



The Views of Nature of Science Expressed by In-Service Teachers Who were Learning History and Philosophy of Science

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Abstract

Science teachers need an adequate understanding of the nature and processes of science as the basis for their pedagogical content knowledge for effective classroom delivery. The aim of the study was to find out in-service teachers' views on the nature of science (NOS) and how their views compared with informed understanding of the NOS. The study adopted an exploratory case study methodology, qualitative in nature, and used convenience sampling. A questionnaire was administered to 50 in-service teachers doing a bachelor of science honours degree at a selected university in Zimbabwe. The students had done a course in history and philosophy of science where there were exposed to some topics on the NOS. Frequency counts and mean scores were used to describe views of the participants. Analysis involved comparing in-service teachers' responses with experts' views. The findings reveal that the students had a naïve understanding of NOS in 5 out of 16 statements from the administered questionnaire. Despite these observations the participants generally had a fair understanding of the NOS as evidenced by the fact that the participants managed to correctly respond to 69% of the questions asked. As such we infer that teaching and learning of nature of science as part of history and philosophy of science had a positive impact on in-service teachers' views. The few instances when participants' responses revealed contradictions, suggest that teaching and learning history and philosophy of science may not be adequate to develop a full understanding of nature of science. Further research is recommended with large samples, using a revised Views Of Nature of Science (VNOS) questionnaire and interviews, and document analysis to reveal how nature of science is taught and learnt.

Keywords: in-service teachers, nature of science, teacher education

1. Introduction

1.1 Nature of science in teacher education

How can we ensure that pre-service and in-service teachers are adequately prepared to use pedagogical practices that help their students develop a functional understanding of nature of science? The obvious answer is teachers need to take nature of science courses. In the 90's calls to include history and philosophy of science courses in teacher education went unheeded. Lately, in-service teachers are required to learn history and philosophy of science as part of teacher

education curriculum. However, teaching and learning of history and philosophy of science employs pedagogical practices inconsistent with teaching methods that make learning of the nature of science explicit. If we consider that teacher educators do not model behaviours and strategies that accurately portray nature of science, it becomes prudent to ask whether pre-service teachers were going to find it easy in planning and implementing teaching strategies that make learning nature of science explicit in their classrooms.

In teacher education students can learn nature of science as a standalone course, or as a component of courses like history and philosophy of science. Teachers' knowledge of nature of science is important for several reasons. Research evidence suggest that perception of and knowledge of nature of science affect pre-service teachers' efforts of making implicit NOS become explicit to secondary pupils who are learning science (Bell, Lederman & Abd-El-Khalick, 2000). Further, some researchers argue that nature of science is a form of subject matter knowledge (Abd-El-Khalick, 2001), such that pre-service teachers' understanding of NOS affect their teaching practices. Matthews (1994) argues that teachers' interest in NOS can assist students' interest in learning science.

1.2 Making explicit the teaching and learning nature of science

An adequate understanding of nature and process of science and curricular flexibility alone are not sufficient to ensure that teachers will use pedagogical techniques that reflect that understanding (Akerson, Abd-El-Khalick & Lederman, 2000). Study by Lederman & Zedler (1987) established that the teachers' understanding of the nature and process of science was unrelated to classroom performance. Teachers need to be explicit about how lessons and activities relate to the nature and process of science for students to improve their understanding in these areas. They need to be prepared with strategies designed specifically for teaching the nature and process of science (Lederman & Zedler, 1987). More research is required to establish in-service teachers' knowledge and views about nature of science, and how this is demonstrated in their planning and teaching during school experience.

Special attention is needed to help students at secondary school learn about the nature and process of science (Kang, Scharmann & Noh, 2004a). Literature reveals that teachers who use explicit and reflective instruction, and who provide students with multiple opportunities to engage with key concepts in different contexts help students to learn the nature and process of science. Researchers have demonstrated the pedagogical importance of making the nature and process of science explicit (e.g. Abell, Martin & George, 2001; Lederman & Lederman, 2004). When teachers fail to make nature of science explicit, their students fail to connect skills and processes of science. Students need help to see the inadequacy of their conceptions (to realise misconceptions) (Akerson, Abd-El-Khalick & Lederman, 2000) as shown in a study where they found out that despite opportunities to reflect and engaging in activities that focused on the nature of science students still held inadequate conceptions to the end of the course.

