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Research Article

Investigating Pre-Service Teachers' Understanding of Nature of Science: Contributions of An Assessment Tool Based on the Reconceptualized Family Resemblance Approach

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ABSTRACT

Several literature sources discuss the importance of nature of science (NOS) understanding and how having an understanding is central to being a scientifically literate citizen. As a result, developing NOS understanding is one of the most commonly stated objectives for science education. Acquiring views on NOS has been a prominent feature of research in this area since the 1960s. The following article provides a proof of concept for the transformation of a theoretical framework into a practical assessment tool (worksheet). The reconceptualized family resemblance approach to NOS is a theoretical framing of NOS which describes components of science in terms of categories subsumed under epistemic, cognitive and social systems. The aim is to explore its potential for use in science education and demonstrate its functionality so as to collect data on pre-service teachers' understanding of NOS and substantiate what can be achieved through its application. The designed assessment tool has many purposes and in this case it was used in a pre-, post-, and delayed-post methodology to investigate pre-service teachers' understanding of NOS following participation in NOS themed workshops. Implications for science teacher education will be discussed.

Keywords: nature of science, pre-service science teacher education, assessment

INTRODUCTION

The paper presents an assessment tool that was developed as part of a study conducted with pre-service teachers (PSTs) in Ireland following the introduction of 'nature of science' (NOS) to the science curriculum. This was the first time that such ideas would be explicitly included and taught in Irish science education. Therefore, would need support to develop their understanding as they would be teaching the curriculum in their practicum. Unique to this study was that the workshops were designed around a NOS theoretical framework called *the reconceptualized family resemblance approach to NOS* (RFN) (Erduran & Dagher, 2014). For several years, the dominant mode of NOS instruction drew on a view commonly known as the consensus view (Lederman, 1992). However, researchers in the field have voiced concerns about the model, which presents a set of tenets, as being limited and the need for a more inclusive and comprehensive framework (Hodson & Wong, 2017). The RFN model was created to address some of the criticisms of other models, and as such was designed to include pedagogic ideas and heuristics for teaching about the NOS. The categories in the model each were used to design the assessment so to produce a tool that would be expansive of collecting participants' ideas of NOS. At the time of the study, the RFN model was new and to date it has served a variety of purposes such as an analytical tool in curriculum analysis (Caramaschi et al., 2022; Cheung, 2020; Yeh et al., 2019), research with PSTs (Erduran et al., 2021; Kaya et al., 2019; Kelly & Erduran, 2018), and ideas from the framework were used in purposely designed workshops to inform in-service teachers views about the nature of scientific methods (Cullinane & Erduran, 2022; Cullinane et al., 2022; Wooding et al, 2020). Erduran et al. (2019) outline how the framework produced studies to show how it is successful for engaging teachers with NOS ideas.

This study designed unique activities that were particularly focused on objectives which unpacked features of the categories from the framework. The workshops were designed to help PSTs' understanding with not only NOS content knowledge but how to incorporate NOS into their teaching and assessment. To investigate the effectiveness of the model to support understanding of NOS, an assessment tool was developed that was provide with the name R-NOS where the R represents the *reconceptualized family resemblance approach*. It is used as a proof of concept to investigate the feasibility of the tool for gathering mainly qualitative views from participants and evaluate the influence of the workshops on the PSTs' understanding of NOS following participation in the voluntary workshops. The article will present the R-NOS questionnaire and its effectiveness for uncovering PSTs understanding of NOS. As this draw from case study research, it was used to gain insights from four PSTs who completed the assessment before and follow participation in RFN workshops.

REVIEW OF LITERATURE

Nature of Science and Science Education

NOS in curricula has been justified and implored through multiple literature sources throughout the years. Each source outlines how having an adequate understanding of the NOS is central to scientific literacy (Abd-El-Khalick et al., 1998; Conant, 1961; Duschl, 1990; Gray & Fouad, 2019; Kimball, 1967). Despite decades of calls for its inclusion, it is only in recent years that curriculum developers have started to incorporate NOS explicitly in core content such as those in New Zealand curriculum (NCEA), the USA (NGSS), and Ireland (NCAA). As a result, education and resources for teachers are essential goals for teacher education providers. Teaching NOS has been advocated for its benefits in potentially achieving scientific literacy, such as enhancing students' understanding of scientific ideas and processes, informed decision-making, responsible citizenship (Driver et al., 1998).

NOS refers to various epistemic and social aspects of scientific knowledge and practices (Erduran & Dagher, 2014) as well as the history, sociology and philosophy of science. It can be defined as how science works, includes its aims and values, the methods and practices used to produce scientific information and knowledge. A set of tenets commonly referred to as *the consensus view* have been established as the dominant mode for instruction, characterizes NOS as essential features of science, such as tentativeness of scientific knowledge (Lederman, 1992; Lederman et al., 2002). For the last three decades, the NOS tenets have largely been used but now are seen as problematic and oversimplify NOS, to the extent that they significantly misrepresent the NOS (Hodson & Wong, 2017). New perspectives that have emerged in recent times include the 'whole science' by Allchin (2011), 'features of science' by Matthews (2012), 'the family resemblance approach' (FRA) by Irzik and Nola (2011), and 'the reconceptualized family resemblance approach to NOS' (RFN) by Erduran and Dagher (2014). The latter is the focus of the study and the following section will describe the model which transitions away from the consensus view to present science as a cognitive-epistemic and social-institutional system. Erduran et al. (2019, p. 312) outline how RFN embodies a set of aims and values, practices, methodologies, and social norms that are worthy of inclusion in the science curriculum as shown in **Figure 1**.

The model is based on a theoretical rationale proposed by philosophers of science, Irzik and Nola (2011) whose work is based on that of Wittgenstein. The idea of the family

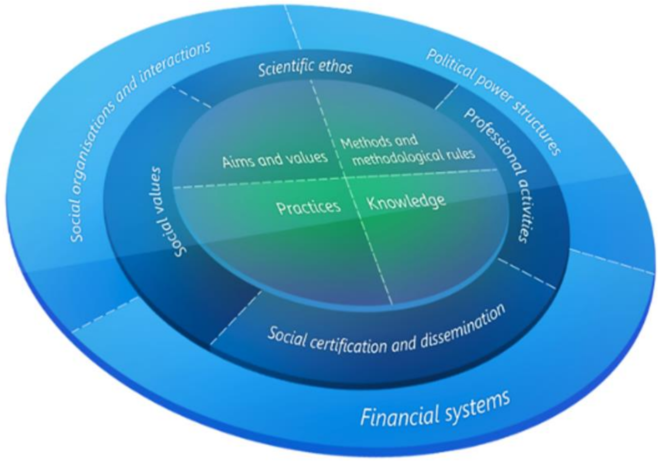

Figure 1. FRA wheel, a generative image of science as a cognitive-epistemic and social-institutional system (Erduran & Dagher, 2014, p. 28)

resemblance is based on the understanding that all disciplines of science share certain characteristics, none of which can define science or detach it from other disciplines (Erduran et al., 2019). As such the perspective provides a coherent approach to capturing domain-general and domain-specific aspects of NOS by highlighting the similarities and unique differences between various sciences (Erduran & Dagher, 2014). It now has practical adaptations for teacher education and science education-related studies (e.g., Cheung, 2020; Cullinane, 2018; Erduran et al., 2021; Kaya et al., 2019; Petersen et al., 2020), and other natural science subjects (Puttick & Cullinane, 2021).

