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Nature of Science: Examining Science Teachers' Knowledge and their Instructional Practices

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Abstract: This case study focused on a university teacher-education course that included NOS content. An adapted questionnaire was used to collect quantitative data on 83 secondary science teachers' views about three NOS themes before and after completing the course. Qualitative data were collected from eight of the teachers who were observed teaching during their field experience after completing the course. The teachers' post-course mean NOS scores were statistically significantly higher than their pre-course scores (t (65) =-10.08, p<.001; Cohen's d = 1.4). Despite the favourable NOS knowledge among the science teachers, low levels of NOS portrayal were observed in their instructional practices. These findings point to some success in explicitly addressing NOS in science education content courses. However, they raise questions about the transferability of teachers' NOS knowledge into their classrooms. The findings have implications for teacher-preparation programmes regarding durability of NOS knowledge.

Keywords: nature of science, secondary science, field experience, science teacher education

Introduction

Nature of Science (NOS) is included in Jamaica's National Standards Curriculum, which was developed to focus on problem solving and inquiry skills, formulating hypotheses, conducting experiments and reporting data (Ministry of Education Youth and Information, 2018). Units in the curriculum such as "Working like a Scientist" provide opportunities for teachers to explore NOS with their students. The curriculum is for primary (grades 1 - 6) and secondary (grades 7 – 9) levels, and has been implemented since 2016 (Ministry of Education, Youth and Information, 2016). Despite these efforts, Jamaican students have been underperforming in science in local primary and regional secondary examinations, respectively (Singh-Wilmot, 2015). This has stimulated ongoing discussions on how to improve students' academic performance.

The critical role of teachers in preparing scientifically literate students has been well established (Mesci & Schwartz, 2016; Sousa, 2016). Lederman and Abell (2014) have proposed that one of the reasons for students' poor performance in science is the inadequacies of teachers' understandings of NOS. Limited NOS knowledge and understanding could affect teachers' ability to describe the scientific enterprise and in turn influence the image of scientists formed by their students (Peters-Burton et al., 2023). Even with adequate NOS understanding, Kurup (2014) highlights that faulty representation of NOS in teachers' classroom practices is possible, for instance, if knowledge of effective pedagogical practices related to NOS is lacking. Herman et al. (2013a) reported that few teachers' instruction consistently reflect NOS or target it as an important educational objective to be planned for, taught, and assessed. This raises the issue of effective transfer of learning from one context to another. Conceptions developed during teacher education programmes are diminished by factors confronting teachers in their schools hence resulting in ineffective, inaccurate, or incomplete transfer of learning (Zeichner & Tabachnick, 1981).

The importance of NOS is reflected in many international school science curricula (e.g., Cullinane & Erduran, 2023; Erduran et al., 2021; McComas & Nouri, 2016; Mork et al., 2022), and the large number of studies conducted internationally on teachers' NOS knowledge, beliefs and practices (e.g., Bjønness, & Knain, 2018; Cansiz & Cansiz, 2022; Deng et al., 2011; Hanuscin, 2013; Kinskey, 2022; Leden & Hansson, 2019; Lederman & Lederman, 2019a, b). Several studies have also examined the relationship between teachers' NOS conceptions and their instructional practices (e.g., Bartos & Lederman, 2014; Brickhouse, 1990; Herman et al., 2013a; Herman et al., 2013b; Herman & Clough, 2016; Kurup, 2014; Lederman et al., 2001; Sarieddine & BouJaoude, 2013). However, explorations of teachers' NOS knowledge and approaches to NOS instruction in the Caribbean has received little attention.

The main purpose of this study was to determine the NOS conceptions of selected Caribbean science teachers within a postgraduate teacher education programme. A related purpose was to ascertain whether NOS concepts they had been exposed to in their teacher education programme were evident in their classroom practices after completing the programme. The findings of this study could provide information on selected Caribbean teachers' NOS knowledge, and insights into its transfer into their teaching, which is crucial for validating or providing ideas for improving teacher education programmes.

The following questions guided the study: (i) How are science teachers' nature of science knowledge influenced by their participation in a course that utilises explicit nature of science instruction? (ii) How do science teachers' classroom practice portray nature of science elements after participating in a course focusing on explicit instruction about the nature of science?

