The nature of science conception: A review of literature

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Abstract
The most important goal of all reform efforts in science education is to achieve a scientific literate citizenry. At the core of that goal, is the strive to enhance students' understanding of the nature of science. The aim of this paper is to present a review of studies on students' and science teachers' conception of the nature of science. The analysis of such studies revealed that both students and science teachers do not possess appropriate understanding of the nature of science that is in line with contemporary science education standards. An accurate understanding of the nature of science is believed to help students identify the strengths and limitations of the scientific knowledge, develop accurate views of how science can and cannot answer some questions. Research suggests that teaching students about the nature of science can facilitate the learning of science subject content and increase student achievement. Studies related to students and science teachers' conceptions of nature of science are hardly found to have been done in Namibia. This paper is part of a study that is currently being undertaken to assess students' and science teachers' conception of the nature of science in Namibia.

Keywords: *scientific literacy, nature of science (NOS), nature of science conception*

Introduction

The most important goal of all reform efforts in science education around the world is to achieve a scientific literate citizenry (Khishfe & Lederman, 2007). At the core of that goal is the strive to enhance students' understanding of the nature of science. Reform efforts have given more attention to the nature of science, particularly in developed countries (Quigley, Pongsanon, & Akerson, 2011; Smith & Scharmann, 1999; Abd-El-Khalick et al., 2017). An appropriate understanding of the nature of science is attributed to developing scientific literacy (Peters-Burton, 2016; Allchin, Andersen, & Nielsen, 2014; Akerson, Hanson, & Cullen, 2007). Several reforms have taken place in the Namibian education system since independence in 1990, particularly in curriculum and assessment areas (Iipinge & Likando, 2012). However, none of the reforms provided explicit guidelines on how to teach the nature of science, particularly in science subjects' specific curricula.

The nature of science is viewed by some science educators as an affective learning outcome and not as a cognitive or instructional outcome of equal status with traditional subject matter outcomes (Schwartz, Lederman, & Crawford, 2004; Lederman, 2006). Subsequently, it is not taught explicitly and reflectively in basic education science curricula, despite such curricula advocating that understanding of the nature of science is a prerequisite for scientific literacy development. It is assumed that students would acquire the understanding of the nature of science just by doing science and inquiry activities (Khishfe, 2008). This approach was found to be ineffective (Abd-El-Khalick & Lederman, 2000a; Khishfe & Abd-El-Khalick, 2002). For this reason, Khishfe and Abd-El-Khalick (2002) suggested that understanding of NOS should be considered as a cognitive learning outcome and should be taught explicitly rather than expected to being acquired through some kind of "osmotic process" while engaging in regular science activities (p. 554).

Research in many parts of the world reveals that students and teachers do not possess appropriate conception of the nature of science (Lederman, 1992; Meichtry, 1992; Moss, Brams, & Robb, 2001; Khishfe & Abd-El-Khalick, 2002; Bell, Blair, Crawford, & Lederman, 2003). There is no shortage of instruments for assessing students' views of the nature of science (Lederman, Wade, & Bell, 1998). However, no such instruments appear to exist in Namibia. Similarly, research on the nature of science is hardly done in Namibia. The development of a valid instrument for assessing students' view of nature of science in Namibia is one of the goals of the present study. This paper presents a review of literature on nature of science in science education coupled with a critical appraisal of the nature of science representation in the Namibian basic education science curriculum.

The Nature of science (NOS)

One of the important goals of science education is to foster students' scientific literacy (Nowak, Tiemann, & Upmeier zu Belzen, 2013; Peters-Burton, 2016). Scientific literacy consists of different components, namely, content knowledge, scientific inquiry and nature of science (NOS). The concept NOS has been commonly used to refer to "the epistemology of science, science as a way of knowing or the values and beliefs inherent to the development of scientific knowledge" (Lederman, 1992, p. 331; 2007). This definition of the nature of science is rather general as to date there is still disagreement among philosophers of science, historians of science, scientists and science educators on the specific definition of the concept (Abd-El-Khalick, 1998). The lack of consensus on the specific definition of NOS is attributed to the complex, multifaceted and tentative nature of the scientific enterprise (Wenning, 2006; Abd-El-Khalick, Waters, & Le, 2008). Similarly, NOS is said to be tentative and dynamic as the conceptions of NOS have changed throughout decades of scientific development (Abd-El-Khalick, 1998; Deng, Chen, Tsai, & Chai, 2011).