The cognitive-epistemic categories make up the center disc (i) methods, (ii) practices, (iii) knowledge, and (iv) aims and values. There were seven categories in the outer discs social institutional aspect that broadly examine (v) scientific ethos, (vi) social certification and dissemination, (vii) social values, (viii) professional activities, (ix) social organizations and interactions, (x) financial systems, and (xi) political power structures. The following article contributes to the academic literature, and demonstrate how a worksheet can be produced around the framework. **Table 1** outlines the categories in greater detail.

A Historical Account of NOS Assessment Instruments

Several instruments have been designed to establish NOS views using a variety of perspectives over the last half-century. The first recognized assessments to investigate concepts of NOS began to appear around the 1960s. One of the first acclaimed instruments developed in the early 1960s for use with senior high school pupils was the test on understanding science or TOUS (Cooley & Klopfer, 1961). TOUS was shown to be highly valid in the science education research community at the time. It consisted of four alternative 60-item multiple-choice test items, where respondents obtained an "overall" or "general" score, as well as three-subscale scores. The three subscale scores were (i) understanding about the scientific enterprise (ii) the scientist, and (iii) the methods and aims of science. TOUS was championed for providing a platform for many other instruments such as NOS scale (NOSS) (Kimball, 1967). As research in the area of NOS conceptions progressed,

Table 1. FRA categories by Erduran and Dagher (2014)

Cognitive-epistemic system aspects	Aims & values	The scientific enterprise is underpinned by adherence to a set of values that guide scientific practices. These aims & values are often implicit & they may include accuracy, objectivity, consistency, skepticism, rationality, simplicity, empirical adequacy, prediction, testability, novelty, fruitfulness, commitment to logic, viability, & explanatory power.
	Scientific practices	The scientific enterprise encompasses a wide range of cognitive, epistemic, & discursive practices. Scientific practices such as observation, classification, & experimentation utilize a variety of methods to gather observational, historical, or experimental data. Cognitive practices such as explaining, modelling, & predicting, are closely linked to discursive practices involving argumentation & reasoning.
	Methods & methodological rules	Scientists engage in disciplined inquiry by utilizing a variety of observational, investigative, & analytical methods to generate reliable evidence & construct theories, laws, & models in a given science discipline, which are guided by particular methodological rules. Scientific methods are revisionary in nature, with different methods producing different forms of evidence, leading to clearer underst&ings & more coherent explanations of scientific phenomena.
	Scientific knowledge	Theories, laws, & models (TLM) are interrelated products of the scientific enterprise that generate and/or validate scientific knowledge & provide logical & consistent explanations to develop scientific underst&ing. Scientific knowledge is holistic & relational, & TLM are conceptualized as a coherent network, not as discrete & disconnected fragments of knowledge.
Social-institutional system aspects	Professional activities	Scientists engage in a number of professional activities to enable them to communicate their research, including conference attendance & presentation, writing manuscripts for peer-reviewed journals, reviewing papers, developing grant proposals, & securing funding.
	Scientific ethos	Scientists are expected to abide by a set of norms both within their own work & during their interactions with colleagues & scientists from other institutions. These norms may include organized skepticism, universalism, communalism & disinterestedness, freedom & openness, intellectual honesty, respect for research subjects, & respect for the environment.
	Social certification & dissemination	By presenting their work at conferences & writing manuscripts for peer-reviewed journals, scientists' work is reviewed & critically evaluated by their peers. This form of social quality control aids in the validation of new scientific knowledge by the broader scientific community.
	Social values of science	The scientific enterprise embodies various social values including social utility, respecting the environment, freedom, decentralizing power, honesty, addressing human needs, & equality of intellectual authority.
	Social organizations & interactions	Science is socially organized in various institutions including universities & research centers. The nature of social interactions among members of a research team working on different projects is governed by an organizational hierarchy. In a wider organizational context, the institute of science has been linked to industry & the defense force.
	Political power structures	The scientific enterprise operates within a political environment that imposes its own values & interests. Science is not universal, & the outcomes of science are not always beneficial for individuals, groups, communities, or cultures.
	Financial systems	The scientific enterprise is mediated by economic factors. Scientists require funding in order to carry out their work, & state- & national-level governing bodies provide significant levels of funding to universities & research centers. As such, these organizations have an influence on the types of scientific research funded & ultimately conducted.

instruments transitioned from closed-end forced choice to open-ended qualitative questions, such as the views on NOS survey (VNOS).

Although initially developed to assess high school pupils' views of the tentative NOS, it now has multiple versions for all education level. VNOS instruments receive criticism for their lack of support in helping participants answer the questions. The underlying topic is theoretically broad, and as a result, the instruments provided little support to participants in answering. Challenges arose in analyzing the responses as participants often misconstrued the questions due to the highly conceptual nature of the items (Akerson et al, 2000; Lederman & Abd-El-Khalick, 1998; Lederman et al.,1998). Criticism of the VNOS instrument relates to declarative knowledge of NOS and probes several explicit declarative tenets about NOS. To which Allchin (2011) suggests the educational aim should be to assess and investigate if higher-level thinking skills are fostered and achieved. Other contemporary instruments that have been developed, including views on science and education questionnaire (VOSE) (Chen, 2006), views of scientific inquiry (VOSI) (Schwartz et al., 2008), and student understanding of science and science inquiry (SUSSI) (Liang et al., 2008). The SUSSI instrument, although not exhaustive, is founded on well-established NOS ideas. Its focus is narrower than those views presented in RFN. They do include ideas of the tentative nature of knowledge, laws vs theories, subjectivity, social and cultural influences, collaboration, scientific methods, creativity, and methodological naturalism. This instrument has been used in studies that utilized the RFN framework (Petersen et al., 2020), and although useful, these instruments were not based on the RFN model.

Another framework, the nature of scientific inquiry (NOSI) fuses the VASI instrument, which is shown to be a valid and reliable instrument for assessing NOSI aspects. The VNOS and VASI are based on two different frameworks–one the nature of scientific knowledge, and the other the nature of scientific inquiry–, which aligns with the broad RFN framework, but was two separate instruments. However, these previous instruments were consulted, and some ideas advanced the development of the worksheet produced here. One instrument to have emerged not based on the consensus view is the RFN survey, which is based on the RFN perspective. However, at the time of the study, the RFN instrument was not yet developed.