Review of Selected Literature

Nature of Science

The NOS has been deemed a difficult concept to define (Bell, 2009) and teach about, which could affect how it is understood and portrayed by teachers to their students. The accuracy of what NOS really is has been questioned, and various representations have been proposed and discussed (e.g., Clough, 2007; Duschl & Grandy, 2013). However, there has been some consensus on NOS aspects, tenets or elements that are useful to guide classroom instruction for secondary schools, and teacher education programmes (Cullinane & Erduran, 2023; Dekkers & Mnisi, 2003; McComas, 2020). These include the idea that scientific knowledge is: (i) tentative; (ii) empirically based; (iii) subjective; (iv) the product of observation and inference; (v) the product of imagination and creativity; (vi) theory-laden and (vii) socially and culturally embedded (Abd-El-Khalick, 2005; Bell, 2009; Lederman, 1999; Peters-Burton, 2013).

Concern has been expressed about having a summarized NOS list that may simply be memorised (Irzik & Nola, 2011). Lederman and Lederman (2014), nevertheless, advanced that these common aspects can be treated as a guide to NOS instruction. To foster students' critical thinking on NOS issues, Clough (2007) proposed presenting the tenets as questions rather than statements. Whatever the preferred NOS approach, providing science teachers with explicit NOS instruction in their science methods courses may increase the likelihood of them understanding, enriching, or changing their NOS views and perhaps by extension, their practices (Abd-El-Khalick & Lederman, 2000; Golabek & Amrane-Cooper, 2013). According to Sumranwanich and Yuenyong (2014, p. 2443), explicit NOS instruction "provides students with a framework to analyze science activities for nature of science aspects and to reflect upon the similarities and differences between the classroom science experience and the experiences of practicing scientists". Duschl and Grandy (2013) argued that the explicit approach should involve students actively engaging in activities that promote the enactment of science as opposed to just pointing out where NOS concepts are present in lessons and activities. Strategies such as using discussion amongst small groups, structured reading, listening, or watching of items involving science stories, historical and contemporary cases, and student-led investigations have been recommended for supporting NOS understanding (Allchin et al., 2014; Clough, 2012; Hodson, 2008; Nott, 1994).

Teachers' NOS Knowledge and Transfer

Investigating whether teacher education programmes can foster the development of NOS understanding among teachers has been a feature of studies internationally, with varying results. Researchers have reported improved NOS knowledge for 19 Palestinian secondary science teachers who participated in a 6-week NOS course (Wahbeh & Abd-El-Khalick, 2014) and 25 middle school teachers who participated in a 6-day professional development programme in the USA (Mulvey & Bell, 2017). However, 50 German pre-service chemistry teachers were found to possess inconsistent or partially informed conceptions about aspects of NOS (specifically the tentative nature) after participating in a 5-week intervention involving historical case studies from chemistry (Mueller & Reiners, 2022).

Wallace (2014) concluded after reviewing several studies that teachers' beliefs are related to their practices. She highlighted that experienced teachers have stable beliefs that are hard to change. Robust teacher-beliefs, particularly if incorrect, can stand in the way of successful implementation of curricular requirements. At the same time, Wallace indicated there are observed mismatches between teachers' beliefs and their practices. Similarly, Darling-Hammond (2014) lamented the gap in the relationship between the experiences in teacher preparation courses and what occurs in fieldwork. The observations by Wallace (2014) and Darling-Hammond (2014) could be applied to teachers' NOS in two ways. Firstly, teachers' NOS knowledge may or may not be transferred to their classrooms. Additionally, if teachers' NOS knowledge is transferred to their classrooms, it is possible it could be done in an incomplete or incorrect manner.

There have been mixed results from studies on science teachers' NOS knowledge transfer into their classrooms. Herman et al. (2013a), Herman et al. (2013b), Herman and Clough (2016), and Mulvey and Bell (2017) reported positive results from studies on middle and secondary school teachers' NOS instructional practices 1 to 5 years after completing teacher education programmes that included a NOS focus. Most of the teachers' practices were consistent with what they were exposed to in the programmes, with NOS implementation ranging from low to high levels. The researchers gave credit for this to the focused attention given to NOS during the teacher preparation stages. Herman et al. (2013a) further reported that NOS instruction was mostly observed in lessons that included inquiry or research activities. Despite the positive findings, Herman et al. (2013b) observed that teachers were less able to capitalise on moments in the lessons that presented opportunities for NOS instruction.

