

Exploring South African high school teachers' conceptions of the nature of scientific inquiry: a case study

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The paper explores conceptions of the nature of scientific inquiry (NOSI) held by five teachers who were purposively and conveniently sampled. Teachers' conceptions of the NOSI were determined using a Probes questionnaire. To confirm teachers' responses, a semi-structured interview was conducted with each teacher. The Probes questionnaire was based on six tenets of the nature of scientific inquiry but only three tenets are presented in this paper, namely: (1) scientists use a variety of methods to conduct scientific investigations; (2) scientific knowledge is socially and culturally embedded; and (3) scientific knowledge is partly the product of human creativity and imagination. The study found that the teachers held mixed NOSI conceptions. These conceptions were fluid and lacked coherence, ranging from static, empiricist-aligned to dynamic, constructivist-oriented conceptions. Although all participants expressed some views that were consistent with current, acceptable conceptions of NOSI, some held inadequate (naïve) views on the crucial three NOSI tenets. The significance of this study rests in recommending explicit teaching of NOSI during pre-service and in-service training which enables teachers to possess informed conceptions about NOSI. With these informed conceptions, teachers may internalise the instructional importance of the NOSI which, in turn, may help avoid the lack of attention to NOSI currently evidenced in teachers' instructional decisions. This might result in teachers' orientations shifting towards an explicit inquiry-based approach from that of an implicit science process and discovery approach.

Keywords: informed views; naïve views; nature of scientific inquiry; NOSI tenets; scientific inquiry; scientific investigations; scientific method; teacher conceptions

Introduction

During the last three decades, the science education community has established a research agenda calling for more studies focused on teachers' conceptions of the nature of scientific inquiry (Keys & Bryan, 2001; Schwartz, Lederman & Lederman, 2008). Nature of scientific inquiry (NOSI) refers to the processes and elements therein of scientific investigations and methods of justifying knowledge (Schwartz, 2007). Conceptions of the nature of scientific inquiry are an individual's ideas, beliefs, understanding and assumptions about the scientific process; what scientists do; and how scientific knowledge is developed and validated (Vhurumuku & Mokeleche, 2009). Recent research (Bartels, Lederman & Lederman, 2012; Hacıeminoğlu, Yılmaz-Tüzün & Ertepinar, 2012; Schwartz, Lederman & Abd-El-Khalick, 2012) and reform documents (American Association For The Advancement Of Science (AAAS), 1993;

National Research Council (NRC), 1996) advocate critical roles for teachers in structuring and guiding learners' conceptions of NOSI; a major learning goal in science education reform efforts. South Africa has not been spared by these reforms (Wolhuter, 2011) where advocacy for scientific inquiry is found in both current science education research agendas and in contemporary school science curricula reform documents (Ramnarain, 2011).

While a number of studies have been conducted, focusing on teachers' conceptions of NOSI (see Abd-El-Khalick, 2002, 2006; Abd-El-Khalick, Bell & Lederman, 1998; Lederman, 1999; Lederman & Latz, 1995; Linneman, Lynch, Kurup, Webb & Bantwini, 2003), the results of these studies have been contradictory. The results of some studies have shown that many teachers harboured naïve and inadequate understandings of NOSI (Abd-El-Khalick, 2006; Lederman & Latz, 1995; Linneman et al., 2003), while other studies have shown that some teachers harboured well-informed views (e.g. Abd-El-Khalick, 2002; Abd-El-Khalick et al., 1998). Results of studies that have shown that teachers harboured naïve views gave an overall picture that the majority of science teachers viewed scientific knowledge as immutable truth, possessed absolutist viewpoints, and had little, if any, formal exposure to NOSI. Lederman (1999:927) found that teachers' conceptions of science did not necessarily influence classroom practice. Of critical importance were teachers' level of experience, intentions and perceptions of students. Given these findings, conceptions were consistent with previous research (Abd-El-Khalick et al., 1998; Abd-El-Khalick & Lederman, 1998; Lederman, 1992). The issue in question is whether teachers should be helped to internalise the instructional importance of NOSI. This may help avoid the lack of attention to NOSI evidenced in teachers' instructional decisions (Duschl & Wright, 1989; Faikhamta, 2013; Lederman & Latz, 1995). It may facilitate focusing teachers' intentions on promoting learners' understanding of NOSI. For this to be done, the starting point would be ascertaining the NOSI conceptions teachers currently harbour. This is what this study seeks to address. Furthermore, Faikhamta (2013) laments that in-service teachers' orientation to teaching NOSI is an implicit science process and discovery approach because they harbour mostly naïve views of science. However, with in-service training leading to teachers better understanding NOSI and having conceptions consistent with contemporary constructivist views, their orientations might shift from an implicit science process and discovery approach towards an explicit inquiry-based approach.