However, some years later, Kaya et al. (2019) developed the quantitative 70-item 5-Likert scale questionnaire, and it was a forced choice inventory instrument. It aims to establish respondents understanding of five of the main categories from the RFN framework. Due to its quantitative nature, the instrument allows limited opportunities for respondents to reason their answers.

Searches of the most up-to-date literature show studies that examine views of NOS continue to use the VNOS or SUSSI instruments (Bilican, 2018; Cofré et al., 2019; Gray & Fouad, 2019; Petersen et al., 2020). Many in the scientific education community continue to use the VNOS instrument to garner NOS views. Multiple versions of VNOS now exist, ranging from six to ten questions and have been modified for use at all educational levels (Abd-El-Khalick et al., 1998). Testing instruments from the RFN perspective was currently limited. Although science educators have transformed RFN, its empirical adaptations are only now emerging in science education research (Kaya et al., 2019). The unique contribution of this article is to add to the growing body of literature and empirical adaptations of the RFN framework.

The R-NOS worksheet presented (see **Appendix A**) was designed for multiple purposes (summative and formative assessment) and was used in this study to gather PSTs NOS views. It was administered before, after and several months following participation in workshops designed to introduce them to NOS ideas. The worksheet was designed to gather qualitative responses but also lends itself to mixed methods approaches by being able to draw some descriptive statistics from the data collected. A scoring rubric was developed so that responses provided were given a number depending on the depth of understanding shown in the responses (see **Appendix B** for the scoring rubric). A more detailed discussion of the scoring rubric is provided later. The qualitative nature of the worksheet enabled the development of rich data that illustrates how PSTs developed their understanding. The following section outlines a historical account of previous NOS testing instruments. The research was conducted with a small sample of PSTs in a four-year bachelor of science education course in the Republic of Ireland over the calendar year of 2016.

STUDY DESIGN AND SAMPLE

The research employed case study methodology which applied an interpretive approach. The PSTs were invited to attend seven workshops designed with the RFN framework. The pre-worksheet was used to establish the PSTs baseline understanding of NOS before participating in the workshops; the post-worksheet determined how their understanding changed following the workshops, and the delayed-post worksheet examined to what extent they retained their understanding several months following the workshops. The sample included four female PSTs with specialisms in biology and chemistry, and were all 21 years old. The pseudonyms Rayanne, Hilary, Felicity and Octavia are used for the participants to keep them anonymous.

The following section outlines the methodology used to develop the questions for the worksheet and the justification for the designed items for the R-NOS worksheet. As well as a "*testing"* instrument, the worksheet was to facilitate reflection, as developing students' reflective thinking skills can facilitate understanding, support conceptual change, and foster critical evaluation and knowledge transfer (Antonio, 2020). The items developed were based on the RFN categories, which formed the basis of the workshops attended by the PSTs and capture what influence the workshops had on their understanding. The worksheet consisted of nine questions, each with individual sub-questions. It presents a proof of concept to investigate if using the RFN theoretical framework can be transformed for practical purposes, to gather views of NOS effectively.

R-NOS Question Development

Question 1: Philosophical perspectives

Research on PSTs worldviews has rarely been systematically related to views on NOS, and so this question was designed as a proof of concept to investigate if their philosophical perspectives changed throughout the study. Respondents were asked to select a view that most closely aligned with their own world view. Three perspectives that offered distinct views on the philosophy of science were presented These considered some of the significant philosophers of science; constructivism (Kuhn), positivism (Comte), and relativism (Plato). In future studies we see other researchers being able to add more views that can capture a wider diversity of philosophical perspectives.

Question 2: Aims and values

The opening statement highlights how scientists have particular aims they want to achieve and various values to which they much adhere. Following this opening statement, seven statements were presented, which were designed around ideas presented by Erduran and Dagher (2014, p. 52). The participants were asked to select their level of agreement with the statements. The statement related to well-substantiated issues in science such as bias, political allegiance, honesty, consilience, accuracy, and objectivity (Cooley & Klopfer, 1961; Kuhn, 1962). It included ideas like politics and funding impacting on scientific aims and values (Allchin, 2011). The questions used Likert scales, where the PSTs had to select their level of agreement with each statement. Participants could provide additional free-response comments under each statement to justify their answers.

Question 3: Scientific knowledge

The question contained four sections, where each section uncovered thinking about theories, laws and models and pseudoscience. The first part of the question presented four images which represented theories, laws and models and pseudoscience. It asked to identify which image was not a form of scientific knowledge. The labels did not identify that the images signified a particular form of scientific knowledge. The next part asked participants to explain why they felt the images did not illustrate examples of scientific knowledge and provided with space for their free responses and eliminated the possibility of forced-choice responses. Participants were asked to explain why they felt the other images were examples of scientific knowledge. It aimed to examine to what extent the workshops influenced their use of terminology to describe the different knowledge aspects. The last question in this section asked the participants to explain if the images were representing similar or different forms of scientific knowledge.

Question 4: Scientific practices

The question sought to assess the participants' views relating to the aspect of scientific practices. The participants were asked to indicate which statements best characterized the practices of biologists, chemists and physicists (Erduran & Dagher, 2014). The question demonstrates domain-specific aspects that assesses any held misconceptions that biologist, chemists, physicists perform different activities. The choices include experimenting, observing the world for interpretation, classifying data to produce scientific knowledge, disseminating research findings through conferences and journals, discussing and debating data. The unique contribution of the question is the domain-specificity aspect it presents.

Question 5: Science in social-institutional systems

This question targets science as a social–institutional system and features five images that represented race, nationality, gender, politics and religion, respectively. The workshops drew on both contemporary and historical aspects as well as science as a way of knowing. Many of our historical heroes, or key characters that are used regularly to teach about science and NOS, will have held views that are wrong, abhorrent and incompatible with today's views. (Stepan, 1982).

Question 6: Scientific knowledge

This question investigated the participants' perceptions of scientific models by asking them to indicate which of the six images represented scientific models. The images were carefully chosen to target the various types of models discussed in the RFN framework (Erduran & Dagher, 2014, p. 118). The first image of the cell represented a conceptual model, the skeleton image represents a scalar model, the chemical reaction was a symbolic model, and the mathematical equation is a mathematical model often used in science, particularly physics. The solar system was also a scalar model and was used to show the diversity of scalar models. The image of the atom was used to represent a theoretical model to represent a theoretical concept (Justi & Gilbert, 2000). Participants indicated why they believed that any image does not represent a scientific model. Similar to question four, the unique offering of this question is the domain-specific opportunities. Adaptations to the images can be made depending on the audience.

Question 7: Scientific knowledge

Three statements assess the understanding of the differences between theories and laws and the tentative nature of scientific knowledge. The questions sought to investigate participants understanding of theories and laws and *the* common misconception relating to theories turning into laws. A popular high school biology textbook was used to develop the statement (O'Callaghan, 2003, p. 2),

> "our knowledge is always changing. When a theory has stood the test of time and is shown to be valid under all conditions that can be tested, it may be given the status of a law."

