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Nature of Science in Preservice Science Teacher Education–Case Studies of Irish Pre-service Science Teachers

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ABSTRACT
Understanding Nature of Science (NOS) is a requisite for improving scientific literacy, and as such, it is increasingly being included in science curricula worldwide. It is now therefore important that teachers understand NOS so that intended learning outcomes become visible in the classroom. Pre-service teachers also need an opportunity to develop an understanding of NOS. As a result of a national curriculum change in the Republic of Ireland, which saw the explicit inclusion of NOS in the school for the first time, the study was designed to develop pre-service teachers (PSTs) understanding of NOS. To aid PSTs understanding, workshops were designed around the theoretical perspective of the Family Resemblance Approach to Nature of Science. The framework is also referred to some authors by the Reconceptualized Family Resemblance Approach or RFN. The article presents case studies to illustrate how the PSTs navigated the ideas presented to them during NOS workshops and how they translated their understanding from the workshops into their lesson preparation. Data were collected over a calendar year, and findings were drawn from interviews, lesson plans, and assessment tools. The results indicate that although the two case-studies in the study had similar attendance and engagement, their understanding of what constituted NOS incorporation differed. The case studies presented are useful for illustrating how PSTs react to courses designed using the RFN framework and for showing evidenced implications for pre-service teacher education during a time of curricular reform.

KEYWORDS
Nature of science; pre-service teachers; case studies, Assessment

Introduction

Nature of Science (NOS) is a meta-perspective of science that includes the views from history, philosophy, sociology, psychology, and practical aspects of science (Galili, 2019). McComas (2004) refers to the definition and scope of NOS as the “rules of the game” (p. 25) which have led to the knowledge production and the evaluation of truth claims in the natural world. His definition states that NOS includes learning about how science functions, viewing scientists at work, and reviewing their interactions in a community. It is commonly outlined how important it is to develop Nature of Science (NOS) understanding and address it in science education as it is an essential component of scientific literacy (Abd-El-Khalick & Lederman, 2000; Matthews, 2012). Science curricula globally are included in NOS more frequently as features of curricular documents (Hodson & Wong, 2017). NOS

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has been topical in science education discussions since the 1960s with the seminal works by Conant (1961) and Klopfer (1969) and is often cited as being one of the most stated objectives for science education. Despite frequent calls for its inclusion, NOS remains limited in scope and explicit applications (Yacoubian, 2021). A rich tapestry of NOS views and perspectives exists (Abd-El-Khalick & Lederman, 2000; Allchin, 2011; Erduran & Dagher, 2014; Irzik & Nola, 2011; Matthews, 2012) which often begs the question of whose view of NOS should be included in school instruction (Lederman et al., 2002; Matthews, 2012).

Many studies on NOS teaching and learning are still frequently using a perspective that is commonly referred to as the 'consensus view' (Lederman, 2007). The consensus view represents a set of tenets, which present NOS-related ideas, such as tentativeness, empiricism, subjectivity, theory-ladenness, and the myth of the scientific method among others. The perspective reflects a level of "consensus" among various philosophical positions. One of the main arguments that favors the consensus view is its accessibility to school students and its ability to be conveyed regardless of an individual's science capital and future career aspirations (Yacoubian, 2021). Many studies have looked at how adopting the view supports understanding of NOS and their results have at times been disappointing for a full understanding, particularly when considered longitudinally. Neoteric work by Khishfe (2014), Herman et al. (2013) and Yacoubian (2021) used longitudinal studies ranging from five months to 12 years. All the studies experienced short-term gains when using NOS interventions that use consensus frameworks embedded within explicit and reflective discussions. Despite short-term gains, Khishfe's study saw the participants reverting to their naïve views 4 months after the intervention. Discourses in the science education community have raised concerns about whether it presents a fragmented and narrow view of science (Galili, 2019; Hodson & Wong, 2017) and alternatives to this view have since emerged (Allchin, 2011; Erduran & Dagher, 2014; Irzik & Nola, 2011; Matthews, 2012). Allchin (2011) has called for a reframing of the current NOS characterizations to the multiple dimensions shaping reliability in scientific practice, from the experimental to the social, in his view, the Whole Science. Allchin argues that many items related to science as an enterprise—funding, motivation, peer review, cognitive bias, fraud, and the validation of new methods—need to be emphasized for learners. Another view that has emerged in opposition to the tenets is that of Matthews (2012), who proposed a set of ideas called Features of Science (FoS). Some ideas of which reflect epistemic aspects of science (e.g., explanation, theory choice, and rationality), others reflect philosophical stances (e.g., feminism, realism, and constructivism).

The study presented results from wanting to explore the influence of another perspective other than the consensus view and also from a national curricular change in the Republic of Ireland, which saw the explicit inclusion of NOS for the first time (DES, 2015). It examines the development of preservice teachers (PSTs) understanding of NOS through participation in a professional development workshop designed around the theoretical perspective of the Family Resemblance Approach (FRA) to nature of science (Erduran & Dagher, 2014). FRA conceptualizes NOS in terms of a cognitive-epistemic and social-institutional system. The idea of a family resemblance is based on an understanding that all disciplines of science share certain characteristics; however, none of these characteristics can define science or detach it from other disciplines. As such, the FRA perspective provides a coherent approach to capturing domain-general and domain-specific aspects of NOS by highlighting the similarities and unique differences among the sciences. Erduran and Dagher (2014) built

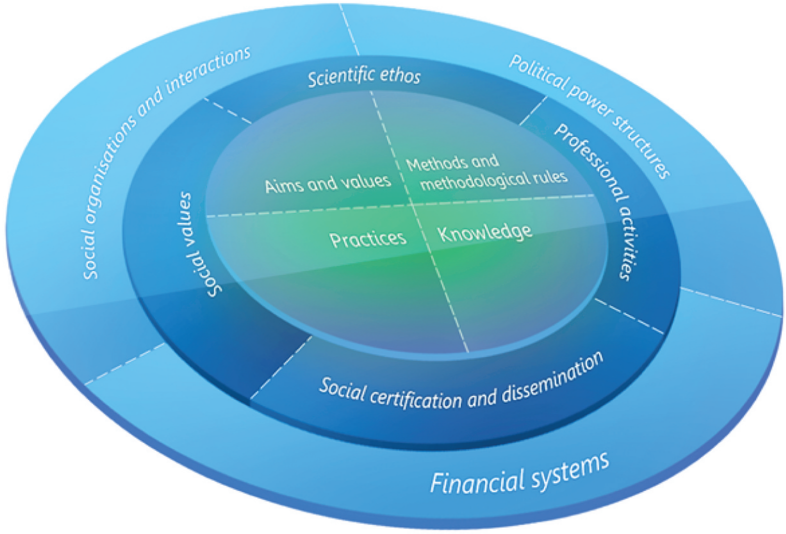


Figure 1. The FRA wheel illustrates science as an epistemic-cognitive and social institutional system (Erduran & Dagher, 2014, p. 28).

on Irzik and Nola's Family Resemblance Approach (FRA) to present a comprehensive and systematic framework and reconceptualize it with science education literature and heuristics for educational purposes. Figure 1 illustrates the FRA categories with further explanation in Table 1. Some authors (Kaya & Erduran, 2016) have referred to Erduran and Dagher's (2014) discussion of FRA as the "Reconceptualised Family Resemblance Approach to Nature of Science" (RFN) in order to distinguish it from its philosophical counterparts. In this paper, we will use the RFN terminology to emphasise the educational adaptations of FRA in science education.

