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Exploring science teachers' views about the nature of science and the implications on their pedagogical content knowledge: A case of 11 in-service South African teachers

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Abstract
This study explored science teachers' views of the nature of science (NOS) and the implications on their pedagogical content knowledge (PCK). The study follows a qualitative approach and uses a single case study design that followed 11 science teachers. The study uses PCK for science teaching as a framework, where the participants were requested to complete the views of NOS questionnaire (VNOS-D+) and each was observed two times in their science classrooms. Furthermore, the study highlights the importance of teachers' PCK in teaching science. The study found that the majority of the participants reflected informed views of NOS. Although the majority of the teachers had a good understanding of the goals and objectives of science education and their solid content knowledge. They had poor knowledge of learners' understanding of science, choice of instructional strategies, and choice of assessment techniques for scientific literacy.

Keywords: nature of science, pedagogical content knowledge for science teaching, pedagogical content knowledge, science teachers

INTRODUCTION

In the past two decades or more researchers sought to explore science teachers' views about the nature of science (NOS) (see Haidar, 1999; Lederman, 1999; Nott & Wellington, 1996). It was initially assumed that science teachers' informed views of NOS suggested good classroom practice, however, later studies revealed a more complex relationship of science teachers' views of NOS as opposed to their classroom pedagogy (see Lederman, 1999; Zeidler et al., 2002). Hence, researchers endeavored into science teachers' views about NOS and how the views impact their classroom pedagogy (see Dekker & Mnisi, 2003; Lederman, 1999; Waters-Adams; 2006). The same researchers and the other majority found that most science teachers reflected uninformed views of NOS and that their views had no influence on their classroom practice (Aslan & Tasar, 2013; Bartos & Lederman, 2014; Mellado et al., 2008; Sarieddine & BouJaouda, 2014). Later on, a handful number of researchers ventured into the studies that focused on the appropriate pedagogical content knowledge (PCK) for teaching NOS (see Demirdogen, 2016; Hanuscin, 2013; Hanuscin et al., 2011). The South African curriculum and assessment policy statements (CAPS) for science advocate for the integration, learners' understanding of NOS and its relationship to society (see Department of Basic Education [DBE], 2011a). However, there is a gap in research on science teachers' views concerning NOS and the implications for their pedagogy through PCK for science teaching.

Several scholars have described NOS like Bell (2009) and Kaya (2012), as a multi-facet idea comprised of history, sociology and the philosophy of science. NOS advocates for the development of scientific literacy and seeks to investigate how scientists work as a community and how society inspires and responds to scientific undertakings (see Bell, 2009; Kaya, 2012; Lederman, 1999). In this study we agree with Lederman (2007); Ayala-Villamil and Garci-Martinez's (2021) assertion of NOS comprising tenets such as tentative, observations and inferences, scientific theories and laws, creativity and imagination, subjectivity, social and cultural integration and the empirical NOS.

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Contribution to the literature

- The use of PCK for science teaching as a framework in this study contributed to exposing some South African science teachers' level of PCK.
- The findings of this study contributed to the body of knowledge by exposing the disconnection between some South African science teachers' informed views of the NOS and their PCK.
- The study's literature review reflects the lack of South African-based studies on how science teachers' views of the nature of science influence their PCK.

Shulman (1986) defined PCK as the teacher's ability to associate content knowledge with relevant and suitable teaching methods. Magnusson et al. (1999) introduced PCK for science teaching model, where they viewed a component 'orientation to science teaching' as an all-embracing component of PCK, suggesting that it shapes the other components without explicitly describing what shape means. Furthermore, according to Demirdogen et al. (2016), science teacher educators largely make use of Magnusson et al.'s (1999) PCK for science teaching model to examine science teachers' PCK in various science areas (see Alonzo & Kim, 2015; Chen & Wei, 2015; Mthethwa-Kunene et al., 2015). Hence, in this study, we view PCK through Magnusson et al.'s (1999) model of PCK for science teaching, which will be deliberated later on.

Literature has proven with empirical evidence that there is a great relationship between what the science teachers know and how they teach, such teachers' knowledge base should be inclusive of science learners' preconceived ideas that can be used as the teachers' starting point (Brown et al., 2013; Kunene, 2014; Treagust & Duit, 2008). Furthermore, it is also suggested that a productive teacher ought to possess other two forms of knowledge; the knowledge that looks into a subject matter, which is usually acquired at tertiary institutions; pedagogical knowledge, which focuses on teaching methods the teacher uses and how teachers run their classroom (Kunene, 2014). Lastly, the ability to use these teaching methods with precision and panache. Meaning that the subject matter expertise and the teacher's teacher repertoire are crucial in this endeavor to allow learners to be more hands-on in the classroom (Chanetsa, 2016). As such, learner understanding of NOS requires a science teacher's informed views of NOS that influence the teacher's PCK for effective teacher classroom repertoire, where the science teacher goes outside the borders of merely teaching science as a frame of knowledge (Bell, 2009). This is because science teaching is expected to rather reflect tenets such as creativity, tentativeness, creativity and imagination etc. to complement this body of knowledge to widen scientific literacy (Ramnarain & Padayachee, 2015). Therefore, the understanding of NOS is viewed as an essential and significant element of the science course of study in growing a scientifically literate society (Hacieminoglu, 2014).

In addition, several studies have revealed that at times the development of proper PCK for the integration of NOS can be achieved over pedagogical experience (Lederman, 2007). As such, for science teachers to comprehend NOS and grow a relevant PCK for science teaching, researchers need to utilize PCK perspective as a lens for studies on integrating NOS in science classrooms (Lederman, 2007). Furthermore, Akerson et al. (2017) suggested that for teachers to integrate NOS need to develop an environment that reflects the standard and practice of science. There also seems to be a consensus amongst researchers that to develop learners' scientific literacy, NOS needs to be embraced in the teaching of science (Allchin, 2014). In particular, research indicates that it is the teacher's duty, through varied pedagogical approaches, to help learners understand NOS (Hanuscin et al., 2011). On one end teachers are supposedly trained individuals that should be able to stimulate the learners' curiosity in a science classroom through methods that influence learners' enthusiasm and interest to learn science (Higgins & Moeed, 2017). On the other end, what they do in the classrooms seems to be influenced by their views (Akerson et al., 2000). As such, we are assuming that teachers' PCK is influenced by their views of NOS. Previous researchers have looked at science teachers' views of NOS highlighting teachers' informed and unformed views (Sarkar & Gomes, 2010; Webb, 2007). Other studies have explored how science: chemistry (see Chen & Wei, 2015); physics (see Alonzo & Kim, 2015); life sciences (see Mthethwa-Kunene et al., 2015) teachers' pedagogical practices reveal their views of NOS (see Alabdulkareem, 2016; Waters-Adams, 2006). However, there is a paucity of studies on science (physical and life sciences) teachers' views on NOS and the implications on their PCK through PCK for science teaching as the lens, especially in South Africa.