The other statements similarly presented ideas on theories and laws changing or not changing. The participants were allowed to select more than one statement if they felt another also statement aligned with their views but were to explain why they represented their views.

Question 8: Methods and methodological rules

This question addressed the myth of the scientific method and asked participants to select between two images and subsequent statements. The first statement discussed the non-linear process of science and how science is conducted in a variety of ways and stated that science is not a linear process and is conducted in a variety of ways. Accompanying the statements was an image of two minds with various thought processes to represent the dynamic work of scientists' methods. The second statement discusses the linear process of the scientific method shown in many school textbooks. This statement is accompanied by the image of the typical scientific method (image: Erduran & Dagher, 2014, p. 94). The statement stated

> "science is a linear process and is conducted through the scientific method; the process that is used by scientists for testing ideas and theories by using experiments and the formulation and surveying of hypotheses (Erduran & Dagher, 2014, p. 94).

The participants were to explain their selected choices.

Question 9: Methods and methodological rules

Question nine also targeted the aspects of methods by looking at the variety of methods and approaches scientists use to conduct science investigations and produce new scientific knowledge. It showcases four types of observational and experimental methods where examples were devised using ideas from the RFN framework in the table entitled "types of observational and experimental methods" by Brandon (1994). It outlines how scientific investigations can vary in their nature such as experimentation and observation. These related to whether or not the method involves (a) manipulation or (b) hypothesis surveying or a combination of these approaches (Brandon, 1994). The following questions were developed to investigate how the PSTs saw different methods scientists use in their inquiries. The unique feature was the reasoning the participants had to undertake to match the four example scientific approaches to an explanation of these approaches. The example approaches represented the explanation to that approach accurately. The unique offering of this question is the argumentation and reasoning opportunities it affords by providing two options to reason their views. Previous instruments do not offer scaffolds for participants to grapple with these ideas to present a coherent response.

Question 10: Change in views

Question ten appeared only on the delayed post-worksheet. It investigated if teaching practice influenced their views since undertaking the workshops and investigate if they

Table 2. Scoring rubric for responses provided to questions on the R-NOS worksheet

Score	0	1	2	3
Description	No response/incorrect view of NOS	Naïve or emerging view of NOS	Transitional/developing view of NOS	Informed view of NOS

Table 3. *Percentage agreement between raters scoring a pre and post worksheets

Total number of items scored (N=22)	Rater 1 (% agreement)		Rater 2 (% agreement)		Rater 3 (% agreement)	
	Pre	Post	Pre	Post	Pre	Post
No. of matched scores	16	17	18	21	18	21
Percentage agreement	72%	77%	81%	95%	81%	95%
Average percentage agreement	**83.5%**					

were involved in any professional development while on school placement. A confidence scale rating was included where the participants had to rate their confidence in the answers they provided.

Scoring Rubric

To afford some descriptive statistics, a scoring rubric was developed. The authors recognize how the articulation of NOS understanding falls on a continuum and so categories were produced to allow for the classification of responses as incorrect, naïve, developing and informed. Zero indicated that if there was no response, or a response was deemed as an incorrect view was provided with a zero. A score of one was awarded to responses that were classed as naïve. A score of two was awarded for responses deemed to be "developing" or "transitioning", and a score of three was awarded for responses deemed to be informed views of NOS. The rubric outlined suggested responses expected at each level. **Table 2** details suggested responses in the rubric, which range from generic suggestions to specific instructions about terminology, as well as ideas for assessment.

Developing the Worksheet

To show how it could work as a proof of concept, the worksheet underwent content validity. It was provided to eight other educational researchers, whom were familiar with NOS and had expertise in educational research and questionnaire design (Andrew & Halcomb, 2009). They were asked to review the worksheet in light of their expertise and assess the format. Amendments were made in light of their feedback. Before the worksheet was used in the study, it was piloted with undergraduate students who were undertaking a science course. As the study used qualitative approaches that used interpretive validity (Maxwell, 1992, p. 292), the necessity for statistical confirmation usually required for quantitative validity is not necessary for this instance. Several statistical experts were consulted at this stage to seek advice on statistical tests that could be carried out. All noted that due to the small sample size there were no reliable test that could be performed to gain a significant result. Therefore, percentage agreement and descriptive statistics were presented to demonstrate proof-of-concept (Miles & Huberman, 1994). Further validation of the instrument was implemented with the application of the scoring rubric. In order to investigate the validity of the rubric and negate interpretation bias, a participant's worksheet was provided along with the scoring rubric to three other researchers familiar with the RFN framework. They used the rubric to score the worksheets, and their scores were compared against the authors, and the percentage agreement was obtained. Although the survey contained nine distinct questions, some of these contained parts that were scored with the rubric. When the raters' scores matched, it was given a zero. The total number of zeros were counted and put over the total number of items (n=22) and multiplied by 100, to get the percentage. Percentage agreement is often used in qualitative research when the number of analyzed items or observed situations are few, making statistical analysis with computer-aided software complicated (Boyatzis, 1998). The average percentage agreement was calculated to be 83.5%. Miles and Huberman (1994) suggest that above 80% agreement is a good indicator for reasonable reliability. Therefore, the results obtained in this study would suggest the worksheet and scoring rubric have a high level of reliability. See **Table 3** for results.

RESULTS

The following section will outline the results that emerged from the analysis. The qualitative findings used the RFN framework as an analytical lens. The identification of patterns in the data involved an inductive process, which was grounded in interpretations of data captured by the worksheet. The quantitative findings presented in **Figure 2** are the PSTs' scores obtained on the pre, post and delayed post-worksheet. **Figure 2** illustrates the increased scores following the workshops and how their understanding changed with each administration. The results indicate that before undertaking the workshops, Hilary had a higher level of understanding. The post and delayed-post-worksheet indicate these views increased for all PSTs. Rayanne improved most from the pre to the post-worksheet, but she did not undertake the delayed-post worksheet.

Qualitative Findings

The following section presents some of the main areas where the PSTs showed shifts in their understanding. Qualitative responses in the worksheet will be used to support purposed findings and illustrate the utility of the worksheet in capturing aspects of participant understanding. The PSTs illustrated a change in their understanding in methods, social aspects of science, knowledge, particularly understanding theories, laws and models. The worksheet was useful in diagnosing the PSTs need for further engagement with the knowledge category.