The following research questions drove the study, in order to explore the influence of the RFN perspectives on the PSTs NOS content knowledge and NOS pedagogical content knowledge (Abd-El-Khalick et al., 1998; Mesci & Schwartz, 2017; Shulman, 1986) at a time of national curricular change:

(1) What influence will participation in workshops underpinned by the Reconceptualized Family Resemblance Approach to Nature of Science (RFN) theoretical framework have on PSTs' content knowledge of Nature of Science (NOS)?
(2) To what extent will participation in the workshops influence the pre-service teachers to incorporate NOS explicitly in lesson planning?

Theoretical framework

The Family Resemblance idea was originally described by Wittgenstein (1958) in response to his recognition that not all terms can be defined in terms of necessary and sufficient conditions to encapsulate the essence of the term. His example describes how members of a family can each resemble one another in some ways but not in others. In his book, *Philosophical Investigations*, Wittgenstein (1958) argues that the term "game" would require

Table 1. Overview of the category definitions and topics of the workshops.

Category	Description	Learning outcome of the workshops
Introduction	Introduced the new curriculum changes and the RFN framework through some group activities which provided a broad overview of the remaining workshops	(1) Reflect on science at a meta-level (2) Identify features of the NOS that will form the structure and aims of the future workshops (3) Engage with the new curriculum
Methods and methodological rules.	Introduced the myth of the scientific method as well as showing how methods in science are manipulative as well as non-manipulative techniques that underpin scientific investigations and how they inform Practices.	(1) Understand the educational implications of highlighting the diversity of scientific methods. (2) Explore the myth of the scientific method. (3) Differentiate between the methods that various scientists can use to conduct science investigations. (4) Compose assessment activities related to the Methods category
Practices	Set of epistemic and cognitive practices that lead to scientific knowledge through social certification namely experimentation, observation and classification.	(1) Understand the different practices used by scientists including experimentation (independent and dependent variables), classification, and observation (observation v's inference) (2) Compose assessment activities related to aspects of Practices.
Knowledge	Theories, laws and models that underpin the outcomes of the scientific inquiry Social mechanisms through which scientists review, evaluate and validate scientific knowledge.	(1) Evaluate how knowledge is presented in school science (2) Understanding the mechanism of knowledge growth so as to distinguish scientific knowledge as coherent networks of theories, laws, and models, rather than discrete and unrelated pieces of information. (3) Demonstrate how theories, laws, and models work together to generate and validate new knowledge. (4) Evaluate the curriculum in relation to the knowledge aspect as examined in the workshop
Aims and values	Cognitive and epistemic objectives of science, such as accuracy and objectivity.	(1) Consider and critique the epistemic and social Aims and Values of science. (2) Appreciate the implications of how the Aims and Values of scientists can impact knowledge production and publication. (3) Analyze assessment tasks in relation to Aims and Values and the JCSS learning outcomes.
Social certification and dissemination	Social mechanisms through which scientists review, evaluate and validate scientific knowledge for instance, through peer review systems of journals	(1) Evaluate various aspects of both positive and negative implications of science in a social institutional system. (2) Analyze assessment activities designed around aspects of science in a social institutional system and the new curriculum learning outcomes
Scientific ethos Social values Professional activities	Norms that scientists employ in their work as well as in interaction with colleagues Values such as freedom, respect for the environment, and social utility	
Social organizations and interactions	How scientists engage in professional settings such as attending conferences and doing publication reviews	
Financial systems	How science is arranged in institutional settings such as universities and research institutes	
Political power structures	Underlying financial dimensions of science including the funding mechanisms; Dynamics of power that exist between scientists and within science cultures.	
Revision	(1) Reflect on and revise *Methods*, Practices and *Knowledge* aspects of the RFN framework. (2) Analyze and evaluate assessment activities design by the author in relation to the RFN framework, new curriculum at a meta-level perspective.	

a number of attempts to define it. Any attempt to define the term "game" must include games as different as ball games, stick games, card games, children's games that do not involve balls, sticks, or cards, such as tag or hide-and-seek, solo games (hop-scotch), mind games, and the like. Nevertheless, Wittgenstein argued that all games form "a family resemblance," establishing a complicated network of similarities (Wittgenstein, 1958). Philosophers of science, Irzik and Nola, adapted Wittgenstein's generic definition to NOS to present science in two aspects: cognitive and epistemic, and science as a social-institutional system, where each have their own distinct categories. This view of FRA characterizes a field of science as a set of broad categories to address a diverse set of features common to all the sciences. The original inception, proposed by philosophers of science Irzik and Nola (2014), sees the theoretical framing embodying a set of aims and values, practices, methodologies, and social norms deserving of inclusion in science curricula. To highlight the distinction between its educational application from Irzik and Nola's philosophical framing, Kaya and Erduran (2016) introduced the "Reconceptualized FRA-to-NOS" (RFN).

FRA responds to criticisms of NOS views, namely that NOS understanding should not be prescribed as a list of declarative statements like those presented in the consensus view (Matthews, 2012), and the ideas should not be so exhaustive that it inhibits education professionals accessing the ideas for teaching and assessment (Cheung, 2020). It is based on an understanding that all disciplines of science share certain characteristics; however, none of these characteristics can define science or demarcate it from other disciplines. The FRA theoretical framing articulates the interdisciplinary aspects of science while at the same time, preserving the disciplinary nuances. FRA conceptualizes science in terms of a cognitive-epistemic system and as a social-institutional system. Science as a cognitive-epistemic system encompasses processes of inquiry, aims and values, methods and methodological rules, and scientific knowledge. Science as a social-institutional system encompasses professional activities, scientific ethos, social certification and dissemination of scientific knowledge, and social values. The FRA framework is novel, as when covered collectively and inclusively, science is presented to learners more authentically and coherently (Erduran & Dagher, 2014; Yeh, et al., 2019). A fundamental reason for teaching about NOS through the FRA perspective is to help students know about the scientific process. By knowing this process, it can help them understand how science works and be able to reach explanations and conclusions that consider several scientific dimensions of socio-scientific issues (Duschl & Grandy, 2013; Erduran & Dagher, 2014). FRA allows science educators to incorporate both the domain-general and the domain-specific features of science. Figure 1 and Table 1 illustrate the ideas of interaction between the various components of NOS. The representation offers an intersecting set of 'permeable' borders. Although the account has similarities to other perspectives, as demonstrated in their 2017 publication, the authors discuss how FRA subsumes other NOS views (i.e. FRA, FoS, whole science, and the consensus view) and it also shows how it includes areas not in any of the perspectives above (Dagher & Erduran, 2017).

