997, p.149).

Emphasizing sociological perspective Yalvac (2005) studied college students' understanding of the NOS in a project called College Peer Review. The project was designed to engage college students in an authentic scientific investigation through original research, on-line collaboration, and peer review. He reported that an instructional strategy that draws upon the sociological NOS and peer review can provide meaningful insights in teaching and learning about NOS.

Bell & Lederman (2000) reported the results of a study designed to look into the relationship between understanding of nature of science (NOS) and decision-making on science and technology based issues. The purpose of the study was to explore differences in decision-making made by individuals with disparate understandings of the nature of science and to delineate the factors and reasoning people use when making these types of decisions.

d-Personal Journals

Looking for effective methods and approaches to enhance reflective practice, the science education literature, has focused on the medium of writing. In order to elicit or to make explicit what is implicit or tacit researchers has used writings for journals, diaries, and portfolios.

Journal writing has become a tool so foundational to learning in teacher education courses that it has been regarded as the primary text utilized for teacher learning (Holly, 1989; Nichols *et al*. 1997). It has been discussed that experiences entered into journals narrate the author's reality and allows both the construction and reconstruction of the author's personal theories (Cortazzi, 1993; Holly, 1989). The aim here is to "*force*" the writers to learn about what they know, what they feel, what they do, how they do it and why they do it (Cortazzi, 1993). In this respect, journal writing can be a useful tool in teaching and learning about the NOS since it allows individuals explore and elicit their beliefs and ideas about the scientific endeavour. In this frame, journals are a "*dynamic text recording the evolution of how science teachers are seeing themselves in their own practices of science education*" (Nichols *et al.* 1997, p.84).

There are some examples in the literature in which journals were used as a tool in order to enhance learners' conceptions about certain aspects of scientific endeavour. As an example, Nichols *et al*. (1997) quote Duckworth's study in which personal journals were used to engage teachers in making regular observations of the moon, sharing their preconceptions about the moon, and reflecting on how their thoughts about the moon (and indirectly about the NOS) evolved over time. However, Nichols *et al*. warn that unless these personal journals are used as an interactive tool providing opportunity for dialogue with others, their effect will be limited. As mentioned before, critical reflection and confrontation are necessary in order achieve a meaningful conceptual change, and this is a collaborative effort where conversation and discussion are required among two or more persons.

e-Reflecting On The Nature Of Science Through Metaphors

When teachers talk about education and the NOS learning in their classrooms, the language used to describe this teaching and learning is laden with metaphor (Nichols *et al.*

1997). Metaphor, in one form or another is "*absolutely fundamental to the way language systems develop over time and are structured, as well as to the way human beings consolidate and extend their ideas about themselves, their relationships and their knowledge of the world*" (Cameron & Low, 1999, p.xii). Language is metaphorical and enables us to re-present the way in which we see the world (Lakoff & Johnson, 1980) and most of the time we use metaphors to present ourselves. Indeed, in a study on science teacher educators' conceptions of the NOS, Irez (2001) reported many metaphorical expressions that people used in their explanations about the aspects of science, such as;

> *… theory is something like a source of light at a distance. You continuously make observations and experiments to reach that source.*

As can be seen from this example metaphors have a function of organising systematic concepts (Lakoff & Johnson, 1980) and some metaphors may be core clichés through which tellers transform images into models (Cortazzi & Jin, 1999). These aspects of metaphors make them useful tools in assisting prospective teachers in thinking about the NOS. Expressing their ideas in the form of metaphors can help science teachers clarify and reflect upon their conceptions about the scientific endeavour. Nichols *et al*. (1997) provide a short but useful list in their study:

> *If science were a song, it would be…*
> *If science were a book … a smell … a sport … a noise … a place … it would be…*
> (p.92)

They reported that this strategy worked very well in assisting science teachers to be aware of their personal theories about the NOS. As this example from their study illustrate;

> *Science is like spelunking -- caving -- because when you explore a cave, you are investigating the unknown. Science involves exploring the mysterious and bringing to light those things that are not necessarily obvious or above ground.* (Student description, p.92)

As teachers interpret and make sense of their personal theories, metaphors can provide a conceptual link between more clearly formulated types of concepts and loosely structured ones (Nichols *et al*. 1997).

f-The Use of Proverbs

Proverbs are "*compact expressions of cultural knowledge which carry with them a point of view or a particular way of looking at events or actions and presumably can present the commonsensical in everyday life*" (White, 1987, cited from Nichols *et al*. 1997, p. 93). Proverbs, like metaphors, are socially mediated personal constructions which can serve as a holistic way of representing knowledge. They often reflect a point of view or certain way of looking at problems, thereby implicitly or explicitly providing recommendations for a desired course of action. By this description, use and interpretation of proverbs offers yet another tool by which to infer and reflect upon teacher beliefs.