This study aims to contribute to this literature gap by exploring 11 science teachers' views about NOS and the implications on their PCK. The following research question guided this study:

1. What are the science teachers' views about NOS and implications on their PCK?

LITERATURE REVIEW

Science Teachers' Views on Nature of Science

The past decade has reflected limited studies on science teachers' views on NOS. However, more than a decade ago both the international and South African literature, reported diverse findings concerning teachers' views about NOS that reflected science teachers' naïve views. Internationally, Sarkar and Gomes (2010) investigated Bangladeshi science teachers' views about NOS and determined that few of the participating teachers had educated views about NOS. The authors concluded that this could be because "Bangladeshi science teachers rarely have the chance to acquire knowledge about the current NOS in their studies" (Sarkar & Gomes, 2010, p. 14). A study conducted by Aslan and Tasar (2013) investigated how Turkish science teachers view and teach NOS revealed similar findings to a study undertaken in Bangladesh, where only a few teachers held informed views. Furthermore, the study revealed that teachers' views did not influence their classroom practices. In the South African context, a study by Linneman et al. (2003), on South African grade 4 to 9 sciences teachers' views of NOS discovered that most teachers reflected naïve views about NOS. Some studies further discovered that South African science teachers have more tolerable dogmas about NOS as well as other levels of scientific concepts, particularly in Limpopo Province, where even the learners have moderate acceptance of scientific concepts (McCall, 2008; Mpeta et al., 2014). However, a similar study through numerous teacher professional development programs using an internationally recognized and validated instrument mirrored the whole opposite in the very province because teachers reflected views on common traditions such as hypotheses developing into theories and then into scientific laws (Dekkers & Mnisi, 2003). Although the studies have been conducted in different countries, the findings suggest that science teachers have common views about NOS.

Whether science teachers' views about NOS influence their classroom practice is dependent on the teacher, this is drawn from contradictory claims presented by Lederman (1999); Ndeke and Keraro (2017); and Ndeke et al. (2015). According to Lederman (1999), teachers' views on NOS have little impact on their classroom practice. However, Ndeke and Keraro (2017) discovered that science teachers' views of NOS were erroneous and suggested that NOS-centered philosophy of science courses be included in teacher education. They posited that "this would help teachers gain a better grasp of NOS and affect their teaching methods, as well as boost secondary science learning". Moreover, Ndeke et al. (2015) discovered that the majority of secondary school life sciences teachers had valid opinions on general creativity in their examination of secondary school life sciences teachers' perspectives on scientific creativity. Yet only a tiny percentage of the teachers were found to have accurate views of scientific innovation. Additionally, the authors recommended that policymakers, curriculum creators, and science teacher education programs emphasize scientific innovation in their courses. They contended that empowering teachers to give learning opportunities that would boost learners' creativity in science would be beneficial (Ndeke et al., 2015). As a result of their findings, it is reasonable to conclude that the authors feel that the teachers' perspectives on specific NOS tenets have a significant impact on how they portray their classroom pedagogy. It is in this regard that we are of the view that the influence of science teachers' views of NOS on their classroom practice is dependent on the type of science teacher.

Research has shown that for science learners to have an effective meaningful comprehension of NOS, science teachers must reflect educated views about NOS and a relevant PCK for integrating it in their science classrooms (Akerson et al., 2017; Lederman, 2007). According to Abd-El-Khalick et al. (1998), NOS may be seen as a fragment of the syntactic subject matter knowledge, which science teachers require to integrate into their science classroom and as such, they have to establish a proper PCK for the integration and teaching. A research study by Demirdogen et al. (2015) on the development of chemistry teachers' PCK for NOS through an intervention found that the teachers' views improved and also influenced their PCK. Furthermore, the researchers revealed four themes that emerged and among the themes was that science teachers needed some comfort in understanding NOS to have an appropriate PCK to teach or integrate NOS (see Demirdogen et al., 2015). A study by Mesci et al. (2020) on enabling factors of science teachers' PCK for NOS revealed that during the program, the two science teachers improved their comprehension of NOS and were able to successfully enact their PCK for teaching and integrating NOS. Furthermore, the study revealed that the "teachers utilized their knowledge of the subject matter, teaching strategies, assessment and curriculum regarding teaching NOS to involve learners in predicting and backing claims with evidence"(p. 263). With such findings, it can be concluded that these teachers were able to account for the domains enshrined in the orientation to science teaching as proposed by Magnusson et al. (1999). However, other similar research studies have provided opposite findings, where science teachers were met with challenges as they try to integrate and teach NOS (Wahbeh & Abd-El-Khalick, 2014). The researchers found that after the intervention, the teachers struggled to translate the NOS conceptions into practice, where the content, context and experience suggested that the teachers had limited abilities with regards to transferring their understanding of NOS into practice (see Wahbeh & Abd-El-Khalick, 2014). Lastly,

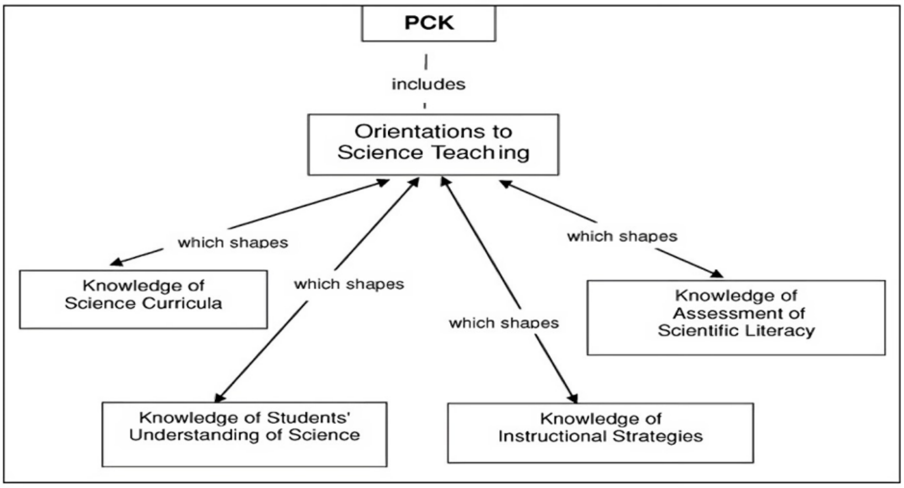

Figure 1. PCK for science teaching (Magnusson et al., 1999, p. 99)

the study by Supprakob et al. (2016) on using the lens of PCK for teaching NOS revealed that the participants had limited PCK for teaching and integrating NOS in terms of all the tenets. The study discovered that the science teachers' content knowledge was strong, but during teaching, they rarely integrated or taught NOS (Supprakob et al., 2016).

THEORETICAL FRAMEWORK

This study is underpinned by PCK for science teaching model (Magnusson et al., 1999) drawn from Shulman's (1986) PCK (**Figure 1**). The two other models namely, the model of teacher knowledge (Grossman, 1990) and the tailored model for PCK (Rollnick et al., 2008) were considered for the framework for this study. However, the two models could be used for any other subjects such as mathematics, while PCK for science teaching is a model specifically designed for science (Magnusson et al., 1999; Roy & Bairagya, 2019), hence, the model relevance for this study.

The model recognizes that the teacher's orientation to science teaching, knowledge of science curricula, knowledge of assessment of scientific literacy, knowledge of learners' understanding of science, and knowledge of instructional strategies all have a significant impact on the teacher's PCK (Magnusson et al, 1999). PCK is made up of the approach to teaching science, which is essential to PCK since it serves as the framework through which all of its components are seen, understood, and infused (Magnusson et al., 1999). Furthermore, Cochran et al. (1993) and Shulman (1986) posited that teachers are different from biologists certainly not in the quality or quantity of their subject area knowledge, but in what way that knowledge is prearranged and utilized. The authors went on to say that science teachers' scientific knowledge is organized from a pedagogical perspective and is utilized to aid learners in understanding science (Cochran et al., 1993). We shall employ PCK for science teaching to try and ascertain if the teachers' views of NOS have any implications on their PCK.

Magnusson et al.'s (1999) PCK for science teaching model possess similarity to the model Grossman's (1990) model with an addition of two components to make five components. The five components include

1. orientations toward science teaching,
2. knowledge and beliefs about science curriculum,
3. knowledge and beliefs about assessment in science,
4. knowledge and beliefs about students' understanding of specific science topics, and
5. knowledge and beliefs about instructional strategies for teaching science,

which are specific to science.