FRA has been used as an analytical framework for curricula and high-stakes assessment analysis (Caramaschi et al., 2022; Cheung, 2020), school textbook analysis (McDonald & Abd-El-Khalick, 2017) as well as a framework for investigating university students' understanding of NOS (e.g., Akgun & Kaya, 2020) and the design of practical lesson resources for classroom learning (Erduran et al., in press). It has been used in teacher education (Erduran et al., 2021; Erduran & Kaya, 2018). Erduran and Kaya (2018) investigated how aspects of NOS such as nature of “scientific knowledge” and “scientific practices” can be represented visually and how they could be used to facilitate teachers’ learning of NOS.

National context of the study

The study took place as a result of NOS being introduced to the middle-school science curriculum in the Republic of Ireland (DES, 2015). Nationally, there were broader political issues that were impacting teacher education. The new science curriculum was part of a significant reform effort of the middle school education system (DES, 2015). The proposals were massively rejected by teachers and teacher unions (Donnelly, 2014). Consequently, the teacher unions announced plans for strike action and secondary schools around the country faced closures for 7 days, spanning the time when the PSTs in the study would be on school placement. One consequence of the strike action was that the unions advised teachers not to attend any professional development sessions and the majority of teachers and schools complied with this order (Donnelly & O’ Keeffe, 2016). The government was determined to implement it, and despite the teachers’ lack of training, the new curriculum was implemented in September 2016. One of the main teachers’ unions; the Association for Secondary Teachers, Ireland (ASTI) outright refused to co-operate with the introduction of reform, although members of the other second-level teachers’ union, the Teachers’ Union of Ireland (TUI) were implementing the changes (Donnelly & O’ Keeffe, 2016). At the time of the study, the PSTs entered into a schooling system in turmoil and split into a two-tier system. Teachers in TUI schools were to teach and assess in certain subjects under the new methods, while ASTI members refused to participate in training for the changes, and would not conduct new classroom-based assessments (Donnelly & O’ Keeffe, 2016).

As a result of the uncertainty around the new curriculum, the university was not organized in their preparation to support pre-service teachers NOS content and pedagogical content knowledge development. At the time of the study, there was no NOS provision in the university. The first author offered an introductory program to facilitate PSTs access to NOS concepts and ideas. The presence of NOS is very prominent in the new curriculum and is an overarching feature. Ten NOS learning outcomes are split across four ‘elements’ of NOS: i) understanding of science, ii) investigation of science, iii) communicating in science, and iv) science in society. The conceptualization of the curriculum is that the NOS strand is integrated within the other contextual strands (DES, 2015). The curriculum document outlines how learning outcomes are attained through the contextual strands and pupils develop their knowledge through scientific enquiry and allow students to develop scientific habits of mind, reasoning skills and build a foundation for understanding phenomena they encounter in everyday life (DES, 2015). It was evident from reading the curriculum document that the PSTs would need an appropriate level of understanding in order to achieve its ambitious aims.

RFN workshops

To facilitate understanding of NOS and the curriculum, the workshops engaged with both the curriculum and RFN framework to develop an understanding of how to embrace the learning outcomes. The first author designed and facilitated the workshops through social constructivist methods, where the PSTs were urged to engage in their own process of learning actively. Six two-hour workshops were designed to take place over consecutive weeks, with an additional workshop taking place following the summer break and prior to a 10-week teaching placement. Table 1 outlines the design of the workshops. This design was in line with realistic interventions in terms of time for the cognitive knowledge development of teachers in science education (Darling-Hammond et al., 2019). The structure of the workshops mirrored their current pedagogical provisions at the university. These pedagogical lectures also took place over a six-week period and tended to focus on inquiry based learning through school laboratory investigations. Each RFN workshop in contrast, examined a category from the RFN framework and explored how ideas from the category could be incorporated into the new curriculum learning outcomes. In addition to focusing on NOS content knowledge, the workshops included the development of teacher knowledge bases and pedagogical skills (Schwarz et al., 2008; Shulman, 1986). Using curriculum materials is a core component of a teacher's practice, and preservice teachers are particularly dependent on curriculum materials to guide their teaching (Schwarz et al., 2008). Therefore, approaches that implement curriculum analysis were used to help PSTs modify curricular materials for classroom use (Schwarz et al., 2008).

Each workshop introduced a category with ideas from the framework. The sequence of the workshops included an introductory session, followed by a session on methods and methodological rules, then practices, then knowledge, followed by aims and values, and finally, the category of science as a social institutional system. A revision session was held after the summer break, prior to their school placement. Table 1 outlines the workshop sequence and the broad content covered in each workshop. The PSTs were provided with written assessments designed by the authors to analyze and evaluate which curriculum learning outcomes and RFN categories, the assessments best captured. Figure 2 contains an image of one assessment task, the curriculum learning outcomes and RFN category statements the PSTs attributed to the assessment task. It allowed insight into the participants' understanding of NOS and how it could be achieved in the classroom through written assessment tasks.

Participants

The workshops were offered to third-year students who were in a four-year concurrent Bachelor of Science Education program. At that stage, the PSTs had experience in the classroom and completed science and education modules as outlined in Table 2.

Participants were recruited via a presentation at a science education lecture where they were introduced to the workshops, and the presentation was subsequently followed up with an email. Prior to the beginning of the study, ethical clearance was granted by the university's Education and Health Sciences Research Ethics Committee (EHSREC—application number 2015_10_06_EHS). Attendance for the PSTs was voluntary, and they received no incentives to participate. The national context at the time was also thought to have influenced participation (i.e. the teacher strike action as outlined previously). Due to all these issues, participation was limited, with 44 expressing interest, eight attending the first evening, and with its voluntary nature resulting in only four participants joining most frequently. Hilary and Felicity (pseudonyms) were selected for the case studies as both reported having no previous experience with explicit NOS education and throughout the