Bartos and Lederman's (2014) study findings on five secondary school teachers in the USA were less positive, as limited congruence was observed between teachers' practices and their expressions about NOS and scientific inquiry in courses completed in a degree programme. In another study with seven in-service high school biology teachers in Lebanon, Sarieddine and BouJaoude (2014) similarly reported that most of the teachers did not possess appropriate NOS views, and their classroom practices lacked explicit reference to the critical NOS elements. This was observed even though the teachers had received NOS instruction in their teacher education programmes and were using a curriculum that provided a framework to introduce NOS. Abd-El-Khalick and Lederman (2000) argue that simply improving NOS understandings is not sufficient to enable teachers to effectively address NOS instruction in their classrooms. Erduran et al. (2020) expressed that high-stakes examinations practiced in many countries could impose limitations on how science is taught, for instance, practical work could follow a 'cookbook' procedure to ensure students' success. To address this, Karaman (2016) and Lederman and Lederman (2019b) suggest that teachers should receive follow-up professional development opportunities or mentorship from experienced colleagues after completing their teacher education programmes. This may help them to internalise, apply, and improve their newly formed NOS conceptions.

The retention of NOS knowledge can be linked to the theory of transfer of learning. Transfer of learning is an important concept in educational practice because the expectation is that whatever is learned will be remembered, retained, and applied in appropriate situations (Leberman et al., 2006). This is particularly relevant for NOS, as it is hoped that teachers in education programmes will be able to transfer their NOS learning to new contexts and situations, such as when teaching science to their students. Transfer of learning, or simply 'transfer', has been a focus of researchers since the early 1900s (Hung, 2013). Various definitions have been proposed, such as "applying previously learned knowledge with various degrees of adaptation or modification of that knowledge in completing a task or solving problems" (Hung, p. 27) and "…the ability to apply knowledge or procedures learned in one context to new contexts" (Mestre et al., 2002, p. 3). However, Ford (1994) cautions that a simple definition does not adequately portray the complexities underlying the transfer of learning. He points out that transfer is not static but rather depends on the specific educational context. Hence, deeper insights into teachers' NOS knowledge and instructional practices in their specific contexts is necessary to determine the adequacy and robustness of their understanding and application of NOS concepts (Emre-Akdoğan & Yazgan-Sağ, 2019).

Methodology

The research design is a case study of a graduate-level course and its participants between the years 2016 – 2020. The data from all participants were combined for analysis as a single case (Rafferty et al., 2015) due to low enrolment numbers for each registration period. The 39-hour blended course is taken by science teachers at a Caribbean tertiary-level institution as part of a year-long programme. Selected content of the course includes: (i) *Nature of science*: definitions, views of science, science as a body of knowledge, a way of thinking, a way of investigating; and (ii) *Instructional strategies*: integrating historical cases into science teaching; NOS-focused lesson-planning. The delivery strategies in the course include structured small-group discussions, structured reading, listening to or watching stories about past and present scientists, and students' reflections on NOS and the history of science (Clough, 2012; Nott, 1994). The assessment tasks include a reflective essay on NOS, lesson planning, and creating learning resources utilising historical cases to assist classroom students in understanding NOS.

The study was conducted on a convenience non-probability sample of 83 science teachers of consecutive cohorts over a 4-year period from various Caribbean countries. To collect quantitative data, a one group pre-test/post-test design was utilised in which a questionnaire was administered during the first and last week of the course. The questionnaire was modified from Liang et al. (2008) and consisted of 18 Likert-type items. The four subscales were: *The role of observations* (4 items); *The tentative NOS* (5 items); *The social and cultural influences on science* (4 items); *Science investigations* (5 items) (See Table 1 for a sample of the items). Two university lecturers checked the questionnaire for validity and the Cronbach alpha was calculated on responses from 22 science teachers who were not a part of the main study. A value of 0.81 was obtained, which is acceptable for this research (Brownlow et al., 2014).

Subscale	Statement
1. The role of observations	(i) Scientists' observations of the same event will be the same because observations are facts. (ii) Different scientists may make different interpretations based on the same observations.
2. The tentative NOS	(i) Scientific theories are continuously being tested and revised. (ii) Scientific theories based on accurate experimentation will not be changed.
3. The social and cultural influences on science	(i) Scientific research is not influenced by society and culture because scientists are trained to conduct unbiased studies. (ii) Cultural values and expectations determine what scientists investigate.
4. Science investigations	(i) Scientists use different types of methods to conduct scientific investigations (ii) Scientists follow the same step-by-step scientific method.