Other obvious ways of making teaching and learning the nature of science explicit are creating independent topics within a course e.g. learning to be a scientist or how science works, emphasis on the notion of being reflective in science lessons, and teaching and learning science within and existing applied context. There is consensus on need to enhance students' understanding of the nature of science (Scharmann, Smith, James & Jensen, 2005) and curriculum reforms articulate teaching and learning of nature of science (American Association for the Advancement of Science, 1993; National Research Council, 1996). The purpose of this study was to explore the views of nature of science expressed by in-service teachers who were learning history and philosophy of science.

2. Research Questions

- a. What were the views of nature of science expressed by in-service teachers who were learning history and philosophy of science?
- b. How do in-service teachers' views compare with informed views of nature of science?

- c. What were the contradictions inherent in the views of nature of science expressed by in-service teachers who were learning history and philosophy?

3. Aspects of Nature of Science

This study adopts definition of nature of science (NOS) by Lederman (1992), that is, the values and assumptions inherent in the development of scientific knowledge. Nature of science is concerned with issues of philosophy, history, sociology, and psychology of science. To make the teaching and learning nature of science effective Crowther, Lederman & Lederman (2005) suggest that NOS should be treated as an aspect of subject matter knowledge. This calls for curriculum decisions to select key aspects of nature of science to teach and learn. In literature, key aspects of nature of science highlighted vary in number. The butterfly project identifies 5 key aspects of nature of science, namely: scientific knowledge is tentative, nature of scientific knowledge (facts/hypotheses/theories), scientific methods, differences of observations and inferences, and the human nature of scientists

(http://www.teacherlink.org/content/science/class_examples/Bflypages/nos.htm). Crowther *et al.* (2005) argue that for science education communities, the nature of science is defined better by examining its components. They go on to list 4 key aspects; science as a way of knowing, history and philosophy of science, science as a human endeavour, and that science is based on evidence. Crowther *et al.* (2005) draw out other components of nature of science from National Science Teachers Association (NSTA) as scientific methods, creativity, and tentative nature. For purposes of the current study we focussed our attention on 7 aspects of nature of science. These were empiricism, tentativeness, observations and inferences, creativity and imagination, theories and laws, variety of methods, and socio-cultural embeddedness (American Association for the Advancement of Science, 2013; National Research Council, 2012; Next Generation Science Standards, 2013; Lederman, *et al.*, 2002). Teacher educators are reminded that nature of science is difficult to teach (Carpendale, 2012), and special attention is needed to prepare in-service teachers to do so. To ensure that teaching of nature of science does not get lost in regular science instruction Crowther *et al.* (2005) support the idea of providing explicitly instruction on nature of science and go on to make suggestions of activities to highlight nature of science. Studying nature of science provides a deeper understanding of science. Our study assumed that when in-service teachers learnt aspects of nature of science in education courses they could demonstrate informed views of NOS like those expressed by science experts.

4. Methodology

4.1 Sampling

The study adopted an exploratory case study methodology, qualitative in nature, and used convenience sampling to select 50 in-service teachers to complete VNOS questionnaires. The cohort had 145 in-service teachers doing Bachelor of Science Education Honours (HBScEd). Through voluntary participation in-service teachers were invited to complete questionnaire. The in-service teachers were invited to pick a questionnaire as they entered the lecture room and 50 complete questionnaires were returned making up the sample. The students, following a block release mode, had come for lectures during the December-January school holidays. Two school holidays constitute a semester. Subjects of specialisation were physics, chemistry, biology, mathematics, geography, and agriculture. These students had done the course History and Philosophy of Science. About one-third of this course is on NOS. We assumed that the in-service teachers had an adequate background and knowledge of nature of science that could be measured using VNOS questionnaire.

4.2 Issues of validity and reliability

The VNOS questionnaire used in the study was adapted from Form B or VNOS-B (Abd-El-Khalick,

Bell, & Lederman, 1998). The VNOS-B has been used and shown to be valid and reliable to seek views of nature of science. Lederman *et al.* (2002) have also revealed that variations of VNOS-B can be used to discriminate naïve and informed views of nature of science. On this basis, we assumed that our questionnaire, an adapted version of VNOS-B can be used to explore in-service teachers' views of nature of science. We acknowledge the weakness that we did not augment VNOS questionnaire with interviews to probe and clarify participants' views, and in future studies we plan to attend to this limitation.