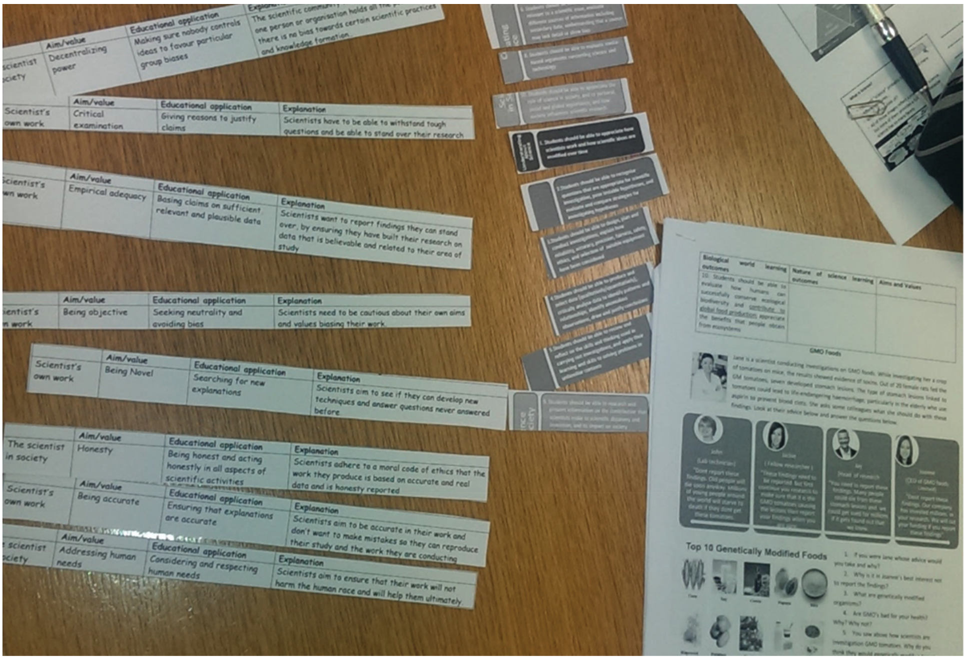


Figure 2. The image presents the learning activity (lower right) based on Aims and Values, along with the learning outcomes from the curriculum (middle) and RFN—aims and values statements (left).

Table 2. Bachelor of Science with concurrent Teacher Education—Biology & Chemistry route.

Year 1 Semester 1	Year 1 Semester 2
Biology 1 General Chemistry 1 Mechanics/Heat/Electricity /Magnetism MA4601Science Mathematics 1 Contemporary Understanding and thinking on education	Biology 2 Inorganic Chemistry 1B Physical Chemistry 1 Science Mathematics 2 Educational Technology for Teaching and learning Understanding young people and they learn
Year 2 Semester 3	Year 2 Semester 4
General Microbiology Introductory Anatomy & Physiology Animal Diversity Organic Chemistry 2 Planning for Learning Understanding Classroom Practices	Teaching Science 1 Preparation for School Placement School Placement 1
Year 3 Semester 5	Year 3 Semester 6**
Plant Physiology Cellular Biology and Biochemistry Inorganic Chemistry 2B Curriculum and Policy Studies Inclusive Education 1: Contemporary Perspectives	[**The NOS workshops took place in this semester] Ecology 1 Analytical Chemistry for the Environment Waves/Light/Modern Physics Teaching Science 2 Inclusive Education 2 Special Educational Needs
Year 4 Semester 7	Year 4 Semester 8
School Placement 2 Understanding Schools Final Year Project	Genetics and Molecular Biology Principles of Human Nutrition Final Year Project Environmental Chemistry Nanotechnology Teacher as Professional

intervention both PSTs were very engaged in the workshops. They attended and contributed to all aspects of the intervention and provided most of what was asked of them during the study, which was a unique trait to these particular PSTs. All participants received similar treatment in terms of introductions to NOS concepts and so neither of the cases were advantaged over the other. The two cases were selected following participation in the study as they indicated what would be feasible if a program of this nature was introduced to the degree program. Data were collected for all participants, but we chose to focus on these two cases for the following reasons. Hilary serves as a contrast to Felicity, as she demonstrated a better understanding of NOS content knowledge as seen in the written tasks, and she was able to demonstrate more aspects of RFN explicitly in her lessons, as shown during interview and her discussion of her lessons and teaching resources she developed. Hilary appeared to implement more aspects of the RFN categories explicitly in her lessons, particularly the aims and values category. The comparison of the cases allows us to investigate potential outcomes from how a program underpinned by the RFN framework can influence teacher NOS content knowledge and lesson planning. Each case will be outlined below separately to provide greater insight.

Case study methodology

Cohen et al. (2007, p. 253) explain that a case study is a specific instance to illustrate more general principles. The intention of using case-studies is to examine the PSTs in-depth following participation, to better understand the phenomenon (Yin, 2003). Case study design was an appropriate approach to provide an in-depth answer to our research questions by providing illustrations of how PSTs react to NOS professional development from an RFN perspective and mediated the translation of workshop material into their lesson preparation.

Study design, data collection, and analysis

Various data sources were used and analyzed through an interpretivist approach, which is often used in small-scale studies (Cohen et al., 2007). Through pattern clarification, a process that involves reading and re-reading the coded data to recognize and separate patterns in the data set (Boyatzis, 1998). The identification of patterns in the data involved an inductive process, which was grounded in interpretations of the data. Table 3 outlines the data captured that include audio-recorded interviews, lesson plans, and teaching resources, as well as their analysis of as classroom tasks developed by the author around the RFN framework categories.

Due to the first author being the facilitator of the workshops, relationships were built with those being studied. Insider research can receive criticism for ‘researcher bias,’ when the researchers’ personal values and experiences influence the research questions, design and data collection procedures (Chavez, 2008). For example, as Hilary was identified as a strong candidate from the beginning, there was the potential that this perspective could inflate observations of her capabilities. To negate issues of bias, the author used a system of critical friends as a sounding board for the findings produced. Other experienced science education researchers were used to validate the findings. They were presented with data and

Table 3. Research questions and data collection tools used and method of analysis implemented.

Research Questions	Data collection tools	Method of analysis
What influence will participation in workshops underpinned by the RFN have on PSTs' content knowledge of NOS?	**Activities in the Workshop** **Pre-written task** **Post- written task** **Delayed written task**	The method of analysis implemented both content analysis and thematic analysis; incorporating simultaneously, the data-driven inductive approach of Boyatzis (1998) and the deductive approach of Crabtree and Miller (1999).
To what extent will participation in workshops influence the pre-service teachers to incorporate NOS explicitly in lesson planning?	**Lesson plans** **Post teaching practice interview**	

coding schemas and asked to observe if they interpreted the data in the same way as the author. Lengthy discussions of the data led to an interpretation that limited bias (Cohen et al., 2007).

A written task was used to gather the PSTs' NOS views prior to, immediately following, and several months following the workshops. The task was designed around RFN and borrowed approaches from other established tools (Lederman et al., 2002). The task contains nine main questions, each with sub-questions to illicit qualitative responses. Qualitative items have the potential to gather detailed views, which can be analyzed for sophistication to indicate depth of NOS understanding (Ayala-Villamil & García-Martínez, 2021). The questions asked about theories, models, and laws, the tentative nature of knowledge, myth of the scientific method and participants were asked to categorize science methods based on whether they used *the scientific method* or not. The task asked participants to indicate their views on: the influence of social issues on science, perspective on the aims and values of science, and examine ideas around the practices of scientists. Each administration of the task had the same questions (in a rearranged order) so that changes to their understanding could be observed. The task underwent content validity when it was given to eight science and math education experts. The science education researchers (n = 4) were knowledgeable about the framework as well as the task design and the math education experts (n = 4) were knowledgeable about item development and questionnaire design. The tasks were amended following their feedback on the appropriateness of the items for the target audience (PSTs), alignment of the questions with the RFN framework, and suggestions to better the design for qualitative and quantitative data collection. Once administered, the quality of the PSTs responses were classified using a scoring rubric consisting of four levels: incorrect, naïve, developing, and informed (see, Table 4), which resembled that used in VNOS. Any response classified as incorrect received no score (zero), a naïve response received a score of one, a score of two was awarded for responses deemed as "developing," and a score of three was awarded to answers judged as informed views of NOS. The scoring rubric produced guidelines for each scoring category for every question and a total score of 66 was possible if all answers were judged as "informed view of NOS." Reliability exercises were performed with three science education experts who were familiar with the framework. They were each provided with the same written tasks and asked to score it independently. When compared with the author's judgment, their results provided an average percentage agreement of 83.5%, which is an indicator of reasonable reliable according to Miles and Huberman (1994).