The present study has been undertaken in the South African context and firstly represents an attempt to explore Grade 11 teachers' conceptions of NOSI. Secondly, the study seeks to promote further debate among science educators for the need to possess informed NOSI views consistent with the main thrust of the science reform agenda (see Department of Education, 2005; NRC, 1996). It is significant to document how teachers in an African setting view and, at the practical level, deal with philosophical, methodological and epistemological issues related to scientific inquiry and

instruction. For science educators, the rise of science, the conduct of science, its influence on values and priorities, and its relation to social responsibility are difficult to discuss without reference to some understanding of the NOSI itself. Given that teachers do not teach what they do not know (Keys & Bryan, 2001), what conceptions are teachers passing on to learners about the NOSI? Another question is: Do South African teachers' hold valid conceptions of the NOSI? Because little is known about how teachers conceptualise inquiry, how these conceptions are formed and reinforced (Windschitl, 2004), this study addresses this omission, charting the line of research pursued in this study as a foray into relatively virgin land in the South African context.

Purpose of the study

The study seeks to explore Grade 11 teachers' conceptions of the nature of scientific inquiry. In order to achieve this purpose, a single research question has been formulated: What are the teachers' conceptions of the nature of scientific inquiry?

Theoretical framework

This study is guided by the literature on operationalization and categorisation of the phrase *conceptions of the nature of scientific inquiry (NOSI)* (Deng, Chen, Tsai & Chai, 2011). Scientific inquiry refers to the methods and activities that lead to the development of scientific knowledge (Schwartz et al., 2008). Within a classroom, scientific inquiry involves learner-centred projects, with learners actively engaged in inquiry processes and construction of meaning with teacher guidance, to achieve meaningful understanding of scientifically accepted ideas targeted by the curriculum (Rossouw, 2009). This entails using a variety of activities to develop learners' knowledge and understanding of scientific ideas and how scientists study the natural world. In this study, conceptions of NOSI are taken to include an individual's ideas about the scientific process and enterprise. What constitutes conceptions of NOSI are not the abilities or skills to carry out investigations, but rather the beliefs, views, perceptions and assumptions attached to the activities by the individual.

Teachers' conceptions of NOSI were established using three NOSI tenets which are: (1) scientists use a variety of methods to conduct scientific investigations; (2) scientific knowledge is socially and culturally embedded; and (3) scientific knowledge is partly the product of human creativity and imagination. Tenets are the ideas, principles, opinions or doctrines about scientific knowledge and the scientific process that are generally believed or held to be true by members of the science education community. These tenets are captured in the Probes instrument used in this study to solicit teacher conceptions of NOSI. However, the instrument used to elicit these conceptions comprised an additional three NOSI tenets, giving a total of six. These tenets are: difference between laws and theories; accurate record keeping, peer review, and replicability in science; and theory ladenness of observations. However, only results for the first three tenets are given in this paper because they have been underexplored where it matters — research among practising teachers (Schwartz, 2007).

There are several frameworks which can be used as lenses to categorise an individual's NOSI conceptions. Examples include: the uni-dimension framework, the argumentative resource framework and the multi-dimension framework. The *uni-dimension* (UD) framework is a lens which perceives conceptions of the nature of scientific inquiry as a continuum ranging from empiricist through mixed to constructivist perspectives. The uni-dimension framework views the nature of scientific inquiry as single components (Hammer & Elby, 2002) of a stable personal epistemology. The uni-dimension framework conceives views of the NOSI as properties of an individual that are independent of the context. This becomes a problem in that contexts vary and are detrimental to a person's views or perceptions, conceptions, preconceptions, dispositions and convictions of the scientific process and enterprise. Closed form instruments and statistical analysis methods are used by researchers who employ the UD framework. Perceiving responses to the survey items as a reliable representation of individuals' conceptions of the NOSI in different contexts is problematic in that it might not be true. The uni-dimension framework's treatment of NOSI conceptions is, therefore, too simplistic and an over-generalisation of reality and hence, was found inappropriate for this study.