5. Findings

The study sample comprised 25 males and 25 females, ensuring equal gender representation. The distribution of these participants by subject of specialism was 16 Biology, 12 Chemistry, 3 Physics, and 19 Mathematics. All participants had work experience as secondary teachers. 13 participants had 5 years or less work experience, and 27 participants had been teaching for more than 5 years before joining the teacher education programme.

5.1 The views of nature of science expressed by in-service teachers who were learning history and philosophy of science

The study used VNOS questionnaire based on aspects of nature of science commonly identified as essential standards in secondary science curriculum (American Association for the Advancement of Science, 2013; AAAS, 1993; National Research Council, 1996; NRC, 2012; Next Generation Science Standards, 2013; Lederman, *et al.*, 2002). Participants were asked to state their level of agreement with statements below that describe views of the nature of science. There were assured that there are **no** "right" or "wrong" answers. The study sought their opinion on several issues about science. The available options were 'strongly agree' (valued 1), 'agree' (2), 'not sure' (3), 'disagree' (4), and 'strongly disagree' (valued 5). In data analysis responses were put into two groups; agree ('strongly agree' and 'agree') and disagree ('not sure', 'disagree', and 'strongly disagree'). Frequency counts, expressed as percentages were used to determine views of the majority. Table 1 shows that majority of participants agree with 13 statements and disagree on 3 statements. Further analysis (Table 2) was required to evaluate and compare participants' responses with informed views of nature science.

Table 1: Frequency, mean scores of participants' views of nature of science ($n=50$)

	Views of the nature of science	Agree f (%)	Mean
1	Scientists develop theories that change with new evidence.	44 (88%)	1.68
2	Science explains the world as it "really" is.	27 (54%)	2.54
3	Observations are used to make scientific claims.	42 (84%)	1.94
4	Science and art are similar.	14 (28%)	3.40
5	Scientists use creativity and imagination when they carry out investigations.	32 (64%)	2.60
6	Scientists always use the scientific method to design their experiments.	35 (70%)	2.16
7	Observations support rather than prove theories.	37 (74%)	2.08
8	Different scientists looking at the same investigations and data can reach different conclusions	33 (66%)	2.40
9	Scientific theories change with new ways of looking at old evidence.	37 (74%)	2.12
10	Scientific models are not a copy of reality.	18 (36%)	3.06
11	When a scientific theory has been proved to be 'true' it becomes a scientific law.	40 (80%)	1.86
12	Science is influenced by culture and society.	40 (80%)	2.06
13	Scientists are biased by what they want to believe rather than by what observations they see	15 (30%)	3.20
14	Scientists use a great diversity of methods to establish the limits of science.	36 (66%)	2.28
15	Different cultures and belief systems have an impact the way science is conducted	40 (80%)	2.08
16	Different scientists looking at the same investigations and data always reach the same conclusions.	38 (76%)	3.12

Mean scores were used to establish the views of most participants. A low mean score (less than 2.5) meant participants agreed with the statement, a mean score of 2.5 meant not sure, and a high mean score (greater than 2.5) meant participants disagreed. In Table 1 above mean scores of participants were less than 2.5 in responses to 10 statements (1, 3, 6, 7, 8, 9, 11, 12, 14, 15), and greater than 2.5 in 5 statements (4, 5, 10, 13,16). In statement 2 the mean score was 2.54, that is, participants were almost equally divided between those who agree and those who disagree that “science explains the world as it is’ really’ is’.

The mean scores in Table 1 were used to evaluate participants’ responses and Table 2 suggests that they had naïve understanding of nature of science expressed in 5 statements (2, 6, 10, 11, and 13). These 5 statements were concerned with “science explains the world as it ‘really’ is” (most participants agree, though a small margin of majority); the myth of the scientific method – that scientists always use the scientific method to design their experiments (majority of the participants agree); scientific models are not a copy of reality (disagree); that when a scientific theory has been proved to be ‘true’ it becomes a law (agree); and that scientists are biased by what they want to believe rather than by what observations they see (disagree).