However, the various disagreements about NOS are not important to science students in the basic education phase (Grades 1-12) due to the abstract nature of the NOS debates (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002). However, a general and simplistic view of some important aspects of NOS can be taken to be accessible and appropriate to basic education science students and it is at this level of simplification that little disagreement exists among historians, philosophers and science educators (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002; Lederman & Abd-El-Khalick, 1998).

In recent decades, there has been a notable consensus among science educators pertaining to the level of simplicity of the aspects of the nature of science that is suggestively accessible and appropriate to basic education science students. This concurrence is based upon the understanding that scientific knowledge is tentative (subject to change); empirically-based (based on and/or derived from observations of the natural world); myth of "The Scientific Method"; subjective (theory-laden); partially based on human inference, imagination and creativity; socially and culturally embedded; observation and inference are different; and theories and laws are distinct kinds of knowledge (Abd-El-Khalick & Lederman, 2000b; Lederman, 2007; McComas, 2008; Osborne, Collins, Ratcliffe, & Duschl; 2003; Niaz, 2009; Abd-El-Khalick, et al., 2017). The eight aspects of NOS that frame this study are symbiotic of one another and are elaborated on in the following sub-sections.

Tentative NOS

Scientific knowledge is reliable and durable, but never absolute or certain (Abd-El-Khalick et al., 2017; Lederman, 2007). All categories of knowledge including facts, theories and laws are subject to change. Scientific claims change as new evidence, made possible through advances in thinking and technological advances, is found. Similarly, existing evidence may be reinterpreted considering new or revised theoretical ideas or due to changes in the cultural and social spheres or shifts in the directions of established research programmes (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002; Abd-El-Khalick, Waters, & Le, 2008).

Empirical NOS

Experiments are useful tools in science but are not the only means to generate scientific knowledge (McComas, 1996). Moreover, scientific knowledge is also derived from observations of the natural world (Lederman, 2007; Lederman, Lederman, & Antink, 2013). However, scientists do not always have "direct" access to most natural phenomena, they rely on the use of human senses augmented by assumptions inherent to the workings of scientific instruments, to make conclusions about the natural world (Abd-El-Khalick, et al., 2017, p. 89).

Myth of "The Scientific Method"

There is a commonly held misconception about science that there exists a single procedure which all scientists follow (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002). "This myth is often manifested in the belief that there is a recipe-like stepwise procedure that epitomizes all scientific practice. This notion is erroneous: There is no single scientific method that would guarantee the development of infallible knowledge" (Abd-El-Khalick, Waters, & Le, 2008, p. 838). Scientists do observe, compare, measure, test, speculate, hypothesize, debate, create ideas and conceptual tools, and construct theories and explanations. However, there is no single sequence of (practical, conceptual, or logical) activities that will indisputably lead them to valid claims, let alone "certain" knowledge (Abd-El-Khalick, et al., 2017, p. 89).

Subjective/theory-laden nature of scientific knowledge

Scientific knowledge is theory-laden (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002). The work of scientists is influenced by their theoretical and disciplinary commitments, beliefs, prior knowledge, training, and expectations (Abd-El-Khalick, et al., 2017). These background factors affect scientists' choice of problems to investigate and methods of investigations, observations (both in terms of what is and is not observed), and interpretation of these observations. This self-identity is attributable to the role of theory in scientific knowledge production (Lederman, 2007; McComas, 2008; Niaz, 2009). Contrary to common belief, science never starts with neutral observations. Like investigations, observations are always motivated and guided by, and acquire meaning considering questions and problems derived from certain theoretical perspectives (Abd-El-Khalick, Waters, & Le, 2008). Further, the impact of individualism on scientific knowledge is mitigated through applying mechanisms such as peer review and data triangulation in order to enhance objectivity (Chen, 2006).

Imaginative and creative nature of scientific knowledge

The empirical nature of science requires the making of observations of the natural world (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002). For this reason, science is not necessarily an orderly enterprise. Scientific knowledge production involves human creativity in terms of scientists inventing explanations and theoretical models and this requires a great deal of creativity by scientists (Abd-El-Khalick, Waters, & Le, 2008). Creativity and imagination are vital at all stages of a scientific endeavour; from planning and designing through data collection to data interpretation, though with variable extent between stages (Wong & Hodson, 2008). The creative NOS, coupled with its inferential nature, entail that scientific entities such as atoms, force fields, species, etc. are functional theoretical models rather than faithful copies of "reality" (Abd-El-Khalick, et al., 2017, p. 89). Chen (2006) claimed that "imagination is a source of innovation" (p. 806). She further asserted that scientists use imagination coupled with logic and prior knowledge to generate new scientific knowledge.