Table 1: Sample of NOS knowledge questionnaire statements

Qualitative data were purposefully obtained through in-person, virtual and recorded observations of teaching episodes of eight teachers (five males, three females) while on their teaching practice (Table 2). Pseudonyms were used to protect the participants' identities. The teachers were from different cohort years and taught different science subjects. The teachers selected had a range of low to high gains between their pre-and post-test scores on the quantitative instrument. A minimum of two lessons was observed for each teacher, with varying durations, depending on the timetables in the specific schools and the observation mode used (Table 2).

Participant	Cohort year no.	Subject taught	Lessons viewed and mode	Length of lessons viewed	Pre-post questionnaire score difference (scale ranged from 18 to 90)
Derrick	1	Integrated Science & Chemistry	Two lesson segments (recorded); Grade 7 & Grade 9	40 minutes	9
Sara	1	Biology	Three (in-person); Grade 10 & 12	3 hours	14
Adam	2	Biology	Two lesson segments (recorded); Grade 10 & Grade 11	30 minutes	17
Lorenzo	2	Integrated Science & Physics	Two lessons (recorded); Grade 7 & Grade 9	1 hr 20 minutes	0
Martha	3	Biology	Three (in-person); Grade 9 & Grade 10	3 hours	11
Matthew	3	Biology	Three (in-person); Grade 11 & Grade 12	4 hours	12
Ellis	4	Physics	Three (recorded); Grade 10	3 hours	2
Kaye	4	Integrated Science & Chemistry	Two (recorded); Grade 8 & 9	1 hr 40 minutes	5
TOTAL	-	-	**20**	**17 hours 10 minutes**	

Table 2: Qualitative sample characteristics

Observations were assisted by a researcher-constructed protocol based on studies by Clough (2012), Herman et al. (2013a), Herman et al. (2013b), Lederman et al. (2002), and Liang et al. (2008). The instrument was organized into three themes: *The nature of scientific knowledge* (6 indicators); *The nature of instructional strategies* (8 indicators); and *The nature and characteristics of scientists and scientific methods* (5 indicators); (See Appendix for sample indicators). Two university science educators and a high school science teacher reviewed the observation tool. Additionally, one of the science educators and the high school teacher used the instrument to analyse two of the recorded lessons to assist with establishing consistency (Merriam & Tisdell, 2016). All feedback was used to make changes to the instrument for its final use. It should be noted that the current study focused on identifying evidence of transfer from one context to another, rather than measuring the extent of NOS learning transfer or its impact. The observation protocol was, therefore, used to look for general evidence of NOS transfer, because the teachers were not specifically asked to incorporate NOS in their lessons by their schools or the researcher.

Data Analysis

Quantitative data from the survey instrument were analysed to determine teachers' NOS knowledge. The questionnaire scale ranged from a minimum score of 18 to a maximum of 90. The scores were divided into four categories where 18–36 represented poor, 37–54 fair, 55–72 good, and 73–90 excellent NOS knowledge. Pre- and post-test mean scores were calculated for the 83 teachers, and a paired sample t-test conducted to determine whether the pre- and post-test mean difference was statistically significant. Cohen's *d* was also calculated to determine the strength of any significant differences. Twenty lessons or lesson segments were observed, described, and analysed using the observation protocol to determine whether and how the NOS indicators outlined were evident in the teachers' classes.

Limitations

The study was limited with respect to low registration numbers in respective semesters, which led to using different cohorts over successive years, particularly for quantitative data collection. The small group size per course offering resulted in no control group being included in the study. Therefore, the pre-test/post-test approach was used to strengthen reliability. Another limitation was that not all indicators on the observation protocol were likely to be identified in each lesson. As a result the qualitative data were analysed by pooling all the indicators observed for each theme, over all the lessons for the teachers in the sample.

Findings

The importance of science in society leads to the continued quest of science teacher educators to find ways to strengthen science teachers' NOS knowledge and instructional practices. The main purpose of this study was to examine science teachers' NOS knowledge after participating in a graduate teacher education course utilising explicit NOS instruction. A related purpose was to look for evidence of NOS practices in teachers' classes after completing the course.