The *argumentative resource* (AR) framework is another lens which can also be used to analyse NOSI conceptions. The argumentative resource framework posits that conceptions of the NOSI should be seen as discursive achievements (Roth & Lucas, 1997) that are illustrated through argumentative resources drawn in practice. Interview and observation methods are used by researchers who employ the argumentative resource framework. Most argumentative resource framework researchers treat language as a cultural tool. According to Roth and Lucas (1997), language mainly constitutes, maintains and reconstitutes reality rather than representing it. Again, looking at the research question posed by this study, the methodological approach employed and instruments used for data collection; the argumentative resource framework was found inappropriate because this study is exploratory and does not include observations of teachers teaching in science classrooms to check on argumentation.

The third framework which can be used as a lens to categorise an individual's conceptions of the NOSI is the *multi-dimension* (MD) framework. The MD framework advocates that an individual's conceptions of the NOSI consist of multiple dimensions. Various studies utilising the MD framework have stressed various dimensions. Commonly investigated dimensions include: (1) theory-laden nature of science (e.g. Liu & Tsai, 2008), (2) nature of and distinction between observation and inference (Ackerson & Donnelly, 2010); (3) imagination and creativity in science (e.g. Tsai & Liu, 2005); (4) socially and culturally embedded nature of science (Constantinou, Hadjilouca, & Papadouris, 2010); (5) nature of scientific methods (e.g. Dogan & Abd-El-Khalick, 2008), among others. In depicting views of the NOSI that do not satisfy national curriculum documents, some MD framework researchers have used the term 'misconception' (e.g. Afonso & Gilbert, 2010). MD studies, unlike the UD framework, rely

much less on closed form instruments and statistical analysis. Looking at the research question posed by this study, the methodological approach employed and research methods (instruments for data collection), the MD framework was found appropriate for this study because it allowed use of semi-open form instruments combined with instruments from other formats as opposed to closed instruments only. Semi-open form instruments usually provide sets of alternative respondent position statements and sometimes provide an additional *others* option to capture viewpoints beyond the instrument.

Different themes and categories were sought from the data by adopting Akerson, Cullen and Hanson's (2009) categorisation of NOSI which belongs to the multi-dimension framework. As a result, the participants' responses were placed into one of three categories: 'informed', 'partially informed' or 'naïve'.

Research methodology

Sampling

The participants were five experienced Grade 11 Physical Science teachers, purposively and conveniently chosen (Patton, 2002) from five metropolitan high schools in Johannesburg, Gauteng, South Africa. The sampling was skewed towards males (one female and four male). The Report to the National Advisory Council on Innovation (Business Environment Specialists (SBP), 2011) stated that at the tertiary education level, gender disparity is evident in terms of student enrolments at the undergraduate level, and becomes a glaring disparity at the postgraduate level in subjects such as engineering and the built environment, and that physical, mathematical and computer sciences remain male-dominated. This might explain why South Africa has more male than female Physical Science teachers. The five teachers, pseudo-named, Ranelo, Hedwick (female), Jairos, Johnny, and Booi were chosen for the study for two major reasons.

First, 10 schools that place emphasis on Mathematics, Science and Technology were identified. From these, five teachers were selected who were adjudged to be the most experienced and also appeared to be cooperative and willing to participate in the study. Their experience in teaching Physical Science ranged from 15 to 22 years. Secondly, all five teachers were qualified to teach Physical Science and had a minimum of a Bachelor's degree in Science including the Education component (with practical work in science being one of the courses). Of the five teachers, two (Ranelo and Hedwick) had a Bachelor of Science degree while the rest had a Bachelor of Education degree. Four of the teachers (Hedwick, Jairos, Booi, and Ranelo) were studying part-time towards a Master of Science degree at a university in Johannesburg. All teachers were teaching Physical Science at Further Education and Training (FET) level, that is, Grades 10–12. The Gauteng Department of Education, as well as the principals and participating teachers of the five schools gave consent for conducting the study. The research design was also approved by the ethics committee of the university which funded this project. The teacher participants were informed that their

participation would be voluntary and they could withdraw from the study at any time. However, no participants withdrew.