Social and cultural embeddedness of science

Science educators claim that science is a human invention that is entrenched and practiced in the context of a larger cultural setting. Different cultures have different perceptual experiences. For this reason, scientific knowledge affects and is affected by various cultural elements and spheres, including social fabric, trends, prestige, power structures, philosophy, religion, and political and economic factors (Abd-El-Khalick, et al., 2017; Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002; McComas, 2008). Such effects are manifested, among other things, through control of scientific research by economic interests e.g. research on carbon emission or on apparent dangers of cellular phone usage can be influenced by oil companies or cellular phone manufacturers respectively. As history would discern, many people believed in the geocentric model of the solar system because of religious authority (McComas, 2008). The space race, though it results in increases in science and technology development; it is more political than scientific between the so-called world super powers

(Leden, Hansson, Redfors, & Ideland, 2015; McComas, 2008).

Difference between observations and inferences

The scientific enterprise involves both observations and inferences (Schwartz, Lederman, & Crawford, 2004). There is a crucial distinction between these two scientific processes skills. Observations are descriptions of the natural world that are accessible to the human senses whereby several observers could easily reach an agreement whilst inferences are interpretations or explanations of observations gathered (Lederman, Antink, & Bartos, 2014; Schwartz, Lederman, & Crawford, 2004). Alternatively, inferences are accounts of phenomena that are not directly accessible to the senses such as the notion of falling objects due to gravity or the structure of an atom as a central nucleus composed of positively charged particles (protons) and neutral particles (neutrons) with negatively charged particles (electrons) orbiting the nucleus (Vesterinen, Aksela, & Lavonen, 2013; Abd-El-Khalick, Bell, & Lederman, 1998).

Difference and relationship between theories and laws of science

There are common misconceptions among students that there is a simplistic and hierarchical relationship between observations, hypotheses, theories and laws of science; and belief that laws have a higher status than theories within a scientific endeavour (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002). The notion that hypotheses are initially developed from observations and then become theories and theories become laws depending on the availability of supporting evidence is inappropriate (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002). Theories and laws are related but are distinct kinds of scientific knowledge and for this reason they serve different roles in the scientific enterprise and hence, theories do not in any way become laws, even with additional evidence (Niaz, 2009; McComas, 2008; Lederman, 2007).

Generally, laws describe relationships, observed or perceived, of the natural phenomena. Boyle's law, which relates the pressure of a gas to its volume at a constant temperature, is one example of a scientific law. Theories are inferred explanations of the natural phenomena and mechanisms for relationships among natural phenomena (Schwartz, Lederman, & Crawford, 2004). The kinetic molecular theory provides an explanation of what is observed and described by Boyle's law (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002). Hypotheses in science may lead to either theories or laws with the accumulation of substantial supporting evidence and acceptance in the scientific community. Hence, "theories are as legitimate a product of science as laws" (Abd-El-Khalick, et al., 2017, p. 90). The next section highlights some criticisms levelled against general NOS conceptualisation.

Criticisms of the general aspects of NOS

Ogunniyi (1982) asserted that "nature of science is a complex concept. It involves the processes, the products, the ethics, the regulative principles, and the logico-mathematical systems, all defining and controlling the methodological inquiries of science" (p. 25). Because of such complexities, understanding NOS becomes a far-fetched goal in basic education. In response to this challenge, science educators have reached a compromise about what NOS understanding for basic education students should entail (Tala & Vesterinen, 2015). This resulted in a list of general characteristics of NOS that are deemed accessible to basic education students (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002; Lederman & Abd-El-Khalick, 1998; McComas, Almazroa, & Clough, 1998).

Subsequently, this general characterisation has drawn criticisms from some science educators, who felt that such characterisations are not comprehensive and hence cannot describe all kinds of science (Tala & Vesterinen, 2015). Duschl and Grandy (2011) bemoaned this consensus view of NOS that it does not adequately cover all philosophical underpinnings that characterise the generation of scientific knowledge. Echoing the same sentiments was Allchin (2011) who called for whole science approach to NOS characterisation. He argued that the "selective lists of tenets" omitted numerous aspects that shape reliability in the scientific enterprise (p. 518). Moreover, Irzik and Nola (2011) castigated general aspect NOS framework, arguing that:

> While we have no objection to this list, provided the items in it are properly understood, we believe that the consensus view has certain shortcomings and weaknesses. First of all, it portrays a too narrow image of science. …Second, the consensus view portrays a too monolithic picture of science and is blind to the differences among scientific disciplines (p. 593).