Orientation to Science Teaching

This represents the knowledge and views that teachers have about the aims and the goals for teaching science at a particular grade level (Magnusson et al., 1999). NOS has to be integrated into the teaching process, according to CAPS statement, and the science teachers' knowledge and views are crucial to how they conduct themselves in the classroom (DBE, 2011b). To address this component the teachers should be able to integrate NOS by reflecting their knowledge of goals and objectives enshrined in science curriculum and by using the appropriate teaching method. Furthermore, the teachers' ability to use the appropriate assessment methods and tasks that allow them to infuse the tenets of NOS as proposed by Lederman (1999).

Knowledge of Science Curricula

Science teachers must have a thorough comprehension of the "goals and objectives" for learners' learning as well as "the latitude and the arrangement of the scientific concepts to be taught" to teach science (Lankford, 2010, p. 20). Teachers needed to be familiar with the science curricula. Although CAPS document does not specify how these teachers should teach and integrate NOS in their classrooms, it indicates the need for teachers to be innovative in their teaching of science (DBE, 2011b). The science teachers' knowledge of curriculum is constituted of two categories:

1. the specified aims and objectives, and
2. specific curricular programs, resources, and materials (Lankford, 2010; Magnusson et al., 1999).

To address this component, the participating teachers should be able to prepare their teaching aids, resources and materials in such a way that they would successfully integrate NOS by infusing the tenets proposed by Ayala-Villamil and Garcia-Martinez (2021) and Lederman (2007) in their teaching.

Knowledge of Learners' Understanding of Science

Aspects of knowledge of learners' comprehension of science include teacher knowledge of the prerequisites for learner learning of specific concepts and potential learning challenges a learner may encounter when learning the concepts (Lankford, 2010). This component is mainly concerned with the science teachers' 'teacher repertory,' or the tools, tactics, and models that the teachers employed in their classes to anticipate and address the learners' learning issues. In the context of this study, we should be able to see these teachers being able to decipher learners' preconceived views and draw them out in an attempt to guide the learners in learning meaningfully and understanding NOS as they infuse the tenets of NOS as they teach.

Knowledge of Instructional Strategies

Understanding instructional techniques refers to numerous teaching tactics that are fundamental in scientific disciplines such as life sciences and are included in this component of PCK (Magnusson et al., 1999). This includes topic-specific approaches and various forms used to display concepts such as models, diagrams, and graphs, to mention a few, as well as to train learners utilizing instructional methods such as investigations and experiments, among others (Lackford, 2010; Magnusson et al., 1999). This meant that science teachers needed to be equipped with the ability to apply numerous teaching methods as well as the knowledge to determine which teaching method would be appropriate for a given science topic in the classroom. In the context of this study, we should not only be able to see the abovementioned, but we must be able to see the teacher using the correct teaching method that will be best suited for efficiently teaching and integrating NOS, where learners learn meaningfully.

Knowledge of Assessment

Understanding of the aspects of scientific learning relevant to assessment and knowledge of assessment techniques and methods through which learners' learning may be measured are the two concepts put forth by PCK's knowledge of the assessment component (Lackford, 2010; Magnusson et al., 1999). These types of progressive assessments include a variety of summative, formative, and informal examinations that are used to gauge learners' grasp of scientific topics (Lackford, 2010). In the context of this study, this implies that science teachers must be knowledgeable about the curriculum, subject matter, and applicable teaching methods, but they must also know what to assess and how to assess.

METHODOLOGY

In this study, we utilized a qualitative research approach (Bhandari, 2020) allowing us for an in-depth analysis of the teachers' views of NOS and their classroom practices. We adopted an exploratory single case study design (Yin, 1984). This study used a purposive sampling, where 11 science teachers were selected. Purposive sampling is a sampling technique by which a deliberate choice of a participant is made due to the qualities the participant possesses (Etikan et al., 2016). Hence, the teachers were sampled on the basis that they were either teaching life or physical science and were stationed within the Dimamo Circuit, Limpopo Province, South Africa and they were willing to participate in the study.

According to McMillan and Schumacher (2010, p. 179), validity infers appropriate interpretation and use of data collected and it is essential to critique the degree of validity that is present based on available evidence. This can be achieved through triangulation, which is defined as the "use of multiple data sources" (Frambach et al., 2013, p. 552). In the context of this study, data triangulation was achieved by collecting data using multiple instruments such as open-ended questionnaires and classroom observations.

McMillan and Schumacher (2010, p. 117), suggested that research ethics are concentrated on what is ethically appropriate and inappropriate when engaged with participants or when accessing archival data. In the context of this study ethical certificate was obtained from the relevant body and permission to conduct the study at the circuit was granted by DBE. The teachers were invited to participate in the study and were requested to complete informed consents, hence, **Table 1** shows the biographic data of the science teachers who participated in the study.

Table 1. Biographic data of the teachers who participated in the study

Teachers	Age	Gender	Highest qualifications	Grade teaching	Subject teaching	Teaching experience
T001	50s	M	BEd honors	11	Physical science	30 years
T002	50s	M	BEd	12	Life sciences	28 years
T003	40s	M	BEd	11 to 12	Physical science	15 years
T004	40s	M	BEd honors	11 to 12	Physical science	24 years
T005	40s	M	Did not indicate	11 to 12	Life sciences	22 years
T006	40s	M	BEd	10 to 12	Physical science	16 years
T007	50s	M	BEd honors	10 to 12	Life science	28 years
T008	40s	M	BEd honors	10 to 12	Physical science	10 years
T009	20s	F	BEd	10 to 11	Physical science	6 years
T010	50s	F	BEd	12	Life sciences	27 years
T011	50s	F	BEd honors	12	Life sciences	27 years

Data Collection

To address the research questions, data were collected in two forms: open-ended questionnaires and classroom observations.

Open-ended questionnaire

To address the first research question, 11 participants completed a version of views of nature of science questionnaire D+ (VNOS-D+) initially developed by Lederman et al. (2001) as VNOS A and improved to VNOS-D+ by Lederman and Lederman (2010). The instrument was used to gain the teachers' views about NOS; hence, the questionnaire used was open-ended. The questionnaire consisted of 10 main open-ended questions covering the seven tenets of NOS. The instrument was validated with a group of 10 secondary science teachers and their learners and the instrument was found to have questions that are more explicit than any other VNOS (Ayala-Villamil & Garcia-Martinez, 2021; Lederman & Lederman, 2010; Lederman et al., 2014)

Classroom observations

To address the second research question, 11 teachers were observed teaching in their respective classrooms. Two observations were done for each teacher to determine if their views of NOS had any bearing on their PCK using an observation schedule

Data Analysis

The data collected from the VNOS-D+ open-ended questionnaire were coded using a deductive coding approach. The views we given codes and scores in the following order: uniformed views=UV, which awarded a score of zero; partially-informed views=PIV, which awarded a score of one; and informed views=IV, which awarded a score of two (Cronje, 2015). The rubric used for coding and scoring the teachers' responses from the aforementioned open-ended questionnaire was drawn from Cronje's (2015, p. 134-138) PhD thesis, which accommodated all the tenets as proposed by Lederman (1999). The deliberation of scores and percentages per code is provided after **Table 1**, followed by the deliberations of the teachers' outstanding responses from the questionnaire to help make meaning. The rubric was validated through an intervention study that focused on science teachers from different provinces in South Africa (Cronje, 2015).

The data gathered from the classroom observations of 11 teachers were presented by holistically describing the major takeaways of what transpired in the majority of the teachers' classrooms and determining if their views about NOS had any bearing on their PCK. The five components of PCK for science teaching were used as the lens through which the classroom observations were analyzed (Magnusson et al., 1999). These components are 'orientation to science teaching, knowledge of science curricula, knowledge of learners' understanding of science, knowledge of instructional strategies, and knowledge of assessment'.