Proverbs can be used in order to assist science teachers to elicit and clarify their conceptions about the NOS. Since most of them are culture specific, they also useful to detect cultural influences on people's understandings and beliefs about scientific endeavor.

To illustrate the potential richness of this tool, Tippins *et al*. (1994) presented two proverbs about teaching and learning (*Teachers are born, not made*, and *Teaching and learning are two sides of the same coin*) to a practicing science teacher, and wanted her to paraphrase and interpret them (cited from Nichols *et al*. 1997). They reported that her paraphrasing and interpretation gave some insights about her beliefs regarding teaching and learning. A similar approach can be used to assess science teachers' understandings about the NOS by choosing and presenting a set of proverbs which have implications about science and scientific enterprise. Another potential benefit of using a set of proverbs could be that teachers' potential selections of proverbs might more deeply illuminate reflections about the NOS because the chosen proverb has potential significance (Nichols *et al*., 1997).

DISCUSSION AND CONCLUSION

As the new complexities of teaching and learning emerge so do the complexities of preparing adequate and effective courses for the future teachers. Science education and science teacher education are no exceptions in this case. There is a lack of consensus amongst science educators concerning the specific content or method of instruction to be included in science teacher education programs (Lederman, 1992); however, there is an strong agreement that science instruction should facilitate the development of an adequate understanding of the NOS or an understanding of science as a way of knowing (Hammrich, 1997). Despite this agreement, research has showed that science teachers do not possess adequate conceptions of the NOS. Evidence from this line of research points out that science teachers' views are generally compartmentalised and lacked consistency; features which are expected given that learners are often not provided with opportunities to reflect on and clarify their views of NOS (Akerson *et al.*, 2000).

Reviewing relevant literature and all proposed approaches to teach NOS effectively, we have argued throughout this paper that a critical reflective approach to the NOS instruction could be the most effective way in enhancing pre-service science teachers' views. Furthermore, some examples of strategies and approaches used in the literature in order to stimulate critical reflective thinking about the NOS among prospective science teachers have been presented. Underlying assumption for the presentation of and discussion about these strategies and approaches was that prospective teachers should be given opportunities to experience, discuss, and reflect on the various aspects of the NOS within the various contexts of teacher education in order to achieve desired conceptual change towards more informed understanding of nature of science.

Although most of the studies reviewed here reported improvement in participants' views of certain aspects of the NOS, there is still much to be desired. The realities of teacher preparation programs and courses impose limits on what can be done within the context of those programs and/or courses to enhance science teachers' views of the NOS (Abd-El-Khalick & Lederman, 2000). Any failure in the attempts to enhance teachers' conceptions of the NOS should not be surprising given that the duration of the treatments was very short. After all, individuals' personal theories about the NOS have developed over years. It is highly unlikely that prospective and practising teachers' NOS views, views that have developed over the course of at least 14 years of high school and college science, could be effectively changed, updated, or elaborated during few hours, days or weeks for that matter.

This statement, however, justifies the appropriateness of a critical reflective orientation to pre-service teacher education courses. It is underpinned in the rationale of critical reflection that learning is not an instant or isolated event; it is rather a lifelong and interactive process and a habit of mind. Teacher education should be viewed as a time of introducing future teachers to ways they can continue to learn from and enhance their own teaching practices. As teacher educators, we have a facilitative role that involves introducing prospective teachers to various resources through which they can extend their professional learning (Nichols *et al*. 1997).

The quality of reflection is inherent in the process of collaborative experiences and communal construction of meaning. Prospective teachers' collaboration and critical reflective thinking about their learning experiences could help to improve their NOS understandings more than any of a particular intervention.

What has not been studied in the reviewed literature, however, is whether and to what extend the participants of these studies have continued their learning and development by using critical reflection effectively as a learning habit. Nonetheless, the results of the research reviewed in this paper indicate that a reflective orientation and employing strategies which stimulate critical reflective thinking in NOS instruction resulted in more students adopting adequate views of the NOS.

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