They therefore suggested a family resemblance approach in which the differences between scientific disciplines are considered although there would be overlap of common characteristics among sciences.

The eight general aspects of NOS explicated above, though criticised by some science educators as being too general, over-simplified, prescriptive and narrow (Irzik & Nola, 2011; Mathews, 2012; Dagher & Erduran, 2016; Grandy & Duschl, 2008) are considered as a guiding framework for this study as they serve as lenses through which to assess science students' and teachers' conceptions of NOS. The decision to adopt this framework is based on the clarification provided by its proponents, who in response to such criticisms stated that the list of the characteristics of NOS is by no means "a definitive or universal definition of the construct" (Lederman, Antink, & Bartos, 2014, p. 286). They further argued that they have never advocated an absolutist stance on those general statements about nature of science.

Moreover, their focus is on understandings that they want basic education students to have given a plethora of hardly productive debates about the definitive description of NOS.

In support, Kampourakis (2016, p. 674) expressed:

> It should be noted that although the "general NOS aspects" conceptualization and the instruments developed by Lederman and his colleagues have been used widely, to the best of my knowledge, there is no empirical evidence that they lead to distorted views of science. In contrast, there is empirical evidence suggesting that this conceptualization is quite effective in teaching and learning about NOS.

He asserted that using the concept of general ideas about nature of science is an effective approach to introduce students to the nature of science, given available empirical data. "Once students start reflecting about general NOS aspects and teachers start addressing their preconceptions, it could be possible to move forward and study NOS in all its complexity" (Kampourakis, 2016, p. 676). The next section discusses the justification of NOS in science education.

Rationales for teaching the NOS

A variety of rationales for teaching nature of science has been suggested by science educators and researchers (Virginia Mathematics and Science Coalition (VMSC), 2013). Bell (2008) argues that an accurate understanding of the nature of science helps students identify the strengths and limitations of the scientific knowledge, develop accurate views of how science can and cannot answer. Moreover, research suggests that teaching students the nature of science can facilitate the learning of science subject content and increase student achievement (Cleminson, 1990; Songer & Linn, 1991; Driver, Leach, Millar, & Scott, 1996; Peters, 2012).

Mathews (1997) posited that an appropriate understanding of nature of science is essential to understanding the relationship between science and religion, the controversy over creation science and science as a distinctive intellectual enterprise with its special values and the essential differences between scientific and non-scientific disciplines. In addition, teaching the nature of science helps increase awareness of the influence of scientific knowledge on society (Driver, Leach, Millar, & Scott, 1996; Meyling, 1997; Lederman, 1999).

Driver et al. (1996) argued that NOS influence society in terms of utilitarian (making sense of science and managing technological objects and processes in everyday life); democratic (informed decision-making on socio-scientific issues); cultural (appreciating the value of science as part of contemporary culture); moral (developing understanding of the norms of the scientific community that embody moral commitments that are of general value to society) and science learning (enhancing the learning of science subject matter). Ultimately, developing appropriate conceptions of NOS has been advocated as critical to acquiring scientific literacy by various science education reform documents worldwide, particularly in United States, United Kingdom, Australia, Canada and South Africa (Lederman, 2006). What follows is the analysis of NOS representation in the Namibian science curriculum.

NOS in the Namibian Science curriculum: A critical appraisal

Science education in Namibia's basic education phase predominantly focuses on teaching the subject-matter content in preparation for high-stakes examinations. Other aspects of scientific literacy such as inquiry skills and the understanding of the nature of scientific knowledge ought to develop in students implicitly. Implicit approach assumes that "students' participation in authentic scientific investigations in itself would help students develop more accurate understandings of the nature of scientific inquiry and knowledge" (Bell, Matkins, & Gansneder, 2011, p. 415). However, the literature shows that this approach has not been effective in facilitating students' and teachers' understanding of NOS (Gess-Newsome, 2002; McDonald, 2010; Lederman, Lederman, & Antink, 2013).

The National Curriculum for Basic Education (NCBE) which is the broad curriculum, states that Natural Sciences are part of the main drivers of the transformation of society and the world. Hence, there is a need to develop students into scientific literate citizens (Ministry of Education, 2010a). According to the NCBE, scientific literacy which is "the understanding of scientific processes, the nature of scientific knowledge, and the ability to apply scientific thinking and skills, is indispensable today" (Ministry of Education, 2010a, p. 12). Therefore, Natural Sciences area of learning should contribute to the foundation of a knowledge-based society by empowering students with the scientific knowledge, skills and attitudes to formulate hypotheses, to investigate, observe, make deductions and understand the physical world in a rational scientific and sustainable way (Ministry of Education, 2010a).