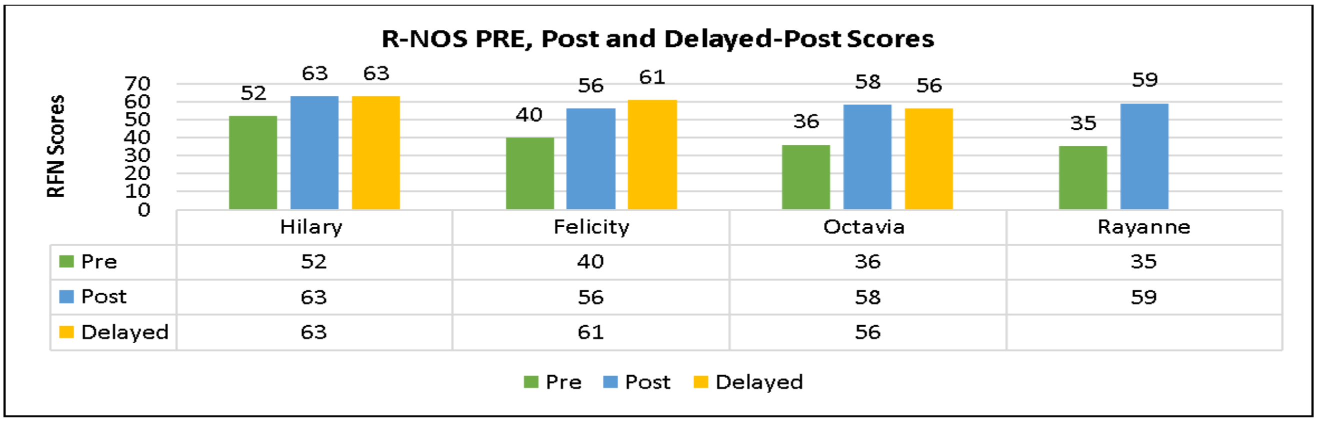

Figure 2. Scores obtained by the PSTs on the pre-, post-, and delayed-post worksheets

Understanding scientific methods

The responses would suggest following participation the PSTs had a better understanding of the different types of methods available to scientists. Before undertaking the workshops, the PSTs believed that science was a linear process and held traditional views of methods in science, and viewed science methods primarily as experimental methods. Rayanne's response from her pre-worksheet below was a typical response from the PSTs to this question.

> Science is still currently very much experiment-based. The scientific method is still highly used. Perhaps in the future, science will not be a linear process. It is currently moving towards 'thinking outside of the box', however it is still mainly a linear process, I think this is due to fear of being wrong and the unknown but it also takes a different way of thinking to 'think outside the box" (pre-worksheet, Rayanne).

However, the PSTs' responses on the post-worksheet indicate they have a more expanded view of scientific methods and see there are a variety of approaches through which scientists conduct their investigations. The change in the terminology used to articulate their view of methods in science is evidence they have furthered their understanding. Felicity, Rayanne and Hilary show they are using more appropriate scientific terminology, when they are using words like observing, testing hypothesis and *independent* and *dependent variables.*

> "There are many different scientific methods such as the normal scientific method observing, categorizing, testing hypothesis" (post-worksheet, Rayanne).

> "There are many different methods used in science; a hypothesis is not always needed, and variables are not always changed" (post-worksheet, Hilary).

> "Science can be done in a variety of manners such as no hypothesis, and hypothesis having independent and dependent variables and observing an event and recording the outcome" (post-worksheet, Felicity).

Although fairly common words in science investigations, the pre-worksheets didn't contain these ideas and therefore would indicate evolving growth in their understanding following participation in the workshops.

Understanding scientific practices

All the PSTs demonstrated to have a good understanding of the ideas in this question. In all applications of the worksheet, they identified that all scientists were involved in experimenting, observing, disseminating research, and producing explanations. Felicity was the only respondent to state she did not see physicists involved in classification exercises in the pre-worksheet. The worksheet was able to identify that she held beliefs that physics was an older science, and there were no classification activities in that field. Her pre-worksheet identified that she held the misconception that physicists *"don't need to classify information"* as is an old science and as such, physical concepts were not open to change. However, following her teaching practice, the worksheet was able to identify she changed these ideas to now see that physicists do utilize classification activities in their work. The other respondents' views remained constant in all worksheets. As such, the participants' views aligned well with those presented in the RFN framework.

Understanding scientific knowledge

The analysis of the worksheet would indicate that there were several instances where the PSTs improved their understanding of scientific knowledge in science such as theories, laws and models. When asked about the misconception of theories turning into laws, the PSTs also held this view before participation in the workshops.

> "Knowledge is always changing due to new technologies and advancements. This is true, but theories can change to laws like Newton's laws but only if they do stand the test that they are correct" (pre-worksheet, Felicity).

The following responses from Felicity and Hilary demonstrate how the PSTs changed their views and demonstrate an understanding of how (a) theories and laws are forms of scientific knowledge and (b) how theories cannot change into laws.

> "A law is a separate piece of knowledge. A law explains something that can be seen, whereas a theory explains

> something that cannot be seen" (post-worksheet, Felicity).

> "Theory represents what we cannot observe. Law represents what we can observe. Therefore, one cannot change into another. However new information and scientific advances are constantly being made" (delayed post-worksheet, Hilary).

The response illustrates Hilary's awareness of the difference between a theory and a law and also the tentative nature of scientific knowledge. However, despite the above change in views, when asked to differentiate between the different types of scientific knowledge (theories, laws, models, and pseudoscience), they displayed varying degrees of understanding. This was evident in the post and delayed post-worksheet, where they presented misconceptions about the nature of knowledge, as demonstrated in the comment below from Octavia.

> "One is a model; one is to do with Darwin's theory, and one is to do with Astrology; another strand of science. I feel the map is also linked with science in some way but it's a map and not really scientific" (delayed post-worksheet, Octavia).

The worksheet identified how the PSTs needed further engagement with ideas from the knowledge category. Like other studies, this aspect is the one that most have difficulty understanding (Mesci & Schwartz, 2017). When asked if the images of theories, laws, models, and pseudoscience represented similar or different forms of scientific knowledge, the PSTs had difficulty articulating their responses. Many of the responses provided in the post and delayed post-worksheets were classed as either naïve or developing.

> "Each are different forms of scientific knowledge. One represents a tree of life, one is a model which can be used to teach Newton's theory of gravity, this is physics and mathematical, one is biological and one astrology" (delayed post-worksheet, Octavia).

One of the interesting findings was how the PSTs now saw the images used as models. Although not an intended answer, it was accurate. The images were models and do indicate how the PSTs understanding of *the scientific knowledge* aspect improved.

> "They are used as models to explain scientific knowledge (post-worksheet, Felicity).

> "As they are all models, i.e., representation of scientific knowledge" (delayed post-worksheet, Felicity).

Although this was not an intended approach of the question, the PST had rightfully identified how the images present were in fact scientific models. This idea will be explored further in future adaptations of the R-NOS survey.