Research Question 1: How are science teachers' nature of science knowledge influenced by their participation in a course utilising explicit nature of science instruction?

The questionnaire mean scores indicated that the science teachers' NOS knowledge was initially good based on a pre-test score of 63.5 (*SD* 8.2). At the end of the course the teachers' NOS knowledge increased to excellent (73.8; *SD* 7.3) (Table 3). The difference between the pre- and post-test scores was statistically significant based on the results of a paired sample t-test (t =-12.22, p <.001), with a very large effect size (Cohen's d =1.41) (Sawilowsky, 2009). The findings suggest that the teachers' NOS knowledge was enhanced by their participation in the course. Table 3 further indicates that the NOS theme which showed the largest gain was "Science investigations". This finding could be useful for examining whether teachers' NOS knowledge is influenced by their classroom practice or vice versa.

	Pre-test		**Post-test**		
Questionnaire theme	Mean	SD	Mean	SD	Difference (%)
The role of observations and inferences	**16.0**	**2.7**	**16.8**	**2.1**	**5.2**
The tentative NOS	**18.2**	**2.5**	**20.0**	**2.1**	**10.1**
The social and cultural influences on science	**13.4**	**3.1**	**16.0**	**2.5**	**19.5**
Science investigations	**15.9**	**3.8**	**20.9**	**3.1**	**31.4**
TOTAL	**63.5**	**8.2**	**73.8**	**7.3**	**16.2**

Table 3: Teachers' scores on the NOS knowledge questionnaire

Research question 2: How do science teachers' classroom practice portray nature of science elements after participation in a course focusing on explicit instruction about the nature of science?

Based on the observation data, all eight teachers incorporated NOS elements from all three themes in their classes, with over 90 NOS-related behaviours observed. However, the lessons reflected a limited number of the possible indicators from the three observation themes (Table 4). For instance, most teachers displayed none or only one of the six possible indicators from theme one (The nature of scientific knowledge). Similarly, the majority did not focus on the role of historical or social factors in shaping scientific knowledge, which was a part of theme three (The nature and characteristics of scientists and scientific methods).

	Number of indicators observed per lesson for three themes								
	Nature of scientific knowledge			**Nature of instructional strategies**			**Nature and characteristics of scientists and scientific methods**		
Lessons / **Participants**	1	2	3	1	2	3	1	2	3
Derrick	2	0	*n/o	4	3	n/o	2	2	n/o
Sara	0	1	1	4	3	5	0	0	1
Adam	3	0	n/o	2	0	n/o	0	2	n/o
Lorenzo	1	2	n/o	4	3	n/o	1	3	n/o
Martha	1	0	0	4	3	1	0	2	1
Matthew	0	0	0	3	2	1	2	0	1
Ellis	1	1	0	3	4	2	1	2	0
Kaye	3	0	n/o	4	2	n/o	0	0	n/o
Total indicators per theme	**16**			**57**			**20**		

(*no lesson was observed)

Table 4: NOS indicators observed in teachers' lessons

Nature of Scientific Knowledge

The teachers' lessons portrayed the nature of scientific knowledge by primarily focusing on science content. For instance, in one lesson observed for Sara where she taught a group of grade 11 students about "Phospholipids", she asked one student to draw a triglyceride structure on the board. A second student was then called to the board to draw another triglyceride. While the two students were drawing, the teacher asked the rest of the students to correct any errors observed. She then gave notes on the topic, explaining the concepts as she went along. It was also noted that sometimes the content presented in a lesson was duplicated. For example, Matthew taught a lesson on "Mitosis" in which a video was shown summarising the stages. Despite the video providing adequate information, Matthew repeated the information for the students at the end of the video. Martha's grade 10 class on the topic "Nutrition" included a variety of tasks, but again they were focused on ascertaining content knowledge. For instance, students were given a fill-in-the blank worksheet on the structures of the digestive system and asked to view a video. Following that they used what they had learned from the video to name the structures on the worksheet. Martha then gave the students additional information on the functions of these structures, which they wrote on their worksheets. Some teachers were observed linking science content to the students' everyday experiences either through the activities, resources, or the types of questions posed. For example, Derrick asked a question and then stated, "*Everybody should know a virus off their head, right? There is a very common virus that is going* [around]*…it is all over the place.*"