Table 4. Scoring rubric for responses provided to questions on the R-NOS worksheet.

Numerical score	0	1	2	3
Description	no response or incorrect view of NOS	Naïve or emerging view of NOS	Transitional or developing view of NOS	Informed view of NOS

Lesson plan analysis

The strike action made access for the author to the classroom more challenging and so lesson observations were not conducted. Although the schools that the PSTs were placed in were TUI schools and were implementing the new curriculum, the schools were still participating in organized strike action. Due to these impediments of the strike action for the researcher to classroom observations, lesson plan analysis was instead chosen as a method to evaluate how the PSTs planned for NOS. This strategy was thought to be the next best indicator of intent to teach about NOS. The PSTs were asked to bring two lesson plans to interview that they thought incorporated NOS effectively. Hilary provided two lesson plans, which consisted of two pages and were extremely limited in detail. Felicity provided one detailed lesson plan but also provided a description of bulleted rationales for each part of the lesson. All these documents were analyzed through content analysis methods using the RFN framework. The documents were analyzed for descriptions of both explicit and implicit cases of NOS. Felicity's lesson plan illustrated no examples of explicit instances. There were aspects that were considered examples of an implicit instance in Felicity's lesson plan. She talked about getting the students to "*create a procedure for the experiment*," instances such as those were counted in both the methods and practices categories of the RFN framework. An example of an explicit instance was in Hilary's lesson plan where the lesson aim mentioned "*develop student understanding of the effects of bias and accuracy on a study*," instances such as those were counted in the aims and values category as this category explicitly deals with *bias and accuracy* in science. The interview showed Hilary's lesson plan contained both implicit and explicit NOS reference, as well as being able to discuss more RFN categories she felt the lesson plan was able to achieve. Her lesson plans showed times where she explicitly planned for incorporating bias and accuracy into the lessons. Felicity found articulation of explicit NOS in her lesson plan much more difficult.

Case study findings

The following section outlines findings from the case studies that emerged from the year-long study that draws on written tasks, lesson plans, lesson resources, and semi-structured interviews that took place after the workshops and again after teaching practicum. The interview questions following the workshop were evaluative in nature and asked them what they felt were the perceived benefits of their participation. The post-teaching practice interview questions focused on their experiences of incorporating NOS into their lessons and lesson planning. Case One presents Hilary, who demonstrated a strong understanding of NOS at an early stage and engaged well in the workshops and incorporation of NOS lessons. Case Two presents Felicity, who was interested in NOS but demonstrated to have difficulty incorporating NOS understanding into her lesson plans. Scores from the written task showed Hilary displayed greater NOS knowledge at the beginning of the study, and further improved during the study and maintained it following her teaching placement. Felicity demonstrated to be less informed about NOS at the beginning of the study, but participation improved this understanding at a greater scale, and even increasing her score in the written task following her teaching practice (see, Figure 3). Her case will illustrate that she had difficulty incorporating NOS into her lesson plans. Both Hilary and Felicity reported how participation in the workshops increased their confidence upon entering the classroom. The next section will individually discuss the nuances of each case.

Case 1 - Hilary

From an early stage in the study, Hilary displayed signs of good understanding as shown from her result in the written task (see, Figure 3). Hilary worked in youth centers and did both voluntary and paid tutoring for high school students, so had more teaching experience then would be typical of a PST at this stage. As she had much more teaching experience, she would be more familiar with science content knowledge and placed her at a higher cognitive developmental stage (Mulvey & Bell, 2017). Throughout the study, she embraced the ideas in the workshops and understood the ideas well through group discussions. Following the workshops, Hilary recognized the importance of incorporating NOS into her lesson planning and how it needs to be thoughtfully planned for to be made explicit in teaching.

> If it was something that naturally came into lessons, it would already be in lessons because we are already taught science, but you don't know nature of science just by doing science. So, I do think it is something you need to plan for because it doesn't just happen.

Although Hilary realized that explicit planning for NOS was important for its enactment in the classroom, her lesson planning documents were limited for NOS content, but her associated lesson resources indicate her knowledge of explicit NOS planning.

Hilary's NOS lesson planning

Despite Hilary showing cognizance of the importance of planning for NOS, the lesson plans she chose to provide were limited in detail. Most evidence of Hilary's NOS planning was illustrated in her lesson resources and the interviews. She was very articulate during the interview about her planning and was able to provide insight into her lessons where she described several instances of NOS incorporation. Hilary was interested in social justice issues and often talked of the socio-economic difficulties of the town she worked in and did her teaching practice in, particularly during the post-teaching practice interview. It was suspected that her links to the youth center brought these issues to the forefront. Hilary reported emphasizing the aims and values aspect of the RFN categories in her lessons. Also, issues such as drug-taking, smoking, and teenage pregnancy filtered through her teaching and used these issues to teach about NOS explicitly and the social system categories of the RFN framework. One of the lesson plans she presented for the study in an interview introduced a research project on the chemical and sociological impacts of recreational drugs. Analysis of the lesson plan shows one instance of the knowledge category where it talks about the knowledge produced by scientists and the socially constructed knowledge. However, the lesson focused on the aim and values aspect and included matters such as

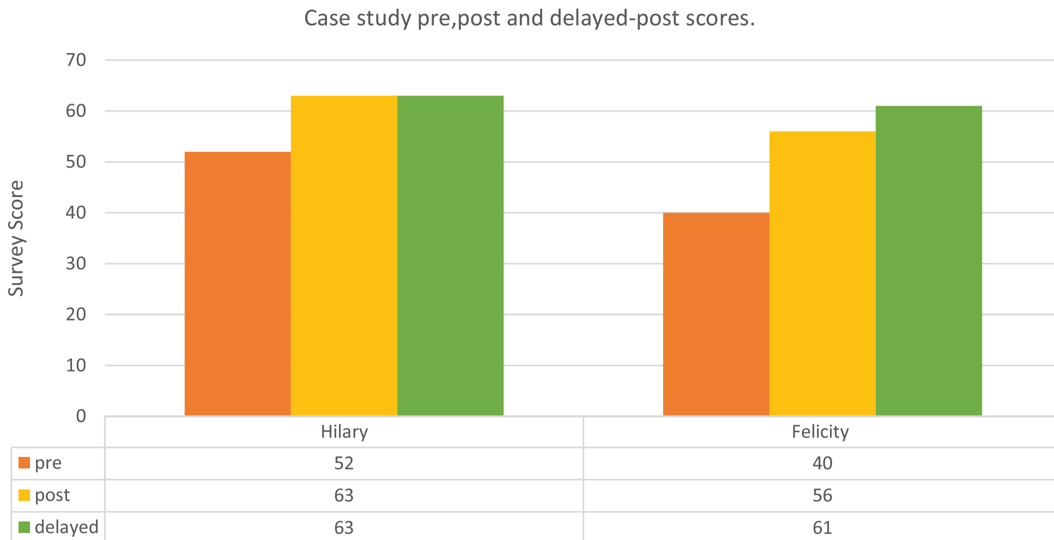


Figure 3. The scores obtained by the PSTs on the pre, post and delayed written task.