Understanding scientific aims and values

The PSTs often indicated that the aims and values aspect was the workshop they enjoyed the most. The PSTs provided limited written responses on the worksheets to these Likert-style questions. Nevertheless, their responses provide beneficial evidence of changed or retained views. When asked about these questions during the workshop, the PSTs discussed how the statements presented were logical, but they had not reflected on them previously. It wasn't until after the workshop that they saw how "blinded" they were to these aspects of science. On looking at their responses, most of the PSTs selected that (a) scientists aim to work with groups and organizations in an unbiased manner bias, (b) scientists aim to be honest in their work, (c) scientists take opposition to their ideas seriously and aim to deal with them, (d) scientists aim to be accurate (e) the interest of funding bodies influencing science, and (g) the scientists' personalities and social circumstances may influence their scientific investigations. However, in statement f, when asked if politics ever influence scientific studies and if scientists ever have to follow the values of the politicians, many indicated that they saw science free from political influence. Views such as these, have the potential to damage understanding of how science works and trust in information if they do not question who is funding the scientist. However, the post and delayed post-worksheet indicated that they disagree, indicating they now see how politics influence science. There is some insight into changing views in the delayed post-worksheet evidenced by Felicity stating how

> "All aspects of our lives are shaped by politics and society."

This would suggest that Felicity now sees how not only science is influenced by these political spheres, but many aspects of our daily lives.

Understanding the social- institutional system

The questions on the worksheet asked about ideas of politics, the influence of race and nationality on science, gender and religion. Before undertaking the workshops, the worksheet demonstrated that the PSTs had some informed views concerning this aspect. They mainly presented commentary that would indicate informed ideas on how religion and gender influenced in the science community; however, they indicated that these were historical issues and not as importance now. The aspect that the PSTs showed less informed views about was the political aspect. Some of the PSTs believed that politics did not influence science, and devoid of political influence.

> "No. Scientists are always finding new discoveries. I don't think politics influence this" (pre-worksheet, Octavia).

Following the workshops, the PSTs responses indicate that they have changed their views on political influence in science, particularly around how they fund scientific research and published results. Rayanne's post-worksheet presents some ideas from the activities used in the workshop.

> "If a scientific discovery/idea is made and it doesn't agree with how politics wants the world to work, e.g. the finding that smoking is bad was kept a secret due to politics" (post-worksheet, Rayanne).

> "Yes. They fund science facilities they can decide what they won't fund and will get funded" (post-worksheet, Octavia).

> "Yes. Politicians will supply money to the research they want the public to know and understand about. They are selective to what they want to supply money to" (delayed post-worksheet, Octavia).

The above quotes indicate that they now see science as politicized. This question contained items that included such topics of race and nationality which is often debated if it has a place for discussion in science. However, it was felt that not including it has the potential to present a false or sanitized view of science and present it as free from racial bias, which history shows is not the case (Stepan, 1982). The PSTs highlight how race does influence the accessibility to science and discrimination different race and nationalities may experience (Stepan 1982). Their responses to the questions on race and nationality questions would indicate that the PSTs too held some informed historical views, such as those by Hilary:

> "Yes. While the race of a scientist is not influential on their work, as with all careers, it can be difficult for minority groups to be given equal opportunity. This can influence science by preventing capable and intelligent scientists from progressing with their work" (pre-worksheet, Hilary).

It diagnozed their naïve views that science is free of these biases, such as the response from Felicity who identified how race and nationality did not influence science. Although she does recognize international collaborations, her response indicates that she does not recognize international collaborations as something that influences science, and she show some naivety about how it is free from biases.

> "No, nationality [and race] does not influence science as scientists across the world communicate on research… It is fact and is not based on the race that discovered the fact" (pre-worksheet, Felicity).

The post-worksheet identified Felicity changed her views, where she now sees that science is influenced historically by external factors of race and nationality and how international collaborations influence on science. Her second response shows the influence of the workshops as she was shown an activity to illustrate how scientists have developed our understanding of the acids and bases were from all different nationalities.

> "Yes, as different races historically are not seen as high up in within the scientific world as this can influence others acceptance of this work" (post-worksheet, Felicity).

> "Different nationalities have helped develop scientific knowledge and understanding, for example, a number of nationalities were involved in helping develop the pH scale" (post-worksheet, Felicity).

The response prompted from the R-NOS worksheet largely indicates that the PSTs saw race and nationality as factors that influence science and were identified to have informed views before participation in the workshops. These views were maintained and expanded on in the subsequent worksheets. Felicity showed to expand and maintain her views as illustrated by her response in the delay post workshops, and her post-worksheet response directly referred to aspects of the workshop that discussed such issues.

CONCLUSIONS AND DISCUSSION

The findings presented above are indicative of some of the rich insights gained from the administration of the R-NOS. A proof of concept is identified as not the final product and is instead looking at the feasibility of theory for practical use. Firstly, in terms of the quantitative approaches, as a proof of concept, it provided interesting insights into the trends of how the PSTs understanding increased and maintained over the course of the study as shown **Figure 2**. And the quantitative data was garnered from a subjective judgement of qualitative statements, the study showed how the developmental exercises provided a relatively consistent view of this data (e.g., over 80%), allowing for a concise and close-ended view of the data (Boyatzis, 1998) The case studies allow for greater exploration of this data as well. The qualitative aspect of the worksheet allowed us to see how ideas have changed from iteration to iteration to capture a holistic picture of conceptual change. Some of these notable changes captured were after the study they held more informed views around the scientific methods, and the variety of approaches scientists use, as well as the practices they engage with and aims and values that drive scientists and scientific discovery aspect was the part that was of most interest to the PSTs. As teachers who will be informing future generations of these ideas now it is on the new curriculum, it is promising to see that the worksheet could capture their improved conceptions of the idea identified above.

Many of the findings show the worksheet is useful in gathering views of NOS. The worksheet removed force-choice inventory in many cases by providing free responses boxes to further understand ideas provided. This approach which attempts to circumvents issues previously identified by other assessment tools critics. It contained questions on domain general and domain specific questions, as well as questions about professional science. Stadermann and Goedhart (2020) found students in their study did not see a difference between professional science and school science. As such, they have questioned the validity of many NOS test instruments using non-contextualized questions and those that do not differentiate between school science and real science. The worksheet aims to tackle criticism such as these by providing professional aspects of science to distinguish between the activities of school science and scientists in society on individual or group discussion activities. As the worksheet presents reasoning and argumentation activities through domain-specificity aspects, it provides vignettes for PSTs to reason the various claims presented to them (Kuhn, 2010) which offers value for professional development and providers of professional development.

A unique feature of the worksheet is its use of visual images to help support responses and when used in the classroom affords discussions to act as an organizing tool for NOS knowledge. As the responses illustrate, the PSTs can express their views of the RFN categories in different ways. The study reported here presents the worksheet as a proof of concept to demonstrate the functionality of a tool designed from the RFN perspective and provides some indications from PSTs. Few studies focus on PSTs understanding of NOS from the RFN perspective (Erduran et al., 2020). As the participants never encountered NOS previously, they would be a good indicator to demonstrate how effective the framework is for informing PST about NOS.