Highlighting scientists and their work, using historical cases, and addressing scientific language were not adequately represented in the lessons observed. There were, however, lessons where two teachers, Kaye and Lorenzo directly included some of the NOS elements in the lessons "The elements and the periodic table" and "The scientific method" respectively. Kaye was observed announcing at the beginning of a class on atoms, "*I am going to share a little bit more about my scientist to give you an idea of what you can put in your assignment*." She then presented information on a scientist using a slide presentation she had prepared for an assignment in the teacher education course being reported on in this study. Lorenzo's lesson began by reviewing the names of selected local and international scientists. He then discussed definitions of "scientist" and "the scientific method", after which he asked the students to view a video and generate a list about what scientists do. Overall, while the lessons observed did not consistently incorporate critical elements related to the nature of scientific knowledge, there were instances where teachers like Kaye and Lorenzo made the effort to do so.

Additionally, statements made by Kaye and Lorenzo in their lessons provided insight into their understanding of science, scientists, and scientific methods. For instance, Kaye said: "*Science is something that is dynamic, it is constantly evolving, so even though things…were discovered we can now find new twists to them*." In Lorenzo's grade 7 lesson on the topic "Working like a scientist" from the Jamaican National Standards Curriculum, he stated "*Scientists are…persons who have to know how to solve problems...there are some steps that are followed when these persons are going to solve a problem*." He also defined scientific method as, "*…a series of steps that a scientist uses when solving a problem*." Although these episodes are positive, Kaye seemed to make no effort to get students to gain deeper understandings of the ways of science and scientists that was relevant to the topic being learnt. In addition, Lorenzo's statements might have contained some misunderstandings of scientists and scientific methods that could have potentially been passed on to his students.

Nature of Instructional Strategies

The observation theme where most of the indicators were noted was the "Nature of instructional strategies". The teachers' instructional strategies were varied (e.g., discussion, use of videos, concept cartoons, practical activities) indicating they were providing multiple ways for students to interact with and understand the material. Martha was observed utilising videos, pictures, and models with her grade 9 students. Kaye used probing questions and gave students tasks in which they worked in pairs. Despite the variety of instructional strategies observed, teacher-centred approaches were frequently utilised, which reinforced scientific knowledge rather than highlighting scientific methods, skills or characteristics. For example, Kaye spent the first 20 minutes of a science lesson on "The structure of the atom" reading from slides to "recap" information from a previous lesson. While doing this she said, "*I know you guys want to draw but just leave the space. I will send you the slides later and you can draw then*." Similarly, Ellis started a lesson on "Moment of a force" by reading some questions from a slide, providing the definition, sharing some diagrams and explaining them without inviting students' inputs. Although Ellis utilised questions in his teaching, they were lower-order type ones. For example, he asked, "*The smaller the force…the longer what*?" and prompted the students to complete the sentence.

On the other hand, Martha's lessons were observed to have more student participation. Martha engaged her grade 10 biology students in a lesson on "Nutrition" by using photographs of individuals showing various forms of malnutrition and by questioning the students about the photographs. This strategy sparked a discussion with the students readily offering their views on what led to the individuals' appearance. In a lesson about microorganisms, Derrick utilised cartoon images of bacteria and viruses. However, like Ellis, he asked questions that only required students to answer "yes" or "no". For instance, he held up a picture of a virus and asked, "*Does anybody know what this is?*" Even though interactive resources were used in the two classes described, the students in Derrick's lesson were not truly allowed to explore the concepts. This highlights the importance of not only using engaging resources but also facilitating meaningful interactions and discussions to promote deeper NOS understanding.

Nature and Characteristics of Scientists and Scientific Methods

The qualities of scientists were addressed in the teachers' lessons. For example, collaboration was encouraged in classes held in-person when teachers asked students to work in pairs or in groups. Collaboration on whole-group activities were evident in online synchronous classes, but these were teacher-led and directed. For example, Martha's class on "Nutrition" included students working in pairs to view a video, identify the structures of the digestive system and share their answers with the class. Practical work was observed to be incorporated into some lessons in which teachers utilised a mixture of inquiry and recipe-type approaches through demonstrations, simulations, investigations, and outdoor exercises (Table 5).