Table 2: Evaluation of participants’ views of nature of science (n = 50)

	Views of the nature of science	Responses	Evaluation of the responses
1	Scientists develop theories that change with new evidence.	Agree	True
2	Science explains the world as it “really” is.	Not sure (Disagree)	False
3	Observations are used to make scientific claims.	Agree	True
4	Science and art are similar.	Agree	True
5	Scientists use creativity and imagination when they carry out investigations.	Agree	True
6	Scientists always use the scientific method to design their experiments.	Agree	False
7	Observations support rather than prove theories.	Agree	True
8	Different scientists looking at the same investigations and data can reach different conclusions.	Agree	True
9	Scientific theories change with new ways of looking at old evidence.	Agree	True
10	Scientific models are not a copy of reality.	Disagree	False
11	When a scientific theory has been proved to be ‘true’ it becomes a scientific law.	Agree	False
12	Science is influenced by culture and society.	Agree	True
13	Scientists are biased by what they want to believe rather than by what observations they see.	Disagree	False
14	Scientists use a great diversity of methods to establish the limits of science.	Agree	True
15	Different cultures and belief systems have an impact the way science is conducted.	Agree	True
16	Different scientists looking at the same investigations and data always reach the same conclusions.	Disagree	True

In Table 2 the last column (column 3) show evaluation of participants’ responses. The decision “true” means an informed view of nature of science, and “false” means a naïve view of nature of science.

In-service teachers who were learning history and philosophy of science displayed informed views of NOS in responding to 11 statements as shown in Table 2 above. As displayed in Table 1, the frequency was 80% for 4 statements, 60–79% for 6 statements, and 50-59% in one statement. This would seem to suggest that learning history and philosophy of science had a positive impact on in-service teachers’ understanding of nature of science. Considering that the study did not report 100% response in a single item, it means that the teaching and learning nature of science does not guarantee that all students will develop an informed view. While participants in our study cannot be identified as science experts at the time of the study, our findings compare favourably with literature that science experts possess a more informed view of nature of science when compared with novices. Lederman *et al* (2002) found out that, a group of experts who had informed views of nature

of science, correctly responded to statements describing 6 NOS aspects (they showed 100% agreement). In the group of experts 89% agree that 'science is a culture within itself'. From the novice group Lederman *et al* (2002) established that the overall average agree response was 33%, indicating that the group had a naïve understanding of nature of science. In our study, there was no statement with 100% agreement and we interpret that in-service teachers were yet to fully develop expertise on nature of science.

5.2 How in-service teachers' views of nature of science compare with informed views of nature of science

The 16 statements on VNOS questionnaire (refer to Table 1) were based on seven tenets of nature of science. These tenets were herein numbered one to seven for convenience. The first tenet is concerned with empiricism, that scientific knowledge is based on observations that are verifiable. This means that accurate observations and evidence are necessary to draw realistic and plausible conclusions. In question 3, most participants agree that "observations are used to make scientific claims". In question 7, most participants agree that "observations support rather than prove theories". In-service teachers in this study showed an informed understanding of nature of science of the tenet concerned with empiricism.

The second tenet of nature of science is that scientific knowledge is tentative, that is, scientific knowledge is open to revision in the light of new evidence. Additional scientific research, new data, and new ways of looking at existing data may produce new information that affects previous conclusions. Both questions 1 and 9 sought participants' views on tentativeness of scientific knowledge. Most participants agree that scientists develop theories that change with new evidence, and that "scientific theories change with new ways of looking at old evidence".

However, participants' responses to questions 2 and 10 appear to contradict their understanding of tentativeness of scientific knowledge. In responding to question 2, most participants (though by a small margin) agree that "science explains the world as it 'really' is". In question 10, most participants disagree that "scientific models are not a copy of reality", implying that they believe that scientific models represent reality. This is a common belief held by novices, contrary to the tentative nature of science. Scientific knowledge is reliable and durable but is never absolute or certain (Lederman, Abd-El-Khalick, Bell and Schwartz, 2002; Popper, 1963).

The third tenet of nature of science is about observations and inferences. Scientific conclusions are based both on verifiable observations (science is empirical) and on inferences. However, observations and inferences are different. An inference is a conclusion based on evidence about events that have already occurred. Observations is what is seen. In-service teachers show an informed view of the role of observations in creating scientific knowledge (see responses to Q.3). Further, participants are consistent when most agree that "observations support rather than prove experiments".