Another useful contribution of this worksheet is its ability to develop both qualitative and quantitative measures. The worksheet and scoring rubric allow for easy translation of the qualitative data to descriptive statistics for quantitative measures. The dual-measures of the worksheet allow for practical implementations with limited need for extensive interviews from the participants to better assess understanding of NOS related content. Many other tools outlined have been criticized for being overly conceptional and doing little to help participants understand what was asked (Lederman et al., 2002). The R-NOS worksheet acts as an organizational tool as it provides visual images, statements and reasoning opportunities to help elicit responses around NOS ideas from the RFN categories. The R-NOS worksheet has diagnostic capabilities and was found helpful to diagnose areas in need of further engagement, both before and after the workshops. Many of the concepts that the PSTs had difficulty were consistent with other studies on NOS understanding. Similar to Akerson et al., (2000), Gray and Fouad (2019), and Mesci and Schwartz (2017), the PSTs had difficulty with the interpretations of the knowledge category. Research on teaching and learning shows that it is important to know students' preconceptions, where responses gathered can be used to engage teachers' instructional decisions in the classroom (Cofré et al., 2019). It is recognized that the worksheet is not without its limitations if used as a testing instrument. There may be assumptions that the respondents know and use the terms in the same way as the researchers do. However, the open responses aim to elevate these issues, as the analysis of the responses will identify issues.

The paper adds to the growing body of literature to demonstrate how the theoretical RFN framework can be transformed for practical applications (Erduran et al., 2019). The effectiveness of the transformation into a worksheet is testament to the value of the RFN framework to NOS research. Cofré et al. (2019) conducted a meta-analysis of studies that look exclusively at the understanding of teachers and students NOS learning and teaching. Despite the article considering literature from a diversity of views, such RFN, many of the studies highlighted, continue to use the same questionnaires (e.g., V-NOS D, POSSE, and SUSSI) for teaching and learning and assessment, which illustrates the narrow philosophical lens and approaches prevalent in gathering NOS understanding. Their review only identified seven studies that focused on aspects of NOS that differed from those supported by the "consensus view". Cofré et al. (2019) highlight the need for empirical research that evaluates different theoretical lens such as the study report here.

What our empirical research provides is an insight into the use of an alternative theoretical approach available for understanding views of NOS. The R-NOS worksheet offers educators a wide range of choices regarding how to embed ideas from the RFN framework's categories into teaching. Another advantage of the worksheet is the visual nature of the questions. As such, it affords the possibility for it to be undertaken by younger participants. Further research could involve not only the application of the worksheet with students in secondary schools and university science students but also an examination of its application as a classroom teaching tool and identifying how the worksheet impacts NOS teaching and understanding.

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REFERENCES

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

Akerson, V. L., Abd-El-Khalick, F., & Lederman, N. G. (2000). The influence of a reflective activity-based approach on elementary teachers' conceptions of the nature of science. *Journal of Research in Science Teaching, 37*, 295-317. https://doi.org/10.1002/(SICI)1098-2736(200004)37:4<295::AID-TEA2>3.0.CO;2-2

Allchin, D. (2011). Evaluating knowledge of the nature of (whole) science. *Science Education, 95*(3), 518-542. https://doi.org/10.1002/sce.20432

Antonio, R. P. (2020). Developing students' reflective thinking skills in a metacognitive and argument-driven learning environment. *International Journal of Research in Education and Science, 6*(3), 467-483. https://doi.org/10.46328/ijres.v6i3.1096

Bilican, K. (2018). Analysis of pre-service science teachers' understanding of nature of science and proposed arguments on socio-scientific issues. *International Journal of Research in Education and Science, 4*(2), 420-435. https://doi.org/10.21890/ijres.410632

Boyatzis, R. E. (1998). *Transforming qualitative information: Thematic analysis and code development*. SAGE.

Brandon, R. (1994). Theory and experiment in evolutionary biology. *Synthese, 99*(1), 59-73. https://doi.org/10.1007/BF01064530

Caramaschi, M., Cullinane, A., Levrini, O., & Erduran, S. (2022) Mapping the nature of science in the Italian physics curriculum: From missing links to opportunities for reform, *International Journal of Science Education, 44*(1), 115-135. https://doi.org/10.1080/09500693.2021.2017061

Chen, S. (2006). Development of an instrument to assess views on nature of science and attitudes towards teaching science. *Science Education, 90*(5) 803-119. https://doi.org/10.1002/sce.20147

Cheung, K. K. C. (2020). Exploring the inclusion of nature of science in biology curriculum and high-stakes assessments in Hong Kong. *Science & Education, 29*(3), 491-512. https://doi.org/10.1007/s11191-020-00113-x

Cofré, H., Núñez, P., Santibáñez, D., Pavez J. M., Valencia, M., & Vergara, C. (2019). A critical review of students' and teachers' understandings of nature of science. *Science & Education, 28*, 205-248. https://doi.org/10.1007/s11191-019-00051-3

Cooley, W. W., & Klopfer, L. E. (1961). *Tous: Test on understanding science*. Educational Surveying Service.

Cullinane, A. (2018). *Incorporating nature of science into initial science teacher education* [Unpublished PhD dissertation]. University of Limerick, Ireland.

Cullinane, A., & Erduran, S. (2022). Nature of Science in Preservice Science Teacher Education–Case Studies of Irish Pre-service Science Teachers. *Journal of Science Teacher Education*. Published online: 5 May 2022. https://doi.org/10.1080/1046560X.2022.2042978

Cullinane, A., Hillier, J., Childs, A. & Erduran, S. (2022). Teachers' perceptions of Brandon's Matrix as a framework for the teaching and assessment of scientific methods in school science. *Research in Science Education*. Published: 26 March 2022. https://doi.org/10.1007/s11165-022-10044-y

Driver, R., Leach, J., Miller, R., & Scott, P. (1996). *Young people's images of science*. Open University Press.

Duschl, R. (1990). *Restructuring science education: The importance of theories and their development*. Teacher's College Press.

Erduran, S., & Dagher, Z. R (2014). *Reconceptualizing the nature of science for science education: Scientific knowledge, practices and other family categories*. Springer.

Erduran, S., Dagher, Z. R., & McDonald, C. V. (2019). Contributions of the family resemblance approach to nature of science in science education. *Science & Education 28*, 311-328. https://doi.org/10.1007/s11191-019-00052-2

Erduran, S., Kaya, E., Cilekrenkli, A., Akgun S., & Aksoz, B (2021). Perceptions of nature of science emerging in group discussions: A comparative account of pre-service teachers from Turkey and England. *International Journal of Science and Mathematics Education, 19*, 1375-1396. https://doi.org/10.1007/s10763-020-10110-9

Erduran, S., Kaya, E., Cullinane, A., Imran, O., & Kaya, S. (2020). Practical learning resources and teacher education strategies for understanding nature of science. In W. McComas (Ed.), *The nature of science in science education: Rationales and strategies* (2nd ed.). Springer.