Practical activity	Description
Demonstration	Teacher used various materials to demonstrate the differences between solutions, suspensions, colloids
Simulation	Teacher used software to demonstrate the moment of a force
Investigation	Students given materials to apply scientific methods to separate salt from rice.
Outdoor exercise	Students asked to go to the schoolyard and use the characteristics of living things to make a list of five living things observed

Table 5: Examples of practical activities used by teachers in their observed classes

By encouraging collaboration and incorporating practical work teachers are helping students to develop essential characteristics and skills that scientists portray, such as creativity and communication and an understanding of scientific methods.

Discussion

Teachers' Improved NOS Knowledge

The findings of the study indicated that teachers' NOS knowledge improved significantly after they were exposed to its tenets in a teacher education course. The findings support those of previous research by Wahbeh and Abd-El-Khalick (2014), and Mulvey and Bell (2017). However, some misconceptions were observed, aligning with findings by Sarieddine and BouJaoude (2014), and Mueller and Reiners (2022) which showed that teachers still lacked adequate NOS views or had inconsistent or partially informed conceptions after receiving instruction in teacher education courses. Despite this, the overall positive results in the current study suggest that the teacher education course effectively addressed NOS concepts, and that teachers took the concepts seriously. The findings support the view held by some researchers that explicitly addressing NOS in teacher education can result in improved teachers' NOS knowledge (e.g., Abd-El-Khalick & Lederman, 2000; Bartos & Lederman, 2014; Herman et al., 2013a; Wahbeh & Abd-El-Khalick, 2014).

The NOS theme with the largest gain was the one dealing with scientists' investigations. It is possible that the historical cases the teachers were exposed to in the course provided some understanding and insight into scientists' work which includes investigations (Clough, 2012; Hodson, 2008). It is also possible that the teachers' interest in investigations was related to the Caribbean region's curricular requirement for students to complete a large number of practical work culminating in external exit examinations from secondary schools (Erduran et al., 2020). Teachers would therefore need to be equipped in understanding the requirements of practical work including designing and conducting experiments. This could have motivated them to engage deeply with the NOS concepts presented in the teacher education course. Another factor that might have contributed to the large gain on the theme dealing with investigations could have originated from teachers' own exposure and experiences with science investigations throughout their schooling, which might have differed from newer knowledge and experiences gained in the teacher education course. According to Cansiz and Cansiz (2022), beliefs about teaching and learning are formed from learners' prior experiences. These beliefs may either enhance or hinder their ability to acquire new knowledge and experiences when they enter teacher education programmes. Therefore, it is important for teacher education programmes to take into account prior experiences and beliefs of their students, and provide opportunities for them to reflect on and integrate those experiences with new knowledge and concepts, particularly in relation to NOS.

There was a High Focus on Science Content, and Less on the Language of Science, Characteristics of Scientists and their Methods

The teachers used a variety of instructional strategies, such as discussion, videos, concept cartoons, and practical activities. This finding is in line with Herman et al. (2013a) who reported that NOS instruction was mostly observed in lessons that included inquiry-based or research activities. However, the classes observed in the current study were mostly teacher-directed and appeared to reinforce scientific content knowledge rather than highlight scientific methods or characteristics of scientists. Even when interactive resources and activities were used, the teachers did not allow students to fully explore the concepts. This finding suggests that teachers valued the idea of the various approaches that contribute to NOS learning (Allchin et al., 2014), but were still inclined towards traditional, didactic teaching methods. Further, there were not many deliberate attempts observed to address NOS issues during the classes, even though there were opportunities to do so based on its explicit presence at least in the lower secondary school curriculum. This observation is consistent with the findings of Herman et al. (2013b) and Sarieddine and BouJaoude (2014) who observed that teachers seemed unable to capitalise on moments in lessons to apply NOS instruction.

The qualities of scientists' practices were evident in the teachers' lessons. For example, teachers encouraged collaboration through classroom seating arrangements or in online spaces by asking students to work in pairs, small groups, or engage in whole-group activities. Additionally, students' observation skills were encouraged through simulation and outdoor activities. However, these activities were frequently teacher-led and directed. It was also noticed that when practical activities were used, they were not linked to describing how scientists do their work or to the scientists who developed the theories (Sousa, 2016). It is important that teachers understand that by portraying the characteristics of scientists in their lessons they are helping students to see the scientific enterprise and can inspire the next generation of scientists.