The fourth tenet of nature of science is about creativity and imagination. Scientists rely on creativity and imagination during all stages of their investigations. When responding to question 4, few participants agree that "science and art are similar" and most disagree. In answering question 5, most participants agree that "scientists use creativity and imagination when they carry out investigations". The attributes of creativity and imagination are human endeavours displayed in both science and art. Participants' responses suggest inconsistencies. This means in-service teachers who participated in this study had not fully developed an understanding of nature of science.

The fifth tenet of nature of science is that theories and laws are different kinds of scientific knowledge. Scientific laws are generalizations of observational data that describe patterns and relationships. Scientific theories are systematic sets of concepts that offer explanations for observed patterns in nature. Both theories and laws may change as new data become available.

In question 11, most participants agree that "when scientific theory has been proved to be 'true' it becomes a scientific law". Participants' perceptions are in contradiction with the notion of tentative nature of science knowledge. Theories and laws are different forms of scientific knowledge. Theories can never be proved to be absolute or certain (Popper, 1963).

The sixth tenet is that scientific investigations use a variety of methods. It is a myth that scientists rely on the scientific method only. Investigations can be classified as observational (descriptive) studies (intended to generate hypotheses), or experimental studies (intended to test hypotheses). Experimental studies sometimes follow a sequence of steps known as the scientific method: stating the problem, forming hypothesis, testing hypothesis, recording and analysing data, stating a conclusion. Science requires different abilities and procedures depending on such factors as the field of study and type of investigation.

In question 6, most participants agree that “scientists always use scientific method to design their experiments”. This is a myth. There is no single method. In response to question 14, most participants believe that “scientists use great diversity of methods to establish limits of science”. Responses to question 14 contradict what participants said in question 6.

The seventh tenet is about the socio-cultural embeddedness of scientific knowledge. Science is a human endeavour. Scientists can disagree because scientific knowledge is subjective and culturally influenced. Differences can be traced to the unique background (social, educational etc.) that individual scientists bring to their research. Participants’ responses suggest an informed view of social and cultural-embeddedness of scientific knowledge. For example, most agree that “different scientists reach different conclusions from same investigations” (Q.8), and seem to acknowledge subjectivity nature of scientific knowledge. In question 12, most participants agree that “science is influenced by culture and society”, and the same distribution was noted in response to question 15, that “different culture and belief systems have an impact on the way science is conducted”. It appears participants show an adequate understanding of social and cultural-embeddedness of scientific knowledge. A departure from this trend was that most participants agree that “different scientists looking at the same investigations and data always reach the same conclusions” (Q. 16), as if to suggest that scientific knowledge is culture-free.

In the majority of cases (69%) in-service teachers in our study showed an understanding of the nature of science. Teachers’ knowledge of NOS is important in science pedagogy (Mudavanhu and Zezekwa, 2012).

5.3 The contradictions inherent in the views of nature of science expressed by in-service teachers who were learning history and philosophy of science

In one instance participants agree that scientific knowledge is tentative (see responses to Q.1 and 9), and in other instances they view scientific knowledge as absolute truth (responses to Q.2 and 10). Participants show inconsistencies and contradictions. It appears participants’ understanding of scientific knowledge as reliable and durable seem to imply that such knowledge is absolute truth.

On one hand, in-service teachers believe that scientists always use scientific method to design their experiments (see responses to Q.6), on the other the same in-service teachers believe that scientists use great diversity of methods to establish the limits of science (see responses to Q. 14).

Responses to question 8, 12, and 15 suggest an acceptable understanding of social and cultural embeddedness of scientific knowledge. However, participants’ responses to question 13 contradicts social and cultural-embeddedness of scientific knowledge. In responding to question 13, few participants agree that scientists are biased and most believe that scientists are not biased. Scientific knowledge is theory-laden. Scientists’ theoretical and disciplinary commitments, beliefs, prior knowledge, training, experiences, and expectations influence their work. Science never starts from neutral observations (Popper, 1992).

6. Discussion

6.1 Science and art are similar

Our findings are that majority of participants disagree that science and art are similar. Experts, with an informed view of nature of science, agree that science and art are similar. Literature suggest that this is an ongoing debate, centred on controversy, where there are scientists who believe that

science and art are different and artists who believe that science and art are similar. Often the stereotypical differences are centred on that science is viewed as data-driven and dominated by technical introverts, and that art is driven by emotion and dominated by expressive eccentrics (Maeda, 2013). There is the argument that similarities far outweigh differences, that both ask questions and search deeply for answers (Maeda, 2013). Others view science as a process of investigation, discovery, reasoning, and conclusion. Similarly, designing a building (art), goes through a similar process (Winston, 2016).