Instruments

Probes

To investigate the five teachers' NOSI conceptions, a Probes' questionnaire was administered. Probes were chosen for this study because they provide contexts for respondents to reflect on their NOSI conceptions (Ibrahim, Buffler & Lubben, 2009). The probes were adapted from three instruments namely; the Views On Science Technology Society (VOSTS) (Aikenhead & Ryan, 1992), the Views of Nature of Science (VNOS)-Form A (Lederman & O'Malley, 1990) and VNOS-Form C (Lederman & Abd-El-Khalick, 2002). One probe is related to each NOSI tenet. Each probe presents a scenario followed by a number of different options, which are presented in the form of conversations (see Figure 1, an example of a probe). The respondents were requested to select only one of the alternatives provided, which they deemed to be most appropriate. By providing the option "I have a different idea" or "I have another view which I will explain" for all probes, respondents were encouraged to formulate alternative choices (with rationale) on the issue discussed in the probe. The explanations for their decisions provided insight into the underlying reasoning on which their choices were built.

Before administering the questionnaire to the sampled teachers, the instrument was piloted in five different schools with five teachers, one from each school. These teachers were not part of the main study. The content validity for each of the probes was improved by peer reviews from university professors (six from science disciplines) and 25 postgraduate Physics, Chemistry and Biology students. Comments from each of these reviewers were considered before the final probes were produced. All these respondents were working in the field of scientific inquiry. The researcher wished to ascertain if the instrument items had the same meaning that the researcher had in mind when designing the tool. These academic experts and postgraduate students were given the instrument for peer review so as to improve the instrument's content and construct validity. After ascertaining face, content and construct validity, the questionnaire was administered to the study sample teachers. Each probe was answered in no strict sequence. Each teacher took between 20 and 30 minutes to complete the instrument. Figure 1 illustrates one of the NOSI probes (probe number five in the instrument) in the questionnaire. In this case, teachers' ideas on the use of human "imagination" and "creativity" in the creation of scientific knowledge were being elicited. This questionnaire was administered before teacher interviews were conducted.

Semi-structured interviews

All participating teachers were interviewed for the purposes of confirming responses from the Probes instrument, and for obtaining a deeper understanding of their NOSI

Now you think about the nature of scientific knowledge

scientific knowledge is
socially and culturally
embedded



A

No, scientific knowledge is
not socially and culturally
embedded



B

I have another view which
I will explain



C

With whom do you most closely agree? (Circle one):

A	B	C
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Explain your choice.

Figure 1 An example of an NOSI item/probe

conceptions. Each teacher was asked a set of core questions around which probing for clarification was conducted. Further probing and prompting was done depending on the responses given by the interviewee. The structuring of the core questions was informed by literature (e.g. Kirschner, Sweller & Clark, 2006). The questions were adapted from Kirschner et al. (2006). The same group of five teachers who validated the probes questionnaire in the pilot study also validated these questions for the context in which they were used. These teachers were not part of the main study. The semi-structured interviewing was done around the following questions:

1. What can you say about the methods scientists use in their investigations or experiments?
2. Is scientific knowledge culture free? Explain.
3. From what you do with your learners during Chemistry practical investigations, what can you say about the use of imagination and creativity in science?
4. Do you think what you do in the Chemistry practical investigation with your learners is similar to what is done in scientific laboratories?
5. Where do you think scientific knowledge comes from?
6. How do scientists build scientific knowledge?