accuracy in reporting data and the importance of objectivity in science. In the summation of her lesson description, she stated how she hoped the lesson would "*make them think twice about taking drugs in the future*." This indicated Hilary was interested in aspects of NOS that went beyond curriculum needs.

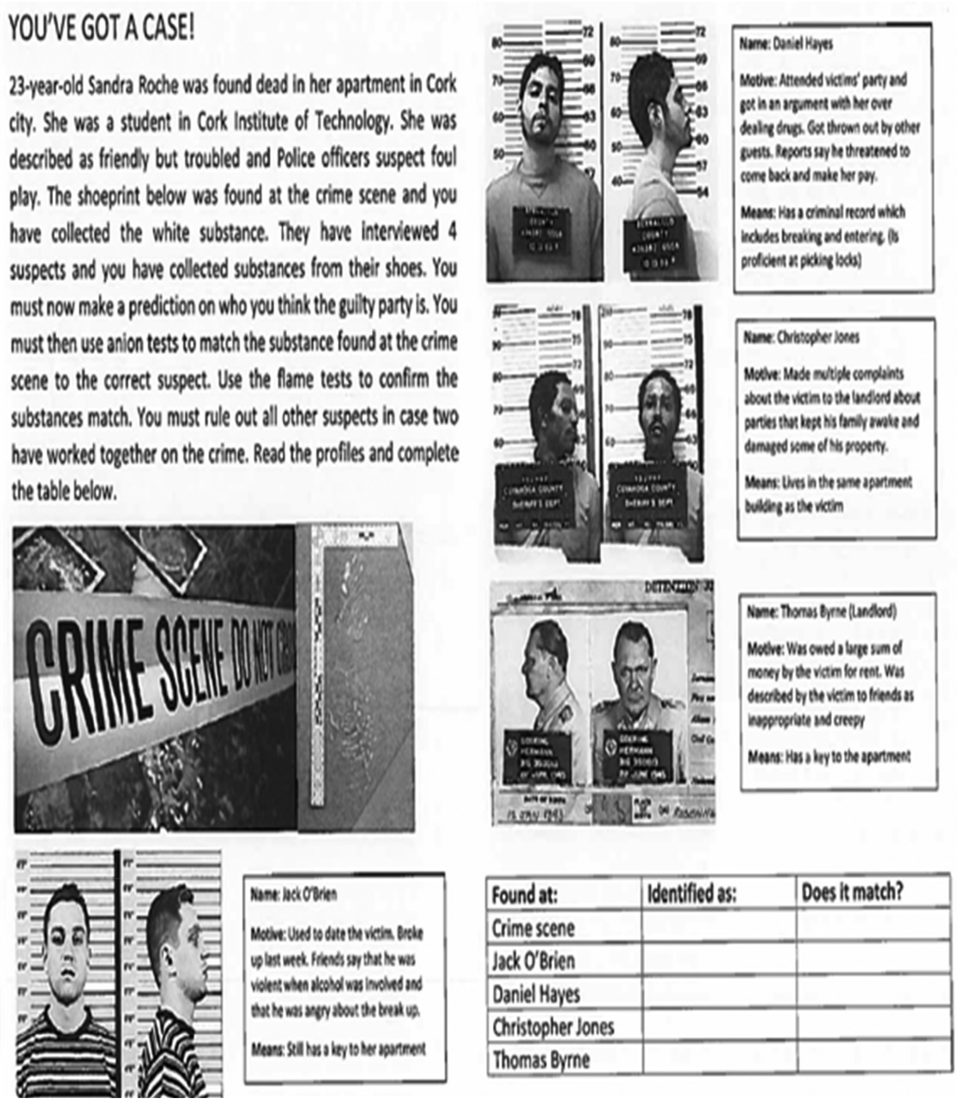
The other lesson she provided examined the aims and values category once again, but this time it was developed through a forensic case that emphasized bias and objectivity in science. She made posters to illustrate redox reactions and developed PowerPoint presentations that provided the science content and good imagery to present science concepts, as well as a unique worksheet that incorporated NOS aspects from the aims and values workshop. The activity designed by Hilary (Figure 4) shows an imaginative way to include NOS in science lessons. This activity was developed as part of a chemistry lesson using a murder case to set the scene for forensic testing—anion/flame testing. The pupils read the suspects' alibis and discussed who they thought was the murder and nominated their suspect prior to conducting the ion test laboratory investigation. Hilary discussed how the idea was to investigate if they would accuse anyone without taking evidence into account and use their interpretation and biases to examine evidence presented to them. She used this strategy to highlight how personal biases can cloud judgment when making decisions, an issue often faced by scientists.

The interview demonstrated how Hilary had an understanding of how to incorporate NOS into her lessons and was imaginative in developing lesson ideas. She had a strong affinity for the aims and values category, which she often linked with aspects of science in the social institutional system category. The first lesson shows only one instance of possible NOS, and her interview provided insight into how she developed aspects of NOS with her pupils. When asked what aspects of NOS the forensic lesson plan targeted from the workshops, she responded.

> I suppose aims and values and science in society …. methods too but more to do with you using secondary data, rather than using primary data. Then, whether or not it was an observation or classification sort of thing.

Here, Hilary demonstrates how the activity she used incorporated many elements she encountered in the workshops. We are aware that findings such as these come with caveats that she may be repeating key terminology presented to her in the workshops. However, in response to that, these lesson plans would have been developed prior to being asked to provide them for interview and so are promising for her encounter with NOS and the RFN framework. During the interview, Hilary discussed another lesson she conducted where she undertook an activity on how scientific studies are conducted. She did not have the lesson plan, but outlined how it looked at how scientific studies are conducted and how different methods used to obtain data could change the results of the study. She used a real-life study which examined the smoking habits of teenagers. This led to the evaluation of the impact of advertising on teenage smoking rates, as well as looking at the bias and accuracy of studies led by corporations with invested interest such as tobacco companies. When asked what elements of NOS, she thought this lesson activity incorporated, she again highlighted aims and values, as well as methods and practices (e.g., experiment and observations).