Teachers' Self-Declared NOS Knowledge was Evident but not an a Sustained way in their Classrooms

Despite the positive NOS gains, these were not adequately transferred to teachers' classroom teaching signalling incomplete transfer of learning and in one case, possible inaccurate or faulty transfer (Kurup, 2014; Zeichner & Tabachnick, 1981). Many NOS elements were evident in science teachers' classes, and these were mostly related to the theme "The nature of instructional strategies". The least observed elements were those related to the themes "The nature of scientific knowledge", and "The nature and characteristics of scientists and scientific methods". Herman et al. (2013b) support this finding when they concluded, after reviewing relevant literature that even with accurate NOS understanding teachers neglect NOS practices in their classrooms. This is the case even for teachers with various levels of experience and in the context of the current study, for teachers of different science subject areas who teach at different grade levels.

The results show that it is possible for teachers to retain their improved NOS knowledge for at least four months after completing a teacher education course. However, it leaves doubt to the proposed relationship among accurate NOS understanding, carefully presented teacher education programmes, and the effective transfer of NOS to classroom teaching. Abd-El-Khalick and Lederman (2000) proposed that numerous contextual and personal factors could influence the transfer of NOS knowledge into instructional practice. Based on the findings of the current study, the relationship between accurate NOS knowledge in carefully presented teacher education programmes, and the effective transfer of this knowledge to classroom teaching appears logical. Therefore, these findings indicate there is potential for the intentional inclusion of NOS content in science teacher education programmes to enhance teachers' understanding and teaching of this important concept. By providing teachers with a deeper and more accurate understanding of NOS, such programmes can help them to effectively convey this knowledge to their students.

Conclusions and Recommendations

Science teachers improved their NOS understanding after completing a course dealing with NOS explicitly. However, there was a high focus on science content, and less on the language of science, characteristics of scientists and their methods. Despite their improved NOS knowledge, teachers did not implement it in their classrooms in a sustained way.

Science education researchers have long advocated for incorporating explicit NOS teaching into science teacher education (e.g., Abd-El-Khalick & Lederman, 2000; Duschl & Grandy, 2013; Sumranwanich & Yuenyong, 2014). The findings of the current study in the Caribbean support existing literature in other international contexts. Despite the positive results with respect to increased NOS knowledge, the findings support the international concern that teachers do not adequately transfer NOS concepts to their classroom practices. Further, the findings in the current study were not limited to teachers of specific science subjects or grade levels in Caribbean schools.

The study's results suggest a possible relationship between NOS instructional approaches in teacher education programmes and teachers' NOS understanding. This relationship is useful for science teacher educators in planning effective NOS instruction. Science teachers should be provided with ample opportunities to engage with NOS in science methodology courses which include content areas such as NOS definitions, views of science, instructional strategies that support NOS and NOS focused lesson-planning.

Seeing that this study utilised a quantitative instrument to determine teachers' NOS understanding, education researchers could explore teachers' NOS choices by using open-ended items or interviews during teacher education courses and the practicum. This would allow for further probing of teachers' NOS knowledge, understanding, and beliefs to determine how these could influence their instructional practices. Further study could also explore providing closer scaffolding for teachers' NOS knowledge development. This could be done by providing specific feedback on instructional practices regarding NOS concepts, during the practicum and beyond the completion of the programme. The teachers' practices could then be observed for NOS elements resulting from the additional support provided.

The findings in this study indicate that further research needs to be conducted to investigate the factors that influence science teachers' long-term retention of NOS knowledge. However, seeing there has been a dearth of studies on teachers' NOS understanding and practices in the Caribbean, the current study provides a foundation for future research in the region.

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Appendix
Nature of Science Observation Protocol (Sample)

Candidate: ____________________________ **Subject: _________________________**

Nature of Science characteristics	**Indicators**	**Please tick to indicate each time the behaviour is observed in the lesson**	**Provide example/s**
1. Nature of scientific knowledge (6 indicators) Guiding question: *How is the NOS addressed in the scientific content?*	Use of historical scenarios/ cases		
	Mentions social/cultural influence on science		
2. Nature of instructional Strategies (8 indicators) Guiding question: *How is scientific knowledge presented?*	Transmission of knowledge/lecture approach not dominant		
	Posing questions to draw attention to NOS issues		
3. Nature and characteristics of scientists and scientific methods (5 indicators) Guiding question: *How are the qualities, characteristics and work of scientists addressed?*	Collaboration strategies/ exercises included		
	Approach to practical activities encourages inquiry approach as opposed to cookbook/ recipe type		