Data analysis

Probes

Coding of teachers' responses was based on the choice of action (A, B, C) together with the explanation for their actions. Categories of responses to individual probes' open-ended responses were created using a *hybrid model* developed by the author after fusing the Ibrahim et al.'s (2009) model for coding probes with that of Liang, Chen, Chen, Kaya, Adams, Macklin and Ebenezer (2009) rubric for scoring Student Understanding of Science and Scientific Inquiry (SUSSI) open-ended responses. For the hybrid model, dimensions from the SUSSI instrument (Liang et al., 2009) were used to develop the coding patterns. The hybrid model was first validated by applying it to data collected during the pilot phase and thus refining some of the codes before being used with data from the main study. It was used in the main study only after thorough testing found it to be valid and reliable. Three researchers, all working in the field of scientific inquiry, who had been previously engaged in the face, content and construct validation of the probes questionnaire, independently analysed a transcript from each of the teachers. Their coding did not vary. An inter-rater reliability coefficient of 0.982 was obtained using Statistics and data (STATA) (an Integrated Statistical Software package for data analysis, management, and graphics) from the analysis. This was taken to signify consensus among the three researchers.

The researcher read through sets of transcripts, making preliminary notes regarding patterns that emerged from individual participants. The transcribed probes data was read looking for patterns, relationships and other themes within the dimensions. Entries were coded according to patterning identified while keeping a record of what entries went with which element of the patterns, as done by Ibrahim et al. (2009).

These procedures involved (1) the simultaneous collection and analysis of probes data and (2) comparative methods of analysis whereby participants' responses were compared between and within each participant, and (3) the integration of a theoretical framework that guided the study. Underlying reasoning was then identified for each teacher by writing the category codes for each probe response. This enabled conceptions of the nature of scientific inquiry to be determined for each teacher's response. Thus, some aspects of grounded theory analytical procedures (Strauss & Corbin, 1998), especially interpretive analysis (e.g. Gall, Gall & Borg, 2003), were used to inductively analyse the participants' probes' open-ended responses.

By adopting Akerson et al.'s (2009) categorisation of NOSI which belongs to the multi-dimension framework, the participants' responses were placed into one of three categories: 'informed', 'partially informed', or 'naïve'. The responses were categorised as 'informed', if the participants' responses indicated that their views were consistent with contemporary constructivist views of NOSI, in which observation is viewed as theory-laden and science is viewed as a set of socially negotiated understandings of the universe. If the responses were partially compatible with constructivist views of NOSI, they were categorised as 'partially informed'. If the responses were completely inconsistent with constructivist views of NOSI, in which science was viewed as a purely objective process for determining knowledge and understanding about the natural world, they were categorised as 'naïve'. Therefore, participants were not categorised as naïve, partially informed or informed but their views of targeted NOSI tenets were.

Semi-structured interviews

Analysis of transcripts from teacher interviews was done using a "hybridisation" of the processes of analytic induction (Gall et al., 2003:21) and interpretational analysis. For each teacher, transcribed teacher interview notes were entered into ATLAS.ti version 6.2 (a powerful workbench software program that facilitates qualitative analysis of large bodies of textual, graphical, audio and video data) and analysed as data sets. The analytic induction involved continued reading and re-reading of transcripts to unveil common patterns. For each data set, emerging patterns were then used to develop categories. Following inter-reliability checks with other researchers in science education, responses were then classified on the basis of the formed categories. Interpretational analysis involved getting meaning out of the data. As a researcher, I asked the following question: What does this mean? Meaning was found by grouping teachers' responses into categories within which the responses fitted.

Results

First, results from the closed-ended section of the Probes instrument are presented. Secondly, for triangulation purposes, interview data are reported verbatim to confirm teachers' responses to the open-ended section of the Probes instrument.

As Table 1 shows, the teachers generally held informed views of the nature of scientific inquiry, considering the closed section of the probes instrument. Four of the

five teachers agreed on the three aspects of the NOSI, whilst one teacher disagreed with the rest.