> I think Aims and Values and Methods because we talked about the different types of ways the scientists were carrying out the experiment or the observations, in the study. So that would have covered methods also because they were different. The methods, they used to collect data



Found at:	Identified as:	Does it match?
Crime scene		
Jack O'Brien		
Daniel Hayes		
Christopher Jones		
Thomas Byrne		

Figure 4. Activity developed by Hilary that targets the RFN aspect of Aims and Values.

> were different. There were surveys, there were observations, and classifications and things like that. And, they were looking at the different things. And it also looked at aims and values because it brought in accuracy and bias and we had a big discussion of what might influence that.

Hilary discussed the lesson idea she developed which conveyed how the Government of the town was trying to get rid of cigarette advertising. Her account of the lesson topic was as follows. The tobacco company ran an investigation into the influence of advertising in two towns. In one town, they advertised cigarettes and in another they had no advertising. The study investigated whether the advertising between the towns influenced teenage smoking rates. The pupils were presented with a scenario where the tobacco company was paying the doctor who ran the study, and they discussed the implications this would have on the findings. She used this to discuss the aims and values of science with the pupils. Like the previous lesson, Hilary outlined how the activity incorporated many elements from the workshops and showed how the workshops influenced her lesson development. Previously Hilary admitted that her favorite workshop was a aims and values session. Hilary's recount of the lessons suggests she was successful at infusing her favored elements from the workshops. The idea of teacher amplifying ideas is common in the literature on teacher education and is evident here in Hilary's case (Gess-Newsome, 2015).

Case 2- Felicity

Throughout the study Felicity appeared enthusiastic and interested in NOS teaching and learning. She was open to the ideas presented to her for the new NOS infused curriculum and frequently contributed to discussions and appeared to relish her self-perceived improvement throughout the workshops. Several instances illustrated Felicity's enthusiasm for NOS, which included her voluntary participation in the study and her enthusiasm to be creative when analyzing tasks created by the author and developing her own tasks. Felicity was affiliated with many organizations, university clubs, and societies and undertook several hours of volunteer work. Despite her heavy university workload and extracurricular activities, she attended and participated in all aspects of the workshops. She often asked the questions that the other PSTs were reluctant to ask and opened space for discussion. She was ardent about the inclusion of the NOS workshops in the B.S.Ed. program and concluded the workshops needed to be mandatory for students. She previously expressed anger at the injustice of not receiving this view of science earlier. *"Everyone has got a great injustice to them coming to college. You don't have an understanding of science. You have a rote learning view of science … like we don't even learn how science even works in the world."*

The workshops facilitated the PSTs to design NOS written tasks as part of the workshop as a way to engage with the NOS material. She indicated that this engagement facilitated an improved understanding of task development. She displayed incredulity at not being able to initially perceive how paper and pencil written tasks could be innovative in the classroom.

> Even the whole the idea of changing your assessment … Because we were coming up with things that wouldn't be appropriate for paper and I think even the slight change of turning this knowledge into paper knowledge. I found it fascinating that we couldn't do it at the start. We were coming up with all these mad ideas, and experiments and everything and you were like - how are you going to put this on paper?- and we were … I suppose we were very limited in how we thought we could use the activities.

Felicity further expressed her enthusiasm when she indicated that she found the workshops to be "mind-blowing" and she stated;

> It was all a bit mind-blowing in certain stages throughout the workshop. There was something always that was like 'wow I never thought of that', and it was such a basic thing that you imagined you would have thought of, but it's funny the little things that you just shade in the background, and you just don't think about it. And, you just see it, and that's it, there is no intricate working to it or anything else behind it. Whereas there is a lot more behind it.

Her enthusiasm for the workshops was evident and her increased scores in the written task made clear she had improved her NOS content knowledge. The next section will examine if that enthusiasm filtered into her lesson planning.

Felicity's NOS lesson planning

This section only draws on one of Felicity's lesson plans as she did not bring more to interview. Although Felicity increased her scores in both the post and delayed-post written task to indicate she improved her NOS content knowledge, analysis of her lesson plan and her discussion of the lesson indicated that she was less successful at including explicit NOS pedagogical ideas. Her lesson plan was analyzed by content analysis for keywords and the analysis found no explicit NOS instances. Implicit instances of NOS were identified where Felicity could have implicitly taught about NOS, but it is not clear without observation to what extent were these mentioned in the live lesson (Duschl & Grandy, 2013). The provided lesson plan also had some details with additional notes, which she had provided for her university tutor. When discussing the lesson plan which she thought contained examples of NOS, it became apparent that Felicity had difficulty incorporating NOS.

> I think it is difficult to incorporate it. I feel the blur between pedagogical approaches and nature of science . . . very difficult. I don't see the difference in it. I did get the [class], . . . we completed the food survey . . . So, I got them to make up their own procedure. I gave them the equipment, a lot of the time and got them to think how you would do the experiment with this equipment and gave them the title to give them a bit of structure and they seem to get it most of the time, but whether that is nature of science, I don't know. Or whether it is a pedagogical approach?

Her response suggests a sense of confusion in her approach, which she herself identifies as a lack of being able to distinguish between NOS content knowledge and NOS pedagogical knowledge. Her response would indicate that the activity took an inquiry-based approach and with a laboratory investigation. She wanted to discuss this lesson plan because not only did she believe that this lesson plan incorporated NOS, but during her teaching practicum, she received negative feedback from her university tutor who observed the lesson. Her university mentor told her that she did not understand NOS following his observation of this lesson. During the interview, she became quite distressed when she discussed how this interaction impacted her confidence teaching NOS, as she believed she had incorporated it into the lesson. When asked if she felt confident going out on teaching practice to teach NOS, she replied in the affirmative that she was confident and offered support to the teachers who had not received training due to the strikes and union directives and who assumed she had more knowledge coming from the university setting. Her response would indicate that she was not overly confident, however, when she says "well just about."

Author: *When you were going out on teaching practice, the fact that you had done these workshops, did that give you some level confidence?*

Felicity: *Yes*

Author: *You felt confident going out?*

Felicity: *Yes . . . and the teachers were asking me certain things. I think I helped them out to understand. Because they were like 'oh you definitely have more training in this than we do.' And I was like, well just about . . .*

Analysis of the lesson plan, however, did show it was limited for NOS content and when asked to discuss why she believed this was NOS she could not articulate it well. She discussed other lessons where she believed she incorporated NOS content from the workshops, but she did not supply the lesson plans for these lessons. She discussed a lesson where she taught the idea of observation versus inference as presented in the practices workshop (a domain general activity) using the tricky-tracks activity (Lederman et al., 1998). She discussed how she included a GMO foods activity (domain specific) presented to her in the aims and values workshop and how during the teaching of this particular lesson she realized how participation in the workshops improved her skills and ability to facilitate debate and higher-order discussion. During the interview, she came to realize how NOS provided a meta-perspective on science; *"it's really . . ., Nature of science is really just the little things."* This was a significant understanding that was lacking previously and why perhaps she found it difficult to incorporate NOS more explicitly into her lessons.