The aims of the broad curriculum (NCBE) are manifested in the specific Natural Sciences curricula (syllabi). One of the syllabi states that providing basic scientific background for students with the hope of producing the much-needed scientists for the country is the main aim of science education in Namibia. It further states that the Namibian society needs to be scientifically literate if it is to cope with the challenges of appropriate global technology requirements (Ministry of Education, 2010b). At the heart of this study is an attempt to ascertain the extent to which science education is developing students' scientific literacy in terms of acquiring informed understanding of the nature of science, given that this aspect of scientific literacy is not taught explicitly in Namibian schools. The study also seeks to gauge science teachers' views about NOS, as they play a vital role in students' learning of science.

Throughout primary and junior secondary phases of the Namibian education system, the specific science curricula state that scientific processes skills topic should not be taught in isolation as such skills form an integral part of the other topics (Ministry of Education, 2010b, 2010c, 2016). This directive to the science teachers suggests that scientific inquiry skills and simultaneously the nature of scientific knowledge should not be taught as a "pull-out" content (Leden, Hansson, Redfors, & Ideland, 2015, p. 1144) but should be integrated in the subject-matter content. What such instruction does not clearly spell out is whether the integration should be implicit or explicit. This analysis is triggered by the claim that explicit teaching of NOS has been effective in enhancing students and teachers understanding of NOS (Lederman, 2007; Bell, Matkins, & Gansneder, 2011; Leden, Hansson, Redfors, & Ideland, 2015). Explicit approach entails using NOS and scientific inquiry (process skills as referred to in the Namibian science curriculum) as context for generation and learning of scientific knowledge (Gess-Newsome, 2002). This can be achieved by purposefully planning and integrating NOS in the science content. Lederman (2007) asserts that the best way to enhance students' conception of NOS is through "explicit, reflective instructions" (p. 869). Moreover, explicit teaching should not be confused with direct instruction however, whether explicit instruction of NOS should be entrenched into the subject content or taught separately is still debatable (Leden, Hansson, Redfors, & Ideland, 2015). Nevertheless, for students to become scientists in the near future as envisioned by the Namibian science curriculum, learning about NOS is a prerequisite (Tala & Vesterinen, 2015).

In the context of this literature review, science refers to Natural Sciences (Physical Science and Biology). There is evident representation of some aspects of NOS within the aims of the Namibian science curriculum. A comparison of the aggregated aims of the Namibian science (Physical Science and Biology) curriculum with the unanimous view of nature of science objectives extracted from eight international science education standards documents (McComas, Almazroa, & Clough, 1998) suggests that the aims of the Namibian curriculum to some extent conforms to international science standards objectives and hence, it is expected that Namibian teachers do teach such aspects of NOS to science students.

However, attention is drawn to one of the aims of the Namibian science curriculum that says students should develop an understanding of *the scientific method* (italics added) and its application (Ministry of Education, 2010d, 2010e). This appears to suggest that there is one single scientific method that all scientists follow. Science educators and scholars argue that there is no single scientific method that would guarantee the development of infallible knowledge. Scientists do observe, compare, measure, test, speculate, hypothesize, debate, create ideas and conceptual tools, and construct theories and explanations. However, there is no single sequence of (practical, conceptual, or logical) activities that will indisputably lead them to valid claims, let alone absolute knowledge (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002; Abd-El-Khalick, Waters, & Le, 2008; Abd-El-Khalick et al., 2017).

Lederman et al. (2014) argued that basic education students and even the public possess an inaccurate view of the scientific enterprise called the scientific method that has been acquired through schooling, from the media and from the way scientific reports are designed. They further posited that "there is no fixed single set or sequence of steps that all scientific investigations follow. The contemporary view of scientific inquiry is that, the questions guide the approach, and the approaches vary widely within and across scientific disciplines and fields" (p. 290). The next section presents a synthesis of research that has been done on the conception of NOS.

Research on NOS conception

Research on NOS can be traced to over half a century ago (Lederman, 2006). Lederman pointed out that studies on NOS focused on students' and teachers' conceptions; curriculum; attempts to improve teachers' conceptions and effectiveness of various instructional practices. Such studies were underpinned by the premise that scientific knowledge is tentative, empirically based, subjective, partially based on human inference, imagination and creativity, socially and culturally embedded, the myth about the scientific methods, the distinction between observation and inference and finally the relationship between scientific theories and laws (Liu & Lederman, 2002). This review focuses on studies conducted in the most recent decades, focusing on students' and teachers' views of NOS.