Table 1 Summary of Probes closed-ended responses ($n = 5$)

Probe	Choice	Description	No. of teachers
1	A	Scientists use one method to conduct investigations	1
	B	No, scientists use a variety of methods to conduct investigations	3
	C	I have another view which I will explain	1
2	A	Scientific knowledge is socially and culturally embedded	4
	B	No, scientific knowledge is not socially and culturally embedded	1
	C	I have another view which I will explain	0
3	A	Scientists use human creativity and imagination to create scientific knowledge	4
	B	No, scientists do not use human creativity and imagination to produce scientific knowledge	0
	C	I have another view which I will explain	1

Scientists use a variety of methods to conduct scientific investigations

Four of the five teachers (Hedwick, Jairos, Ranelo, and Booi) believed that scientists use a variety of methods to conduct scientific investigations. When responding to the probe related to this aspect, two of these four teachers wrote:

PMSCIT1 (Ranelo): *Scientists use a variety of methods. The procedure of an experiment depends on the question to be addressed. However, the scientific method must be used to check the conclusions.*

PMSCIT2 (Hedwick): *There are so many methods of doing investigations. Some discoveries are made by accident (e.g. penicillin). I understand the structure of benzene was discovered based on a dream.*

These responses show informed views. Of interest is Ranelo's response, who believes other methods can be used to conduct investigations but components of the scientific method should be used to confirm/validate the results. During the interview, Hedwick, Jairos and Booi maintained their position by giving more or less the same responses they had given in the probes questionnaire. Ranelo qualified his probe response during interviewing. He said:

Tr1Int (Ranelo): *Scientists employ a variety of methods but for confirmation of results, scientists have to use an orderly step-wise procedure. Only then can they be sure of their results, after having followed a logical common method.*

This response shows that Ranelo believes other methods can be used to conduct investigations but components of the scientific method should be used to confirm the

results. Johnny did not agree with this view. His probe response was:

PMSCIT4 (Johnny): *Scientists use one method of logical steps known as the scientific method to perform various investigations.*

This view is categorised in this context as naïve. The view was cross-checked and validated during interviewing and Johnny qualified his conception by further saying:

Tr4Int (Johnny): *Scientists need to prove each other incorrect in scientific arguments. For them to be able to do this ... there is only one method known to establish accuracy, called the scientific method. I use this method with my learners as from Grade 10[...]*

This response fits into Rudolph's (2005) description of the scientific method when he lamented that the more nuanced step-based accounts of scientific processes, when formalised for school curricula, risk getting altered and distorted into rigid steps. The idea that science is a linear process, often portrayed in the science classroom by the scientific method, is also raised by the majority of the teachers (85%) in a study by Abd-El-Khalick (2006). The "scientific method" (McComas, Clough & Almazroa, 1998:513) in this study is operationalised as a recipe-like step-by-step procedure that all scientists follow and that guarantees developing claims. The step-by-step procedures which are followed are: the purpose/question, research, hypothesis, experimentation, analysis and conclusion.

Scientific knowledge is socially and culturally embedded

Four of the five teachers held contemporary and informed views that science is part of social and cultural traditions. Hedwick, Jairos, Johnny, and Booi were of the opinion that scientific knowledge is not social- or culture-free. When responding to the probes item regarding this aspect, the two of the four teachers wrote:

PNSKT3 (Jairos): *Science is everywhere and as such, scientific ideas are affected by their cultural, social and political settings.*

PNSKT5(Booi): *Scientists' knowledge comes from what they believe in, (i.e.) their social and cultural locale; social issues affect science in a way that scientists find a need in their social life and try to fix that problem using science.*

These responses were confirmed by the teachers during interviewing. Jairos explained:

Tr3Int (Jairos): *Science as a human endeavour is influenced by the society and culture in which it is practised. On one hand, in school science for example, politicians will always influence the design and contents of the science syllabus. [...] Social problems on the other hand, determine the research to be pursued to solve those nagging societal problems. For example, nowadays there is so much expanded research on Human Immunosuppressive Virus (HIV) and Acquired Immunodeficiency Syndrome (AIDS), global warming and the use of genetic engineering.*

Booi concurred:

Tr5Int (Booi): *As much as science knowledge aims to be universal and general,*

science is affected by social and cultural beliefs because science reacts to societal and cultural problems. Cultural values determine what science is conducted and accepted. Issues like the HIV and AIDS pandemic, use of non-renewable energy sources and famines have resulted in so much money being channelled by politicians into the research of HIV and AIDS, global warming and genetic engineering.