FINDINGS AND DISCUSSIONS

In this section, we present data drawn from the instruments previously deliberated upon. We started with the data gathered from the VNOS-D+, followed by data gathered during the classroom observations.

Data Gathered from VNOS-D+

This section presents the coded responses of the views of NOS or VNOS-D+ gathered from 11 science teachers who participated in this study with keys to help make sense of **Table 2** presented.

Table 2 highlights that 10 out of the possible 11 teachers' responses suggested that they hold informed views, which account for 90.9% of the teachers. On the other hand, teacher 004's response to the questionnaire reflects that his views are uninformed, and he accounts for 9.1% of the teachers. Out of the possible 120 responses reflecting informed views, the teachers managed to accumulate 81 responses reflecting informed views, which account for 67.5% of the responses. Furthermore, out of the possible 120 responses reflecting the teachers managed to accumulate 22 responses reflecting uninformed views, which

Table 2. Summary of coded VNOS-D+ responses of participants from the Dimamo Circuit

Teacher	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Overall score
001	IV	PIV	IV	IV	IV	UV	IV	IV	IV	UV	1.5
002	IV	IV	IV	IV	IV	IV	IV	IV	UV	UV	1.6
003	IV	PIV	IV	UV	IV	IV	IV	IV	IV	IV	1.7
004	IV	UV	UV	UV	PIV	IV	UV	IV	UV	IV	0.9
005	IV	IV	IV	IV	IV	IV	UV	IV	PIV	IV	1.7
006	IV	IV	UV	IV	IV	UV	IV	IV	IV	UV	1.4
007	IV	PIV	IV	IV	IV	IV	IV	IV	IV	PIV	1.8
008	IV	IV	IV	IV	IV	IV	UV	IV	IV	UV	1.6
009	IV	IV	UV	IV	UV	IV	UV	IV	IV	IV	1.4
010	IV	IV	IV	IV	PIV	IV	UV	IV	IV	IV	1.7
011	UV	IV	IV	IV	IV	UV	IV	IV	IV	IV	1.6
Total UV	1	1	3	2	1	3	5	0	2	4	22
Total PIV	0	3	0	0	2	0	0	0	1	1	7
Total IV	10	7	8	9	8	8	6	11	8	6	81

Note. Q: Question; UV: Uninformed views (0); PIV: Partially-informed views(1); & IV: Informed views (2)

accounts for 20% of the responses and seven responses reflecting partially-informed views, which account for 12.5% of the responses. Lastly, generally, the majority of the teachers reflected informed views about NOS.

In the section below, we make deliberations on some of the outstanding responses provided by the teachers in answering some of the questions. These responses either reflected uninformed views or partially-informed views or informed views from the teachers. We will first begin by deliberating on responses that reflected unformed views, secondly, we will make deliberations on the responses, where they reflected partially-informed views and conclude our deliberations with informed views.

Some Outstanding Responses That Reflected Uninformed Views

We will start with question number 3 of the questionnaire, which reflects the tentative NOS, and the three teachers did not agree with the notion that science is subject to change. One of the participating teachers responded to the question by stating that "*no, the knowledge will not change since it is tested and proven e.g., the principle of gravitation that explain the motion of falling bodies on the surface of the earth*". Some misconceptions can be deduced from the teacher's response. Firstly, the misconception appears from the teacher's suggestion that when knowledge is tested and proven cannot change in light of new knowledge, secondly, the misconception emanated from the teacher's suggestion that the principle of gravitation will not change. An example contrary to the teacher's position, Pluto was originally recognized as a planet, conversely, in 2006, the International Astronomical Union stripped it of its planetary status (Carmen, 2006). Johnson (2006, p. 1) posited that "the reclassification of Pluto is an example of how researchers challenge each other and correct mistakes because science is an honest human endeavor". Carmen (2006) warned that the union argued that other dwarf celestial bodies, including Pluto, might qualify for planetary status if Pluto were to remain a planet. Assumptions based on observations made by scientists will occasionally need to be rectified or updated due to new technological breakthroughs.

Another outstanding response emanated from question number 7, which focused on the creativity and imagination NOS. In this case, the five teachers posited that scientists do not use creativity and imagination. One of the teachers responded to the question by stating that "*scientists do not use their creativity and imagination, because they follow the scientific skills in conducting the investigations and experiments*". Contrary to the teacher's response "scientists do not produce scientific knowledge using a single universal scientific technique" (Bell, 2009, p. 3). While many science teachers force learners to follow the published guidelines to conduct these experiments, this reflects inconsistent behavior during laboratory activities. According to McCommas (1998), scientists' creativity aids them in their quest to find scientific laws and develop scientific ideas. In addition, McCommas contended that reviews would frequently arrive at the same results if there were a uniform scientific methodology. Yet, as scientists use a range of creativity and imagination with a personal touch, it is not true, and it is not certain that it will occur (McCommas, 1998).

The last outstanding responses emanated from question 10 of the questionnaire, which focused on indigenous knowledge as science and the three teachers' responses suggested that indigenous knowledge is not science. In response to the question, one of the teachers stated that "*indigenous knowledge cannot be verified by scientific criteria, nor can science be adequately assessed according to the tenets of indigenous knowledge. Each is built on distinctive philosophies, methodologies and criteria*". Contrary to the teacher's claim Cronje et al. (2015), in their paper focusing on the development and use of an instrument to investigate science teachers' views on indigenous knowledge, presented a juxtaposition of tenets for both knowledge systems. The presentation of such juxtaposition reflected that NOS and nature of indigenous knowledge (NOIK) share the majority of their tenets except that NOIK is holistic and metaphysical in nature, tenets that are not there in NOS. Scholars such as Steenkamp et al. (2019) and Zinyeka et al. (2016) argue that NOS and NOIK have some shared tenets, while Ogunniyi (2010) posited that indigenous knowledge has been there even before colonialism and the natives have survived through it centuries. As such it can be viewed as a science. Lastly, Merriam-Webster dictionary provides a synonym of science as 'scientia', which is a Latin word for 'knowledge', meaning indigenous knowledge can be viewed as an indigenous science or a local science.

Some Outstanding Responses That Reflected Partially-Informed Views

In this section we will make deliberations based on responses reflecting partially-informed views drawn from one question of the questionnaire namely, question 2, where as many as three teachers' responses reflected partially-informed views.

Of 11 teachers who responded to the question only three were able to reflect partially-informed views on the question that sought to determine what distinguished science from other subjects and the teacher stated that *"scientific discipline is different from other subjects in that it deals with facts, which are proven while other subjects deal with philosophy and theory"*. The teacher's response does acknowledge that science is factual and seeks to prove certain phenomena. However, the participant appears to suggest that science does not give attention to theory and does not have a philosophical aspect. As such, the response by the participants reflected views that are partially-informed (McComas, 1998).

Some Outstanding Responses That Reflected Informed Views

In this section we will make deliberations based on responses reflecting informed views drawn from two questions of the questionnaire namely, question 4 and question 8, where as many as nine and 11 teachers' responses reflected informed views respectively. We will begin with responses from question 4 and finish with question 8.

Of the 11 teachers who responded to the question, nine were able to reflect informed views. In response to the question, one teacher responded by stating that scientists know that dinosaurs existed *"through the study of fossils and they constructed the structures from remains they found in rocks and through the compilation of literature from different sources helped determine and agree that 65 million years ago dinosaurs got extinct"*. Such response seemed to be in line with Yoon et al. (2014) assertion that "scientists made observations of evidence (bone fossils) and inferred that dinosaurs existed, and they have different interpretations of facts, because of their background knowledge and experiences" (p. 2676-2677).