Students' conceptions of NOS

Students' views of NOS have been studied extensively by various researchers and science educators mostly in developed countries (Deng, Chen, Tsai, & Chai, 2011). Results consistently show that students throughout basic education (Grades 1-12) possess inadequate (naïve) and often inappropriate views of NOS (Lederman, 1992; Meichtry, 1992; Moss, Brams, & Robb, 2001; Khishfe & Abd-El-Khalick, 2002; Bell, Blair, Crawford, & Lederman, 2003). The study of which this literature review is part of attempts to assess the state of NOS conceptions amongst Namibian science students and teachers in the highest phase of basic education (Grades 11 & 12). Students in this phase of basic education in Namibia have been studying science for almost twelve years.

Vhurumuku (2010) labelled views about the NOS as either naïve or sophisticated. Students can be designated as possessing naïve views when they reveal understandings such as: scientific knowledge is certain and fixed, proven true, exclusively empirically based (relies entirely, on observation, experimental evidence) and objective; theoretical models (atom structure) are copies of reality; there is one single method of science which all scientists follow; science can answer all questions in nature and scientific observations are free from human prejudices. From Schwartz, Lederman and Crawford (2004) such naïve understandings are such as observations and inferences are one and the same; and that theories become laws.

In extension to Vhurumuku's assertions, students possess sophisticated views of NOS when they exhibit understandings such as: scientific knowledge is dynamic, tentative, scientific claims are subject to change as new evidence is found or existent evidence is reinterpreted; there exists multiple truths and realities which are neither fixed nor absolute; there are several appropriate methods in science; scientific observations are theory-laden and dependent on the prior experience and preconceptions of the observer; while scientific knowledge is empirically based (based on evidence), imagination and creativity of scientists (atom structures) also play roles in knowledge creation; and that although scientists try to be open-minded and objective, there is always an element of subjectivity, which has to do with the fact that scientists are human beings. Furthermore, students should be able to distinguish between observation and inference and between scientific laws and theories. They should moreover, be able to explain that observations are products of the use of human senses and that inferences are the conclusions made after making such observations; and that laws are descriptive statements of what happens based on what is observed, whereas theories are explanations of what happens (the how and the why) (Lederman et al., 2002; Lederman, 2007). Other science educators use other variations to describe students' views about NOS but still similar to naïve and sophisticated categorisation such as inconsistent versus consistent; adequate versus inadequate and naïve versus informed (Vhurumuku, 2010).

Moss et al. (2001) conducted a qualitative participant observation study to investigate five purposefully sampled high school (Grades 11-12) science students' understandings of the nature of science for a period of one year in the United States. Moss et al. developed a model of NOS (for their study only) to examine students' conceptions of NOS through semi-structured, formal and one-to-one interviews. They captured the narrative of students' descriptions of NOS verbatim and interpreted them according to the NOS model developed for the study. The model consisted of eight characteristics pertaining to both the nature of the scientific enterprise and the nature of scientific knowledge.

The study found that students held informed views that scientific knowledge is subject to change, however, they were not familiar with the idea that scientific knowledge was robust and is a product of many kinds of methods. Further, it was reported that students' preconceptions that scientific knowledge emanates from a specific method such as the scientific method, were largely not impacted by their participation in the year-long project-based, hands-on science course.

Similarly, Bell et al. (2003) employed a pre-post training assessment of ten "high-ability" (p. 489) secondary school (Grades 10-11) students' understandings of the nature of science and scientific inquiry. They used an open-ended questionnaire and semi-structured interviews and their study used NOS framework as advocated by science education reform documents in the United States such as the National Science Education Standards. The study attempted to explain the effect of an 8-week science training (originally apprenticeship) programme on ten high-ability secondary school students' understandings of the nature of science and scientific inquiry with a view to illustrate any variations in participating students' understandings of the nature of science and scientific inquiry; and to evaluate any direct or indirect effects of participating in the training programme on their understandings of the nature of science and scientific inquiry.