While these responses show informed views of this NOSI aspect, Ranelo did share this view. He thought science is a search for universal truth and facts which is not affected by culture and society. When completing the probe item in regard to the nature of scientific knowledge, Ranelo wrote:

PNSKT1 (Ranelo): Science knowledge is not influenced by society and culture, but by facts. For example, lightning has the same effect, no matter how it is produced and which culture one belongs to.

This view is categorised here as naïve. During interviewing, this is what he said:

Tr1Int (Ranelo): Science is based on facts. Most of the time, science proves social and cultural beliefs held by individuals wrong. In the olden times, people believed that the sun moved around the earth, but Science proved that it was the earth that moved around the sun [...]. Another example is that of lightning, which has the same effect no matter how individuals believe it is produced. [...]

Though Ranelo's argument is reminiscent of the argument peddled with much emotion by Copernicus and the Christian religion, according to Inokoba, Adebowale and Perepreghabofa (2010), science as an endeavour and phenomenon is not conceived and operated in a cultural and environmental vacuum. It is a social phenomenon greatly influenced by the prevailing cultural traits and worldview of a people such as their social values, priorities, ideas, skills, ethics, perception of social reality, and belief systems.

Scientific knowledge is partly the product of human creativity and imagination

The five teachers' views fall into two categories regarding this NOSI aspect. Hedwick, Jairos, Johnny, and Booi believe that science knowledge and truth are not fixed by nature but are also creations of the mind. In responding to the corresponding probe item, two of the four teachers wrote:

PCKST3 (Jairos): One has to be highly creative and imaginative to further pursue general views, so imagination and creativity are used a lot by scientists in creating new knowledge.

PCKST4 (Johnny): Scientists are the most creative and imaginative beings on this planet, because it is these two, imagination and creativity, that they use very well and new knowledge is born.

These views are categorised here as informed. Through further probing and prompting, interesting responses were given by the teachers to solidify their views and position. This is what Jairos said:

Tr3Int (Jairos): *For anybody to come up with something recognisable or of academic stamina, one has to imagine things. When one has an idea, one has to be creative [...] Boyle had to be very creative [...]. He used his imagination and creativity to come up with what we call today the Boyle's apparatus.*

Interviewer: In your teaching of investigations how do you make sure these two constructs are infused?

Tr3Int (Jairos): *It is a point of saying to the learners that most of the time, we know the expected or desired result, but if it does deviate from the norm, that is, if you do get observations that are out of expectation, then do not be afraid to record what you have established, because that is how science functions. There are no set of rules to follow [...]*

Ranelo had a different view to the other four teachers. He did not think that science knowledge was a product of imagination and creativity and to him; both human creativity and imagination are in conflict with scientists' objectivity. When completing the probes instrument, Ranelo wrote:

PCSKT1 (Ranelo): *Scientists do not use imagination and creativity when creating new knowledge, because the two interfere with objectivity and I do not use creativity and imagination at all as an individual.*

During interviewing, Ranelo said:

Tr1Int (Ranelo): *Scientists don't use imagination or creativity because they won't be able to prove what they have come up with. I do the same, I do not use it and I encourage my learners not to use it, because it interferes with objectivity. Science is all about proving facts.*

This response shows naïve views of the NOSI and can be described as “realist” (Eflin, Glenman & Reisch, 1999:112). Ranelo's meaning of the term “objective” appears to be the same in this instance as that for the term real. To Ranelo, if an idea cannot be proven, then it is not scientific and not real. Ranelo has to be reminded that scientists do not solely rely on logic and rationality. In fact, both creativity and imagination are a major source of inspiration and innovation in science. It permeates the ways scientists design their investigations, how they choose the appropriate tools and models to gather data and how they analyse and interpret results.