Secondly, all 11 teachers' responses from question 8 were able to reflect informed views. The question was more interested in traditional medicine versus Western medicine and how the two knowledge systems generate the knowledge of such medicines. In response to the question, one teacher stated that *"knowledge of traditional medicine was handed down through generations ... scientists detect and treat a large number of different types of the medical condition and the traditional doctors and scientists both use observations as a guide"*. Via traditional rites, oral transmission, and in some cases written transmission, indigenous knowledge is passed down from one generation to the next. It continues to be a cornerstone of modern food preservation, environmental protection, and health care, to name a few (Senanayake, 2006). According to the literature, IK is still very much relevant and valid today and aids in the discussion of issues like diseases, poverty, and hunger that are promoted by sustainable development (Cronje et al., 2015; Odora Hoppers, 2004). In addition, it is distinguished by addressing issues that include all local cultural practices (Snively & Corsiglia, 2001). Gorelick (2014) asserts that individuals will only be able to comprehend that Western science and IK merely represent distinct historical perspectives, investigate various phenomena, and occasionally utilize different data.

Overall Comments from 11 Teachers' Responses to VNOS-D+

The emerging trends from the teachers' responses reflect that the majority of the teachers have informed views about NOS, something that is different from studies conducted in the same province more than a decade ago (see Dekker & Mnisi, 2003; Mpeta et al., 2014). The average overall score from the teachers' responses is 2.5 out of the possible three. Furthermore, some of the misconceptions reflected by the teachers, particularly regarding the tentative NOS and the creativity and imagination in science, a trend that was reported more than two decades ago (see McComas, 1998). Where he highlighted that most teachers still see science as having one universal method that needs to be followed, thus eliminating creativity and imagination.

Presenting & Analyzing Data Drawn from Classroom Observations

We have carried out classroom observations on 11 science teachers, and each teacher was observed twice and PCK for science teaching was used as a benchmark to determine if their views of NOS had any bearing on their PCK. Hence, **Table 3** represents the topics, which the teachers taught in their classrooms, the grades, which they taught, and the duration of each period lasted for sixty minutes.

Table 3. Topics & grades taught by the science teachers

Teachers	Topic taught	Grade
T001	Electric circuits	11
T002	Genetics	12
T003	Electrostatics	11
T004	Newton's laws & applications of Newton's laws	11
T005	Photosynthesis	11
T006	Atomic structures	10
T007	Biosphere & ecosystem	10
T008	Atomic structures	10
T009	Electric circuits	10
T010	Darwinism & natural selection	12
T011	Nervous system	12

Table 3 reflects the grades and topics the teachers taught. Out of 11 teachers, six taught physical sciences, while five teachers taught life sciences. Out of 11 teachers, three teachers taught grade 12 classrooms, while four taught grade 11 and 10 classrooms, respectively

A holistic presentation of all the teachers' classroom practice is presented below using the five components and only the aspects that stand out are deliberated upon.

Orientation to science teaching

As highlighted in the introduction that this component embraces the other four components (Demirdogen et al., 2015). Therefore, generally, what could be deduced from the other four elements is that the teachers reflected knowledge of the curriculum from the respective topics they taught. However, it was difficult to tell if the teachers could decipher the learner' understanding of science. Furthermore, the teachers also struggled to use the relevant teaching methods that would reflect the bearing their views on the NOS have on their PCK, and the assessments they offered to learners were mostly not par standard. Lastly, further deliberations are addressed below.

Knowledge of science curricula

Pedagogically, the majority of the teachers appeared to understand the goals and objectives" for learners' learning as well as the scope and the sequence of the scientific concepts to be taught" to teach science. However, it was difficult to determine if such understanding was intentional or coincidental because none of the teachers who were observed had any evidence that they had prepared any of their lessons. For example, during the observation period of T006 on Atomic structures in his grade 10 classroom, all the learners produced their physical science textbooks, and this was also in T002 (genetics), T003 electrostatics), T005 (photosynthesis), T009 (electric circuits), and T011's (nervous system) classrooms. These textbooks contain objectives on each topic presented (Beckett, 2012; DBE, 2011a). The other teachers presented their lessons using the chalkboard and some prints out.

T006 and T008 who were teaching the same topic (atomic structures) used different approaches to their classroom, T006 asked the learners *"what is an atom?"* and the second question requested learners to name scientists who contributed to the evolution of the discovery of an atomic structure. The learners were able to define an atom correctly and named the likes of Dalton, Rutherford and Bohr. However, the learners could not differentiate the models and T006 just guided the learners to open a particular textbook page number to see different models (DBE, 2011b).

T008 similarly, asked the learners *"what is an atom?"* the learners defined an atom correctly, however instead of looking for the contributing scientists to the evolution of the atomic structure, the teacher told the learners that *"the focus of the period would be on Niels Bohr's model of an atom"*. T008 continued to tell the learners about the position of electrons, protons and neutrons and learners were in position of the sheets that had the models of Niels Bohr's model of as atom.

For life sciences T005 who taught photosynthesis started the lesson by asking the learners to *"define photosynthesis"*. One of the learners responded by stating that *"photosynthesis is the process, where plants manufacture their food"*. T005 continued to present the process of photosynthesis using a formula. On the other hand, T011 who taught on the topic of the nervous system, her focus appeared to be interested in the types of polar neurons. The teacher asked the learners *"how they can identify and differentiate unipolar, dipolar or multipolar neurons from each other?"* Since the learners had the textbooks they were expected to differentiate the neurons and the learners had difficulties in identifying what made the neurons different from each other.

Knowledge of learners' understanding of science

A teacher's understanding of the prerequisites for learners to acquire particular ideas as well as potential learning obstacles they could face when learning the concepts is two aspects of their understanding of learners' grasp of science (Lankford, 2010). This aspect speaks more about the teachers' abilities to develop a conducive relationship and environment for learners to learn best and reflect if learning is not taking place. Furthermore, this aspect requires an observant teacher to have better communication skills.

T006 and T008 introduced their lessons by both asking the learners to *"define an atom"*. For teachers to understand learners' understanding of science baseline questions such as *"what do you understand by an atom?"* By asking the question this way it because possible to determine the learners' prior knowledge and their understanding of science. According to Khuzwayo and Khuzwayo (2020), too many teachers lack the know-how to apply baseline assessment. Furthermore, had the teachers presented different models of atoms for learners to differentiate them using observation and inferences instead of naming the scientists responsible for the different models (Bell, 2009). Hence, Confre et al. (2019) highlighted that tenets such as observations and inferences, empirical and creativity are much easier to teach, but the teachers reflected a poor ability to teach them despite informed views about NOS.

T005 who taught photosynthesis could have asked the learners to present the process of photosynthesis in a chemical formula format, in this way, the learners not only define the process but also get to understand the components responsible for the process. Furthermore, the teacher could have allowed the learners to experiment with the process of photosynthesis to allow the learners to connect the process to context (Bell, 2009). T011 who taught the nervous system could have presented the lesson by presenting the three types of polar neurons, where the learners used observations and inferences (Ayala-Villamil & García-Martínez, 2021; Bell, 2009; McComas, 1998; Yoon et al., 2014) to differentiate the unipolar from bipolar and multipolar neurons. Hence, the majority of the teachers reflected no content knowledge problem, but their ability to decipher the learners' learning needs left a lot to be desired. This was seen as the majority of the teachers were more focused on teaching and learners hardly had the opportunities to ask questions. There was never in any of the classrooms observed an incident, where the learners were allowed to ask questions or any opportunity to engage with other learners.