Findings from this study were not any different from the previous study reviewed above. It was found that students' views of the nature of science and scientific inquiry were mostly not commensurate with the objectives of the current reforms. Students' views were characterised by inconsistent or incomplete interpretations. Worth pointing out are for instance the view expressed by all students that data is the only prerequisite for change to scientific claims, missing the notion that theories might also change as a result of reinterpreting existing evidence (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002). The belief that scientific laws represent absolute knowledge and failure to delineate the difference between theories and laws are all conforming to a plethora of research findings that basic education students barely possess views of NOS that are in line with science education reform objectives (Lederman, 1992; Meichtry, 1992; Deng, Chen, Tsai, & Chai, 2011). The study found that despite apparent minimal gain in the students' knowledge about the processes of scientific inquiry, their preconceived views about key characteristics of NOS remained nearly the same (Bell, Blair, Crawford, & Lederman, 2003).

The two studies above were all underpinned by an implicit approach to enhancing students' NOS views. Implicit approach assumes that students would acquire NOS understanding "automatically" just by doing science and engaging in hands-on-activities (Khishfe, 2008, p. 471). Using a different approach in comparison with the two studies above, Khishfe and Abd-El-Khalick (2002) conducted a quasi-experimental study following a "pre-test-post-test non-equivalent group design" (Cohen, Manion, & Morrison, 2007, p. 282) to assess the influence of an explicit and reflective inquiry-oriented instruction compared with implicit inquiry-oriented instructional approach on students' understanding of NOS.

The study involved sixty-two sixth graders allocated to two intact groups. The explicit (intervention) group was exposed to inquiry activities supplemented by reflective discussions of the target NOS aspects. The implicit (comparison) group was exposed to the same inquiry activities but no discussion of any NOS aspect was applied. Due to the abstract nature of NOS, even at the simplified level deemed appropriate for basic education students and with the age of participating students in hindsight, the study was limited to four aspects of NOS namely, tentativeness; empirical; creative and imaginative NOS as well as the difference between observation and inference.

The study found that at the beginning of the intervention, most students in both groups possessed incomplete views of the four target NOS characteristics. However, at the end of the study, most students in the explicit group exhibited a more informed view of one or more of the target NOS characteristics while there was no change in views of students in the implicit group. These results point to the same conclusion as other studies conducted on this component of scientific literacy (Moss, Brams, & Robb, 2001; Bell, Blair, Crawford, & Lederman, 2003). However, this study suggests that involving students in discussions related to NOS during inquiry activities effectively facilitates a shift in their conception of NOS (Khishfe & Abd-El-Khalick, 2002).

Closer to home, Ibrahim, Buffler, and Lubben (2009), conducted a study involving 179 undergraduate students in a South African university. The study was aimed at capturing and describing physics students' views of the NOS using what they referred to as NOS "profiles" (p. 250). These profiles are conceived to be brief descriptions of different views of individual students which can be used to investigate their views of NOS and other associated observable aspects of the scientific endeavour. They found that only 44% of the sample exhibited desirable views of NOS. Such findings are not surprising as similar results are reported the world over.

Another African perspective on students' views of NOS can be found in Vhurumuku, Holtman, Mikalsen, and Kolsto (2006). They investigated Zimbabwean high school chemistry students' images of NOS during a laboratory session. They found that a substantial percentage of students view scientific knowledge produced by chemistry experiments and observations as "true" (p. 139). Moreover, those who viewed experimental results as not always true justified their reasoning with a blame on "failure to follow procedures, contamination of reagents, faulty apparatus, or unfavourable laboratory conditions" (p. 139). These findings about students' images of NOS point to the prevalent inappropriate view about the validity of scientific knowledge (Vhurumuku et al., (2006). McComas (1996) claimed that the availability of empirical evidence regardless of how much such evidence is does not ensure the generation of valid scientific knowledge due to the problem of the method of induction. He explains that:

> It is both impossible to make all observations pertaining to a given situation and illogical to secure all relevant facts for

> all time, past, present and future. However, only by making all relevant observations throughout all time, could one say that a final valid conclusion had been made (p. 12).

Despite that students and teachers views about NOS have been studied extensively in the last two decades, it has not been possible to locate such studies done in Namibia. Deng et al. (2011) conducted a thorough and critical review of research within the last two decades (from 1992 to 2010) and found 105 empirical studies that examined students' views of NOS. The search was conducted on some major online academic databases. They could locate such similar studies done in South Africa and Zimbabwe (these two countries being closest neighbours of Namibia) but none was found to have been done in Namibia.

A search on the University of Namibia's publications list and online repository came up with only one study that is closely related to NOS and scientific inquiry. It was conducted by Kandjeo-Marenga (2011). This study investigated the implication of two teaching approaches on the students' learning of process skills in Biology. The main focus of the study was "process skills" learning opportunities during practical work (p. 44). Such skills are typical components of scientific inquiry (Lederman, Lederman, Bartos, Bartels, Meyer & Schwartz, 2014). However, the study fell short of tapping from "inquiry processes as a model of scientific practices" (for a better theoretical grounding) as well as recognizing the relationship between inquiry-based approaches to enhancing students' understanding of NOS (Allchin, Andersen, & Nielsen, 2014, p. 467). Against the foregoing, the theoretical grounding of this study could be extended. Teachers' views of NOS are discussed in the following section.