Felicity's case is useful to show how improvement in NOS understanding (i.e. her NOS content knowledge as determined by the written task) is not necessarily an indicator that it will translate into the classroom (i.e. NOS pedagogical content knowledge; Gess-Newsome, 2015; Shulman, 1986). Felicity did not have as much teaching experience as Hilary, and so may be potentially starting from a lower-cognitive developmental stage (Mulvey & Bell, 2017). Felicity's retention of her NOS understanding several months following may be as a result of her enthusiasm and enjoyment of engaging with the idea during participation Her statement about how she felt there were aspects of the course that were often eye-opening for her, potentially allowed her to retain the NOS content and ideas.

Discussion and conclusion

The study illustrates case studies resulting from working closely with PSTs who participated in NOS workshops designed through the RFN framework. The idea is to present illustrative cases to show how PSTs react to NOS interventions based on the RFN framework at a time of curricular and political reform (Lincoln & Guba 1985). Unique to the study, is the national context of the industrial action, which hampered classroom observations due to several days of school closures, so the evidence relies heavily on the PSTs self-reports. We acknowledge that research on teachers' own testimony about their practices can be flawed (Lederman, 1992; Lederman et al., 2002). Despite this limitation, the study offers insights into how programs underpinned by the RFN framework can have positive influences on teachers' enthusiasm and knowledge. The written task demonstrated how participation influenced their NOS content knowledge, which was evident in their increased scores on the written task. Despite the positive results, the case studies demonstrate that the 6 weeks of workshops had limited bearing on their lesson planning. We acknowledge that without classroom observations the study is limited, and we cannot necessarily determine its influence on practice since lesson plans are not a wholly suitable substitute for formal observations. However, the data from the study indicate how the PSTs plan for the incorporation of NOS in their classrooms, but we have insufficient data to be able to know if it had a more well-rounded effect on their classroom practice. If policy developers and university officials want to see a systematic change in the schools and curricula, they need to ensure that there is adequate provision of NOS by initial teacher education providers that not only improves NOS understanding but NOS pedagogical understanding as this study. Studies highlight that, in order for teachers to teach NOS effectively, they are expected to have a high-level understanding of NOS knowledge as well as the experience of how to teach NOS aspects through effective NOS pedagogical content knowledge (Brickhouse, 1990; Faikhamta, 2013; Mesci & Schwartz, 2017).

Acquiring an understanding of how PSTs conceptualize NOS for lesson preparation is currently limited (Cofré et al., 2019; Schwarz et al., 2008), but it is important to capture it as it provides insight into how NOS materializes in future teaching (Erduran & Kaya, 2018; Schwarz et al., 2008). However, with varying amounts of mastery, the PSTs showed evidence of adapting NOS from the workshops into the lesson preparation. The two case studies explain some parameters that can manifest when working with PSTs in NOS courses in times of curricular reform. Although the PSTs had similar levels of interaction and engagement in the workshops, the outcomes in terms of their tangible understanding of NOS pedagogies were different. The interview illustrated the initial difficulties Felicity had articulating what NOS was and how she incorporated it into her lessons. With further probing and reflection, she was able to express instances where she felt she had indeed incorporated workshop ideas. Although her lesson plan showed limited explicit NOS, her enthusiasm and ability to articulate NOS strategies was promising for her future teaching (Abd-El-Khalick et al., 1998; Campbell & Evans, 2000; Lederman, 1992, 2007; Lederman et al., 1998; Schwartz & Lederman, 2002).

What is unique about the approach used in this study is that it demonstrates how PSTs utilize the RFN framework to develop their understanding and classroom resources for NOS discussion. The research questions explored the influence of participation in the workshops on the PSTs knowledge and explicit use of NOS in their lesson planning. Both Hilary and Felicity report how participation in the workshops increased their confidence upon entering the classroom. Although self-efficacy was not explicitly researched in this study, the conversations about their improved confidence are positive indicators that the workshops can help improve self-efficacy (Bandura, 1977). Studies investigating teacher confidence and efficacy show both are difficult to determine, as multiple factors may influence confidence and efficacy (Bandura, 1977); however, the importance of a teacher's self-efficacy in shaping classroom practice is reported as the most powerful impact factor in achievement (Donohoo, 2017). Linked to confidence and self-efficacy is the idea of belief versus practice. Felicity shows how her beliefs were not indicative of her planning. Her lesson plan was limited to NOS content and did not align with her initial strong advocacy for inclusion of NOS content in the classroom (Brickhouse, 1990; Chen, 2016). The literature suggests her lack of teaching experience (Mulvey & Bell, 2017), limited content knowledge (Shulman, 1986), novice teacher issues (Lederman et al., 2001), and the political tension in the school, which is linked to lack of engagement from in-service teachers (Donnelly & O'Keeffe, 2016). There are many factors that mediate the translation of science teachers' NOS views into corresponding instructional practices such as their concern with classroom management, lesson preparation, and their preoccupation with survival issues such as negotiating daily tasks and responsibilities (Akerson et al., 2010, Lederman et al., 2001, Wahbeh, & Abd-El-Khalick 2014). Felicity revealed how although she felt confident in helping the in-service teachers following participation in the workshops, she suggested they were reliant on her to aid their knowledge. The study reveals that implementing a curriculum at a time when in-service teachers had no professional development resulted in the PSTs receiving little support in schools to develop NOS content and pedagogical content knowledge to bridge that theory practice divide. Mulvey and Bell (2017) acknowledge that teachers with more experience have a higher metacognitive awareness of their own thinking' and may support reflection on their improved conceptions and increased retention of improved conceptions. In Hilary's case, she appears to have a higher level of innate understanding (i.e. NOS content knowledge) from the beginning of the study as indicated by her scores on the written task. She had several more hours of teaching experience from her tutoring job and these factors both demonstrated how experience influenced her explicit use of NOS in her lesson planning and may account for her level of NOS pedagogical understanding (Mulvey & Bell, 2017).

A unique offering of the study is the transformation of a theoretical framework into a pedagogical strategy for pre-service teachers' professional development during a time of curriculum reform. At the time of the study, the transformation of the RFN framework for practical use was limited (Erduran et al., 2019; Erduran & Kaya, 2019). Hilary and Felicity's perceptions and lesson representations suggest that programs designed with RFN can enhance skills to negotiate the translation of sophisticated epistemic NOS ideas and link these ideas to lesson ideas and vignettes (Brickhouse, 1990; Cofré et al., 2019). It was the PSTs first exposure to NOS from the RFN perspective so it is encouraging that they engaged with the content over the course of the calendar year. It is anticipated that this study will be used to inform further transformations of the theoretical model for practical use in the classroom as well as other teacher education studies. Science educators interested in extending preservice and in-service teachers' epistemological understanding of the nature of science to a wider range of contexts would be interested in using the RFN framework.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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