Knowledge of instructional strategies

This PCK component's knowledge of instructional techniques subheading alludes to a variety of instructional strategies that are crucial to the teaching of scientific subjects like science (Magnusson et al., 1999). Having said that, none of the teachers observed has displayed a teaching method that would be deemed suitable for the time of subject science and the kind of learners. The teachers presented a teacher-centered approach in their classroom, where learners never had opportunities to engage or even ask questions. In their quest to determine if argumentation can be used to integrate IK in science classrooms, Otulaja et al. (2011) considered argumentation as a prospect to integrate IK, because of how well it works in teaching science. Furthermore, science CAPS documents are rooted in the idea of using constructivist learning methods, where learners are independent and are guided to learn independently through facilitation (DBE, 2011a). T001 to T011 asked questions such as *"define the potential difference, current; define phenotype and genotype; define Coulomb's law; define Newton's law of motion; what is photosynthesis?"* etc. In other words, the teachers approached their classrooms' pedagogies in a traditionalist approach, where the lessons were more centered on them than the learners. Hence, it is important to remember that purposeful teaching is not the same as direct instruction, by just reading a list of NOS tenets, learners are unlikely to obtain an understanding of NOS, and instead, learners should participate in activities that highlight certain aspects of NOS (Bell, 2009).

Knowledge of assessment

Understanding of the aspects of scientific learning relevant to assessment and knowledge of assessment techniques and methods through which learners' learning may be measured are the two concepts put forth by PCK's knowledge of the assessment component (Lackford, 2010; Magnusson et al., 1999). Looking at the previous four components, it can be concluded that knowing a component does not necessarily translate to the ability to implement it. From the four previous components, it was evident the majority of the teachers observed reflected their knowledge of the goals and objectives, of science. However, the choices of their instructional strategies did not provide favorable moments for them to integrate NOS. T006 provided the first assessment by providing the learners with an activity requesting them to name the particles found in an atom and asking them to describe each and highlight, where they should be positioned. The following day his questions were focused on atomic number and atomic mass. Similarly, T008 assessed the learners based on the components of an atom by also including clouds found on each energy level and requested the learners to describe each component. The second lesson focused on atomic numbers and mass and asked questions based on the Aufbau principle.

T005 assessed learners by giving them class activity, where they were required to define photosynthesis, name the components and by-products of photosynthesis and a leaf diagram with a label. The second lesson focused on the internal and external factors affecting photosynthesis. Furthermore, T011 provided a classroom activity that required the learners to differentiate the polar neurons. However, there was never a point, where the learners were allowed to investigate or provided with inquiry-based activities that could be used effectively as contexts in which to introduce and reinforce NOS concepts (Bell, 2009). In other words, the type of assessment techniques employed by the teachers did not encourage creativity and imagination from the side of the learners (Ayala-Villamil & Garcia-Martinez, 2021). Hence, in this section, it was not different. The teachers appeared to know the assessment techniques, however, it seemed like they preferred the easy route, where rote learning and teacher-centered learning were preferred by the teachers.

Overall Comments from 11 Teachers' Classroom Practices

Common emerging trends from the classroom observations are that the teachers appeared to be familiar with the goals and objectives enshrined in the science CAPS document that encourages the integration of NOS (DBE, 2011a). Furthermore, the teachers' content knowledge generally reflected a solid content knowledge, however, their instructional strategies and assessment techniques did not encourage the integration of NOS. This is because the teachers used mundane teaching strategies and some assessment techniques that were not problem-based that could have encouraged participation and critical thinking as prescribed in CAPS document (DBE, 2011a, Utulaja et al., 2011).

The one theme emerging from the findings: The teachers reflected informed views of NOS, yet their views bared no implications to their pedagogical content knowledge

The one emerging theme suggested that the majority of the science teachers who participated in the study reflected informed views about NOS. However, a small section of the science teachers reflected uninformed views regarding the tentative nature of NOS, the creative and imagination NOS, where the science teachers did not believe that scientists used creativity and imagination instead they suggested that scientists use scientific methods in their scientific endeavors. This type of trend is similar to the one that emerged from the study conducted in Nigeria, where the teachers assumed creativity was a tenet relevant to the arts, not science (see Ndeke et al., 2015). Lastly, few science teachers reflected views that suggested that IK is not science, a suggestion that is contrary to views shared by Cronje et al. (2015), Steenkamp et al. (2019), Zinyeka et al. (2016), where amongst other things presented tenets shared by both knowledge systems in their studies.

The second trend emerged from 11 science teachers' classroom pedagogy, where there was no evidence that their views about NOS had bared any implications on their PCK. An element that was revealed in many kinds of research, where teachers did not have appropriate PCK for teaching and integrating NOS in their science classrooms (see Demirdogen et al., 2015; Mesci et al., 2020; Wahbeh & Abd-El-Khalick, 2014). The participating science teachers also reflected a lack of character or charisma, panache or appropriate teacher repertoire that would help draw curiosity out of the learners.

CONCLUSIONS

Although the study was limited to 11 science teachers in one circuit and a qualitative research approach, the results revealed that the majority of the teachers held informed views of NOS. On the other hand, some responses reflected uninformed or partially-informed views, indicating the need for further professional development in NOS among science teachers. One of the outstanding responses reflected a misconception that tested and proven knowledge cannot change, highlighting the importance of understanding the tentative NOS. As such future studies should consider conducting the studies using a pool of teachers from various circuits using mixed methods that allow different data collection methods such as interviews and focus groups to gain more comprehensive views from the teachers. To provide more nuanced insights into teachers' views on NOS, future studies could focus on specific aspects of NOS, such as the tentative NOS, and the role of creativity and imagination in science, that shape scientific research.

Although the teachers were observed a fairly limited number of times, the study highlights the importance of teachers' PCK in teaching science and the majority of the teachers had a good understanding of the goals and objectives of science education and content knowledge. Their knowledge of learners' understanding of science and assessment techniques appeared to be limited and not effectively utilized in the classroom. Some teachers (T005, T006, T008, and T011) had the opportunity to use tenets such as observations and inferences as well as creativity and imagination during their lessons, but they appeared unmindful of the opportunity. Therefore, science teacher training programs should focus on increasing teachers' PCK to better equip them with the required skills and knowledge to effectively teach science or NOS.

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REFERENCES

Abd-El-Khalick, F., Bell, R. L., & Lederman, N. G. (1998). The nature of science and instructional practice: Making the unnatural natural. *Science Education, 82*(4), 417-436. https://doi.org/10.1002/(SICI)1098-237X(199807)82:4<417::AID-SCE1>3.0.CO;2-E

Akerson, V. L., Abd-El-Khalick, F., & Lederman, N. G. (2000). Influence of a reflective explicit activity-based approach on elementary teachers' conceptions of nature of science. *Journal of Research in Science Teaching, 37*(4), 295-317. https://doi.org/

10.1002/(sici)1098-2736(200004)37:4<295::aid-tea2>3.0.co;2-2

Akerson, V. L., Pongsanon, K., Park Rogers, M., Cater, M., & Galindo, E. (2017). Exploring the impact of a university course on preservice science teachers' views of the nature of science. *Journal of Science Teacher Education, 28*(2), 117-138.

Alabdulkareem, S. A. (2016). The impact of science teachers' beliefs on teaching science: The case of Saudi science teachers. *Journal of Education and Learning, 5*(2), 233. https://doi.org/10.5539/jel.v5n2p233

Allchin, D. (2014). Achieving scientific literacy: Strategies for teaching NOS in context. *The Science Education Review, 13*(1), 31-37.

Alonzo, A. C., & Kim, J. (2015). Declarative and dynamic pedagogical content knowledge as elicited through two video-based interview methods. *Journal of Research in Science Teaching, 53*(8), 1259-1286. https://doi.org/10.1002/tea.21271

Aslan, O., & Tasar, M. F. (2013). Investigation of Turkish science teachers' views about the nature of science. *Procedia-Social and Behavioral Sciences, 89*, 311-315.