Discussion

One of the most widely held naïve ideas about science – the existence of a universal, step-wise “Scientific Method” (McComas et al., 1998:513) – was confirmed by this study. Interestingly, only one teacher harboured this view. The other teachers believed scientists can use all other methods they can come up with, but at the end, the steps of the “Scientific Method” (McComas et al., 1998:513) should be used to verify and confirm results. Reform documents (AAAS, 1993; NRC, 1996) have for long debunked this notion. There is no such method (Bauer, 1994). Such naïve patterns are highly unlikely to be attributed to chance. Through introspection of some teachers' responses, it is most likely that these teachers might have been *explicitly* exposed to these naïve

ideas about science knowledge during their teacher training. Alternatively, these teachers might not have been exposed to any views at all which are either partially informed or informed. Partially informed views include statements such as ‘many methods being used’ without further elaboration. Informed views include statements such as ‘using many different methods because scientists are not limited in any way’. The other possibility is that the teachers may not have been exposed to the NOSI construct at all during their training.

To McComas (1996), people believe in the existence of the scientific method because of the way scientific research has been propagated and reported in journals and books. In many instances, the reports are presented in the same format as the so-called scientific method (e.g. Emiliani, Knight & Handwerker, 1989). From the formats of these reports, people have drawn erroneous conclusions that this is how science works. While scientists may do some of the activities listed in the so-called scientific method, in practice they do not go step-by-step through the steps. What happens in reality is that scientists approach and resolve problems in different ways. Serendipity and dreams can also be used, as suggested by some of the teachers.

Four of the five teachers believed science knowledge is subjective to a certain degree. They gave such factors as the existing scientific knowledge, social and cultural contexts, the researcher’s experiences and expectations influencing how data are collected and analysed and conclusions drawn from such data. These results are, however, inconsistent with results from a study conducted on Turkish high school teachers by Macarolu, Taşar and Cataloglu (1998). In particular, these researchers found that their participants believed that science knowledge was objective, that is, it lacked social and cultural embeddedness. This is the same view held by one teacher in this study which is naïve. As a human endeavour, science is influenced by the society and culture in which it is practised. Topical issues like HIV and AIDS, global warming and genetic engineering are getting well researched because of their impact on different societies and cultures. Liang et al. (2009:992) sum it up by saying “cultural values and expectations determine what and how science is conducted, interpreted and accepted”.

Intricately linked to the subjectivity of science is the use of imagination and creativity in scientific investigations. Some naïve ideas harboured by the teachers are that if imagination and creativity were to be used in science, then science would lose its worth of being a body of facts. This is a naïve and realist argument put forth by some of the teachers. As a word of caution, Bell, Maeng, Peters and Sterling (2010:11) hint that “scientists do not solely rely on logic and rationality”. As science is a blend of logic and imagination, creativity becomes a major source of inspiration and innovation in science. Similar and consistent findings have been found in other studies (e.g. Abdel-Khalick, 2006, Bartels et al., 2012, Schwartz et al., 2008). Scientists have to think and be creative – like an artist would create an artefact out of wood or stone or a musician compose music or a poet write poetry – when inventing hypothesis or theories to imagine how the world works.

Conclusion

The five teachers' NOSI conceptions on the three NOSI tenets were found to be fluid and lacked coherence. Although all participants expressed some views that were consistent with current acceptable conceptions of NOSI, some held naïve views of crucial NOSI aspects, on all three NOSI aspects investigated in this study. I have attempted to understand and describe teachers' NOSI conceptions. Is it not high time that a systematic and concerted effort to help teachers develop their NOSI conceptions be pursued and systematically evaluated? This may significantly affect teachers' instructional intentions (Clark & Peterson, 1986) which, in turn, affect what occurs in classroom practice (Lederman, 1999). This can be done through science teacher education programmes (pre-service and in-service) by continuing their efforts well beyond the often advocated development of teachers' conceptions of NOSI (Gallagher, 1991). In addition, more professional development activities should focus on teachers' understandings of NOSI so that they develop conceptions consistent with contemporary constructivist views of NOSI. In so doing, the in-service teachers might shift their orientations to teaching NOSI from that of an implicit science process and discovery approach towards an explicit inquiry-based approach.

As this study was based on a relatively small sample, it is recommended that more studies with larger samples be conducted to ascertain the conceptions teachers harbour. While this study has not been conclusive, it is reasonable to suggest that much more research evidence needs to be accumulated, eliciting teachers' conceptions of using more NOSI aspects, before we can confidently state that these teachers harbour naïve NOSI conceptions.

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