Science teachers' conceptions of NOS

Current teaching and learning practices follow the learner-centred approach that is underpinned by the constructivist view (Ministry of Education, 2010a). This principle advocates the provision of opportunities for students to construct new understandings for themselves at both individual and social levels (Brooks & Brooks, 1993). However, the teacher has a significant role to play in this endeavour (Lederman, 1992). The role of the teacher is that of a "guide, provocateur, creator-of-opportunity, and co-developer of understanding with the students" (Windschifl, 1999, p. 191). Therefore, science teachers must possess an adequate understanding of NOS to effectively contribute to students' understanding of this concept (Lederman, 1992).

Nevertheless, it has been reported that teachers do not generally possess consistent or adequate conception about the NOS (Lederman, 1992; Abd-El-Khalick & Lederman, 2000a; Dogan & Abd-El-Khalick, 2008). Subsequently, it can be assumed that teachers cannot effectively teach concepts that they do not understand (Bell, Matkins, & Gansneder, 2011). However, Abd-El-Khalick, Bell and Lederman (1998) argued that even though teachers' understanding of the NOS can be assumed to be a necessary condition for effective teaching of NOS to students, it is not sufficient to make NOS visible in their science classrooms. In corroboration of this argument, Bell et al. (2011) maintained that teachers with inadequate understandings of the NOS are likely to promote absolutists views while overemphasising vocabulary of the science content. Thus, suggesting that enhancing teachers' conceptions of NOS is a vital preliminary attempt to improve NOS teaching to basic education students.

Aslan and Tasar (2013) investigated science teachers' NOS views with the intention of determining how their views influenced their instructional practices. They used items from the Views on Science-Technology-Society (VOSTS) questionnaire, semi-structured interviews and classroom observations, to assess teachers' NOS views. Their findings were consistent with earlier studies. They found that the participating science teachers held naïve views on many aspects of the NOS and further found that teachers' views about NOS did not directly influence their classroom practices. Other intervening factors such as the high stakes examinations, expectations of school administrators, students and parents, influenced teachers' instructional practices.

The common conclusion that can be deduced from the studies reviewed is that both in-service and pre-service teachers do not possess adequate understanding of the NOS.

None of the studies reviewed was done in Namibia though.

Conclusion

The nature of science is a multifaceted and complex concept. To date there is no complete agreement among philosophers, historians, sociologists of science and science educators on how to define it. Notwithstanding this, there is less disagreement among philosophers of science and science educators about the general aspects of the nature of science that are deemed less controversial and appropriate for inclusion in the basic education science curricula. Those aspects are manifested as unanimous view of the nature of science objectives in eight international science education standards documents as presented by McComas et al. (1998).

The general characterisation of the nature of science has been criticised by some science educators. However, the closing arguments that provided the way forward are that the disagreements among science educators are not necessarily relevant to basic education science students as such students do not study philosophy, history or sociology of science. The aim is to make NOS accessible to such students. Furthermore, the emphasis is that using the concept of general ideas about nature of science is an effective approach to introduce students to the nature of science.

NOS is an important component of scientific literacy. An accurate understanding of the nature of science is believed to help students identify the strengths and limitations of the scientific knowledge, develop accurate views of how science can and cannot answer all questions. Moreover, research suggests that teaching students the nature of science can facilitate the learning of science subject content and increase student achievement. Developing appropriate conceptions of NOS has been advocated as critical to acquiring scientific literacy by various science education reform documents worldwide, particularly in the United States, United Kingdom, Australia, Canada and South Africa.

Some aims of the science curriculum in Namibia were found to overlap with some objectives of international science education standards documents. Namibia envisions developing future scientists through the teaching of natural sciences. This dream can be realised if students acquire appropriate understanding of the nature of scientific knowledge. However, the science curriculum adopts the implicit approach to teaching the nature of science as is prevalent worldwide. However, research shows that this approach is not effective, hence the need follows explicit-reflective instructional approach.

Research results of students and science teachers' views of NOS consistently reveal that both students and teachers possess naïve (inconsistent) views about NOS. Studies of this nature have not been carried out in Namibia. This constitutes a gap that needs to be filled.

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