Ayala-Villamil, L.-A., & García-Martínez, Á. (2021). VNOS: A historical review of an instrument on the nature of science. *Interdisciplinary Journal of Environmental and Science Education, 17*(2), e2238. https://doi.org/10.21601/ijese/9340

Ayala-Villamil, M. A., & Garcia-Martinez, M. A. (2020). The nature of science: A systematic review of the literature. *Journal of Research in science teaching, 57*(1), 1-25.

Bartos, S. A., & Lederman, N. G. (2014). Teachers' understanding and teaching of the nature of science: An updated review of the literature. *Journal of Science Teacher Education, 25*(6), 767-792.

Bell, R. L. (2009). Teaching the nature of science through inquiry to prospective elementary teachers: A tale of two teachers. *Journal of Elementary Science Education, 21*(1), 1-14.

Bhandari, R. B. (2020). *Qualitative research: A practical guide*. Routledge.

Brown, D. E., Friedrichsen, P. M., & Abell, S. K. (2013). Understanding and teaching the nature of science: An overview of empirical research. *Journal of Research in Science Teaching, 50*(6), 653-667.

Carmen, A. Z. (2006). *Recruiting native American college students: "Why don't they just show up from their high schools like other students do?"*. University of Oregon.

Chanetsa, T. F. (2016). *South African science teachers' repertoire of practices in the teaching of nature of science* [Doctoral dissertation, University of the Witwatersrand].

Chen, B., & Wei, B. (2015). Examining chemistry teachers' use of curriculum materials: In view of teachers' pedagogical content knowledge. *Chemistry Education Research and Practice, 16*(2), 260-272. https://doi.org/10.1039/c4rp00237g

Cochran, K. F., DeRuiter, J. A., & King, R. A. (1993). Pedagogical content knowing: An integrative model for teacher preparation. *Journal of Teacher Education, 44*(4), 263-272. https://doi.org/10.1177/0022487193044004004

Cofré, H., Núñez, P., Santibáñez, D., Pavez, J. M., Valencia, M., & Vergara, C. (2019). Correction to: A critical review of students' and teachers' understandings of nature of science. *Science & Education, 29*(1), 221-232. https://doi.org/10.1007/s11191-019-00062-0

Cronje, A. (2015). *Epistemological border-crossing between western science and indigenous knowledge and its implications for teacher professional development* [Unpublished PhD thesis]. University of Johannesburg.

Cronje, A., de Beer, J., & Ankiewicz, P. (2015). The development and use of an instrument to investigate science teachers' views on indigenous knowledge. *African Journal of Research in Mathematics, Science and Technology Education, 19*(3), 319-332. https://doi.org/10.1080/10288457.2015.1108567

DBE. (2011a). *Curriculum and assessment policy statement for life sciences grade 10-12*. Department of Basic Education.

DEB. (2011b). *Curriculum and assessment policy statement: Mathematics and physical sciences (grade 10-12)*. Government Printing Works.

Dekkers, P., & Mnisi, S. (2003). South African natural science teachers' views of the nature of science. *Journal of Research in Science Teaching, 40*(3), 253-269.

Demirdogen, B. (2016). Interaction between science teaching orientation and pedagogical content knowledge components. *Journal of Science Teacher Education, 27*(5), 495-532. https://doi.org/10.1007/s10972-016-9472-5

Demirdogen, B., Hanuscin, D. L., Uzuntiryaki-Kondakci, E., & Koseoglu, F. (2015). Development and nature of preservice chemistry teachers' pedagogical content knowledge for nature of science. *Research in Science Education, 46*(4), 575-612. https://doi.org/10.1007/s11165-015-9472-z

Demirdogen, B., Kavak, N., & Turgut, M. (2016). Pre-service science teachers' understanding of nature of science: A longitudinal study. *Journal of Education and Practice, 7*(3), 39-47.

Etikan, I., Musa, S. A., & Alkassim, R. S. (2016). Comparison of convenience sampling and purposive sampling. *American Journal of Theoretical* *and Applied Statistics, 5*(1), 1-4. https://doi.org/10.11648/j.ajtas.20160501.11

Frambach, J. M., van der Vleuten, C. P., & Durning, S. J. (2013). AM last page. Quality criteria in qualitative and quantitative research. *Academic Medicine, 88*(4), 552. https://doi.org/10.1097/ACM.0b013e31828abf7f

Gorelick, R. (2014). Indigenous sciences are not pseudosciences. *Ideas in Ecology and Evolution, 7*(1), 43-55. https://doi.org/10.4033/iee.2014.7.11.c

Grossman, P. L. (1990). *The making of a teacher: Teacher knowledge and teacher education*. Teachers College Pr.

Hacieminoglu, E. (2014). In-service teachers' perceptions regarding their practices related to integrating nature of science: Case study. *Procedia-Social and Behavioral Sciences, 116*, 1268-1273. https://doi.org/10.1016/j.sbspro.2014.01.381

Haidar, A. H. (1999). Emirates pre-service and in-service teachers' views about the nature of science. *International Journal of Science Education, 21*(8), 807-822. https://doi.org/10.1080/095006999290309

Haidar, A.H. (1999). Epistemological views of science teachers: Coherence and change. *Journal of Research in Science Teaching, 36*(3), 257-277.

Hanuscin, D. L., Lee, M. H., & Akerson, V. L. (2011). Elementary teachers' pedagogical content knowledge for teaching the nature of science. *Science Education, 95*(1), 145-167. https://doi.org/10.1002/sce.20404

Hanuscin, D.L. (2013). Approaches to teaching nature of science: Investigating instructional strategies used by practicing scientists and science faculty. *Science Education, 97*(4), 574-590.

Higgins, J., & Moeed, A. (2017). Fostering curiosity in science classrooms: Inquiring into practice using cogenerative dialoguing. *Science Education International, 28*(3), 190-198. https://doi.org/10.33828/sei.v28.i3.2

Johnson, M. L. (2006). Mind, metaphor, law. *Mercer Law Review, 58*, 845.

Kaya, E. (2012). The nature of science as a foundation for fostering a better understanding of evolution. *Science & Education, 21*(9), 1249-1264.

Khuzwayo, M. E., & Khuzwayo, H. B. (2020). Baseline assessment in the elementary mathematics classroom: Should it be optional or mandatory for teaching and learning? *International Journal of Learning, Teaching and Educational Research, 19*(8), 330-349. https://doi.org/10.26803/ijlter.19.8.18

Kunene, M. (2014). Teachers' pedagogical content knowledge and learners' science achievement in South African primary schools. *International Journal of Educational Sciences, 7*, 1,

Lankford, D. (2010). Pedagogical content knowledge in science education: Perspectives and potential for progress. *Science & Education, 19*(6-8), 707-729.

Lederman, N. G. (1999). Teachers' understanding of the nature of science and classroom practice: Factors that facilitate or impede the relationship. *Journal of Research in Science Teaching, 36*(8), 916-929. https://doi.org/10.1002/(sici)1098-2736(199910)36:8<916::aid-tea2>3.0.co;2-a

Lederman, N. G. (2007). Nature of science: Past, present, and future. In S. K. Abell, & N. G. Lederman (Eds.), *Handbook of research on science education* (pp. 831-879). Routledge.