6.2 *Scientific knowledge is reliable and durable versus scientific knowledge is tentative*

We found out that majority of participants (though a small margin) believe that science explains the world as it really is. In-service teachers, in our study, would seem to believe that science knowledge is absolute truth. This finding contradicts the informed view that scientific knowledge is tentative, and subject to change. In-service teachers may be misconstruing the notion of “reliable and durable” with the idea of absolute truth. Further, textbooks often used in schools tend to portray the same misconception. We found out that few in-service teachers believe that scientific models are **not** a copy of reality, inversely most believe that they are. In-service teachers demonstrate a naive view that scientific knowledge is absolute truth and explains the world as it really is. Models can only be a representation, though approximation, of reality not reality itself. Even though knowledge transfer from the model to reality is often problematic models are of central importance in many scientific contexts (Frig & Hartman, 2017). It is a myth to believe that science ideas are absolute and unchanging.

We established that majority of in-service demonstrate an informed view of the tentative nature of scientific knowledge. They agree that scientists develop theories that change with new evidence and new ways of looking at old evidence. When asked to express their views of theories, in-service teachers agree that these change with time. Why do in-service teachers think that scientific explanations and models are absolute truth, and at the same time believe that theories, though reliable and durable, can change with new evidence? Further probing using interviews is needed in future to establish whether in-service teachers demonstrate an informed view of the differences and similarities of scientific knowledge such as explanations, laws, theories, and models as forms of knowledge of science.

6.3 *The myth of the scientific method*

In our study, in-service teachers on one hand believe that scientists always use the scientific method, and on the other believe that scientists use a great variety of methods. How can it be that the same in-service teachers who believe in the myth of the scientific method, that scientists always use scientific method to design their experiments, also believe that scientists use great diversity of methods to establish the limits of science? Assuming the in-service were clear about the wording in both statements, their responses show inconsistencies. Otherwise, in further studies, interviews are needed to probe responses like these.

Our findings contradict the informed view that the scientific method is a myth. As exemplified by Copernicus, Sir Isaac Newton and Charles Darwin who did not use the scientific method, scientists are thought to approach their work with a combination of imagination, creativity, prior knowledge, library research, perseverance, and sheer luck (Rampton & Stauber, 2001). There is no single method of science. The scientific method/experiment is just one of many different methods used in science like basic observation, and historical exploration (Science Learning Hub, 2011a).

6.4 *Social and cultural embeddedness of scientific knowledge*

In our study in-services responses to 3 items of 4 revealed an informed view of social and cultural embeddedness of scientific knowledge. In-service teachers believe that different scientists reach different conclusions from same investigations, that science is influenced by culture and society, and that different cultures and belief systems have an impact on the way science is conducted.

Lederman *et al* (2002) reported similar findings with their group of experts. However, in our study we found out that few in-service teachers believe that “scientists are biased by what they want to believe rather than what they want to see”. Most do not believe in subjective nature of science. In-service teachers’ responses to items 8, 12, and 15, consistent with experts informed views of NOS, contradicts responses to subjectivity inherent in item 13. We need to acknowledge a lack of objectivity, that scientific interpretations can be biased because science is a human endeavour and scientific observations are preceded by theory. The science community or peer reviews are used to scrutinize scientific work and this helps to balance individual scientists’ leanings (Science Learning Hub, 2011b). Peer reviewed journals give peers opportunity to refute some claims, and the authors of the refuted publication the opportunity to respond, then both the refutation and the response are rigorously peer reviewed (Editorial, 2001).

7. Conclusions

Overall in-service teachers who were learning history and philosophy of science displayed informed views in most aspects of nature of science. Nuances were evident because no item recorded a 100% agree or disagree response. When compared to experts and novices’ views of nature of science in-service teachers in our study express views leaning toward informed views. As such we infer that teaching and learning of nature of science as part of history and philosophy of science had a positive impact on in-service teachers’ views. Despite in-service teachers revealing informed views of nature of science, there were instances when their responses revealed contradictions. Our findings seem to suggest that teaching and learning history and philosophy of science may not be adequate to develop a full understanding of nature of science. Further research is recommended with large samples, using a revised VNOS questionnaire and interviews, and document analysis to reveal how nature of science is taught and learnt.

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