Lederman, N. G., & Lederman, J. S. (2010). Research on teaching and learning of nature of science. In N. G. Lederman, & S. K. Abell (Eds.), *Handbook of research on science education, volume II*. Routledge. https://doi.org/10.4324/9780203097267.ch30

Lederman, N. G., Abd-El-Khalick, F., Bell, R. L., & Schwartz, R. S. (2002). Views of nature of science questionnaire: Toward valid and meaningful assessment of learners' conceptions of nature of science. *Journal of Research in Science Teaching, 39*(6), 497-521. https://doi.org/10.1002/tea.10034

Linneman, S. R., Lynch, P., Kurup, R., Webb, P., & Bantwini, B. (2003). South African science teachers' perceptions of the nature of science. *African Journal of Research in Mathematics, Science and Technology Education, 7*(1), 35-50. https://doi.org/10.1080/10288457.2003.10740547

Magnusson, S., Krajcik, J., & Borko, H. (1999). Nature, sources, and development of pedagogical content knowledge for science teaching. In J. Gess-Newsome, & N. G. Lederman (Eds.), *Science & technology education library* (pp. 95-132). Springer. https://doi.org/10.1007/0-306-47217-1_4

McCall, A. (2008). *Investigating the efficacy of an intervention designed to promote acceptance of scientific concepts among secondary school learners in a rural South African District* [Doctoral dissertation, University of the Witwatersrand].

McComas, W. F. (1998). The principal elements of the nature of science: Dispelling the myths. In W. F. McComas (Ed.), *The nature of science in science education* (pp. 53-70). Springer. https://doi.org/10.1007/0-306-47215-5_3

McMillan, J. H., & Schumacher, S. (2010). *Research in education: Evidence-based inquiry*. Pearson.

Mellado, V., Bermejo, M. L., Blanco, L. J., & Ruiz, C. (2007). The classroom practice of a prospective secondary biology teacher and his conceptions of the nature of science and of teaching and learning science. *International Journal of Science and Mathematics Education, 6*(1), 37-62. https://doi.org/10.1007/s10763-007-9081-z

Mesci, G. (2020). The influence of PCK-based NOS teaching on pre-service science teachers' NOS views. *Science & Education, 29*(3), 743-769. https://doi.org/10.1007/s11191-020-00117-7

Mesci, G., Schwartz, R. S., & Pleasants, B. A.-S. (2020). Enabling factors of preservice science teachers' pedagogical content knowledge for nature of science and nature of scientific inquiry. *Science & Education, 29*(2), 263-297. https://doi.org/10.1007/s11191-019-00090-w

Mpeta, M., de Villiers, J. J. R., & Fraser, W. J. (2014). Secondary school learners' response to the teaching of evolution in Limpopo Province, South Africa. *Journal of Biological Education, 49*(2), 150-164. https://doi.org/10.1080/00219266.2014.914555

Mthethwa-Kunene, E., Onwu, G. O., & de Villiers, R. (2015). Exploring biology teachers' pedagogical content knowledge in the teaching of genetics in Swaziland science classrooms. *International Journal of Science Education, 37*(7), 1140-1165. https://doi.org/10.1080/09500693.2015.1022624

Ndeke, G. C., Okere, M. I., & Keraro, F. N. (2015). Secondary school biology teachers' perceptions of scientific creativity. *Journal of Education and Learning, 5*(1), 31. https://doi.org/10.5539/jel.v5n1p31

Ndeke, R., & Keraro, F. N. (2017). Science teachers' perceptions of the nature of science (NOS) in relation to their classroom practice. *International Journal of Science Education, 39*(12), 1599-1615.

Nott, M., & Wellington, J. (1996). Probing teachers' views of the nature of science: How should we do it and where should we be looking. In G. Welford, J. Osborne, & P. Scott (Eds.), *Research in science education in Europe* (pp. 283-295). Falmer Press.

Onwuegbuzie, A. J., & Collins, K. M. (2007). A typology of mixed methods sampling designs in social science research. *Qualitative Report, 12*(2), 281-316.

Otulaja, F.S., Cameron, K., & Msimanga, A. (2011). Integrating indigenous knowledge in science classrooms through argumentation: The teachers' role. *African Journal of Research in Mathematics, Science and Technology Education, 15*(2), 136-146.

Ramnarain, U., & Padayachee, K. (2015). A comparative analysis of South African life sciences and biology textbooks for inclusion of the nature of science. *South African Journal of Education, 35*(1), 1-8. https://doi.org/10.15700/201503062358

Rollnick, M., Bennett, J., Rhemtula, M., Dharsey, N., & Ndlovu, T. (2008). The place of subject matter knowledge in pedagogical content knowledge: A case study of South African teachers teaching the amount of substance and chemical equilibrium. *International Journal of Science Education, 30*(10), 1365-1387. https://doi.org/10.1080/09500690802187025

Roy, S., & Bairagya, S. (2019). Conceptualization of pedagogical content knowledge (PCK) of science from Shulman's notion to refined consensus model (RCM): A journey. *Journal of Dialogue on Education, 8*(2), 10-53.

Sarieddine, D., & BouJaoude, S. (2014). Influence of teachers' conceptions of the nature of science on classroom practice. *EURASIA Journal of Mathematics, Science and Technology Education, 10*(2), 135-151. https://doi.org/10.12973/eurasia.2014.1024a

Sarkar, S., & Gomes, D. (2010). Science teachers' views of nature of science: A critical review of research. *Educational Research Review, 5*(1), 11-32.

Senanayake, S. G. (2006). Indigenous knowledge as a key to sustainable development. *Journal of Agricultural Sciences–Sri Lanka, 2*(1), 87-94. https://doi.org/10.4038/jas.v2i1.8117

Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher, 15*(2), 4-14. https://doi.org/10.3102/0013189x015002004

Snively, G., & Corsiglia, J. (2001). Discovering indigenous science: Implications for science education. *Science Education, 85*(1), 6-34. https://doi.org/10.1002/1098-237X(200101)85:1<6::AID-SCE3>3.0.CO;2-R

Steenkamp, J., De Beer, J., & Petersen, N. (2019). *The conundrum of integrating indigenous knowledge in science curriculum themes: A review of different viewpoints*. https://uir.unisa.ac.za/

Treagust, D. F., & Duit, R. (2008). Conceptual change: A discussion of theoretical, methodological and practical challenges for science education. *Cultural Studies of Science Education, 3*(2), 297-328. https://doi.org/10.1007/s11422-008-9090-4

Wahbeh, N., & Abd-El-Khalick, F. (2013). Revisiting the translation of nature of science understandings into instructional practice: Teachers' nature of science pedagogical content knowledge. *International Journal of Science Education, 36*(3), 425-466. https://doi.org/10.1080/09500693.2013.786852

Waters-Adams, S. (2006). The relationship between understanding of the nature of science and practice: The influence of teachers' beliefs about education, teaching and learning. *International Journal of Science Education, 28*(8), 919-944. https://doi.org/10.1080/09500690500498351

Webb, P. (2007). Teachers' understandings of the nature of science. *The epiSTEME Reviews, 2*, 62-78.

Yin, R. K. (1984). *Case study research: Design and methods*. SAGE.

Yoon, S. A., Elinich, K., Wang, J., Steinmeier, C., & Klopfer, E. (2014). Developing and validating a learning progression for energy in socio-ecological systems. *Journal of Research in Science Teaching, 51*(10), 1282-1312.

Zeidler, D. L. (2002). Dancing with maggots and saints: Visions for subject matter knowledge, pedagogical knowledge, and pedagogical content knowledge in science teacher education reform. *Journal of Science Teacher Education, 13*(1), 27-42. https://doi.org/10.1023/a:1015129825891

Zinyeka, G., Onwu, G. O. M., & Braun, M. (2016). A truth-based epistemological framework for supporting teachers in integrating indigenous knowledge into science teaching. *African Journal of Research in Mathematics, Science and Technology Education, 20*(3), 256-266. https://doi.org/10.1080/18117295.2016.1239963

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