Gray, K. L., & Fouad, K. E. (2019). A novel method for teaching the difference and relationship between theories and laws. *Science & Education, 28*, 471-501. https://doi.org/10.1007/s11191-019-00040-6

Hodson, D., & Wong, S. L. (2017). Going beyond the consensus view: Broadening and enriching the scope of NOS-oriented curricula. *Canadian Journal of Science, Mathematics and Technology Education, 17*(1), 3-17. https://doi.org/10.1080/14926156.2016.1271919

Irzik, G., & Nola, R. (2011). A family resemblance approach to the nature of science for science education. *Science & Education, 20*(7-8), 591-607. https://doi.org/10.1007/s11191-010-9293-4

Justi, R., & Gilbert, J. (2000). History and philosophy of science through models: Some challenges in the case of 'the atom'. *International Journal of Science Education, 22*(9), 993-1009. https://doi.org/10.1080/095006900416875

Kaya, E., Erduran, S., Aksoz, B., & Akgun, S. (2019). Reconceptualised family resemblance approach to nature of science in pre-service science teacher education. *International Journal of Science Education, 41*(1), 21-47. https://doi.org/10.1080/09500693.2018.1529447

Kelly, R., & Erduran, S. (2018). Understanding aims and values of science: Developments in the junior cyclespecifications on nature of science and pre-service science teachers'views in Ireland. *Irish Educational Studies*. https://doi.org/10.1080/03323315.2018.1512886

Kimball, M. E. (1967). Understanding the nature of science: A comparison of scientists and science teachers. *Journal of Research in Science Teaching, 5*(2), 110-120. https://doi.org/10.1002/tea.3660050204

Kuhn, D. (2010). Teaching and learning science as argument. *Science Education, 94*, 810-824. https://doi.org/10.1002/sce.20395

Kuhn, T. S. (1962). *The structure of scientific revolutions*. The University of Chicago Press.

Lederman, N. G. (1992). Students' & teachers' conceptions of the nature of science: A review of the research. *Journal of Research in Science Teaching, 29*(4), 331-359. https://doi.org/10.1002/tea.3660290404

Lederman, N. G., & Abd-El-Khalick, F. (1998). Avoiding de-natured science: Activities that promote understandings of the nature of science. In W. McComas (Ed.), *The nature of science in science education: Rationales and strategies* (pp. 83-126). Kluwer. https://doi.org/10.1007/0-306-47215-5_5

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

Lederman, N., Wade, P., & Bell, R. L. (1998). Assessing the nature of science: What is the nature of our assessments? *Science & Education, 7*(6), 595-615. https://doi.org/10.1023/A:1008601707321

Liang, L. L., Chen, S., Chen, X., Kaya, O. N., Adams, A. D., Macklin, M., & Ebenezer, J. (2008). Assessing preservice elementary teachers' views on the nature of scientific knowledge: A dual-response instrument. *Asia-Pacific Forum on Science Learning and Teaching, 9*(1), 1-19.

Matthews, M. (2012). Changing the focus: From nature of science (NOS) to features of science. In M. S. Khine (Ed.), *Advances in nature of science research* (pp. 3-26). Springer. https://doi.org/10.1007/978-94-007-2457-0_1

Maxwell, J. A. (1992). Understanding and validity in qualitative research. *Harvard Educational Review, 62*(3), 279-301. https://doi.org/10.17763/haer.62.3.8323320856251826

Mesci, G., & Schwartz, R. S. (2017). Changing preservice science teachers' views of nature of science: Why some conceptions may be more easily altered than others. *Research in Science Education, 47*, 329-351. https://doi.org/10.1007/s11165-015-9503-9

Miles, M. B., & Huberman, M. (1994). *Qualitative data analysis: A sourcebook of new methods*. SAGE.

Petersen, I., Herzog, S., Bath, C., & Fleißner, A. (2020). Contextualisation of factual knowledge in genetics: A pre- and post- survey of undergraduates' understanding of the nature of science. *Interdisciplinary Journal of Environmental and Science Education*, *16*(2), e2215. https://doi.org/10.29333/ijese/7816

Puttick, S., & Cullinane, A. (2021). Towards the nature of geography for geography education: An exploratory account, learning from work on the nature of science. *Journal of Geography in Higher Education*. https://doi.org/10.1080/03098265.2021.1903844

Schwartz, R. S., Lederman, N., & Lederman, N. (2008, March). *An instrument to assess views of scientific inquiry: The VOSI questionnaire* [Paper presentation]. The International Conference of the National Association for Research in Science Teaching. Baltimore, MD, USA.

Stadermann, H. K. E., & Goedhart, M. J. (2020). Secondary school students' views of nature of science in quantum physics. *International Journal of Science Education*, 42(6), 997-1016. https://doi.org/10.1080/09500693.2020.1745926

Stepan, N. (1982). *The idea of race in science: Great Britain 1800 -1960*. The Macmillan Press. https://doi.org/10.1007/978-1-349-05452-7

Wooding, S., Cullinane, A., & Erduran, S. (2020). *Supporting the teaching of scientific methods in practical science*. University of Oxford. https://doi.org/10.5287/bodleian:xqvKxnmnX

Yeh, Y., Erduran, S., & Hsu, Y. S. (2019). Investigating coherence on nature of science in the science curriculum documents: Taiwan as a case study. *Science & Education, 28*(3-5), 291-310. https://doi.org/10.1007/s11191-019-00053-1

APPENDIX A: R-NOS WORKSHEET

Name: ______________________________ **ID:** ______________________________

Nature of Science Pre-Test Questionnaire

Nature of science examines how science works and what makes science "science". Depending on perspective, everyone sees science differently; therefore the aim of this questionnaire is to get your perspectives as pre-service teachers. Please answer each of the following questions. You can use all the space provided and extra pages to answer a question if necessary. Please try to write answers for all parts where necessary. This is not a test and will not be graded.

1.1. Which statement represents your view of science? Place a tick in the box under the statement you agree with. Please select only one.

A	B	C
Science is another way of knowing. All other perspectives and views are as equally valid, i.e., all religious positions, all art forms, all political movements. What is considered knowledge is relative to the person's perspective on the world.	Science knowledge is the only authentic knowledge, because it comes from the confirmation of theories and objective scientific methods. Scientists have to be objective in their research and reality can be studied independently of the scientists influence on the data obtained.	Scientific knowledge is constructed by a scientist's perception and social experience, and is not just discovered from the world through an objective scientific method. Therefore, it holds that there is more than one valid methodology to seeking scientific knowledge.

1.2. Please explain why the statement you have chosen represent your views of science.

1.3. Is there a second statement from the list above that you feel also represents your views?

2.1. In the scientific community, scientists have certain aims they want to achieve and various values to which they much adhere. Please tick if you strongly agree, agree, disagree or strongly disagree or don't know, in the boxes provided to indicate how you feel about each statement.

A. Scientists aim to work with groups and organisations in an unbiased manner.

Strongly agree		*Agree*		*Disagree*		*Strongly disagree*		*I do not know*	

Any comment:

B. Scientists aim to be honest in their work.

Strongly agree		*Agree*		*Disagree*		*Strongly disagree*		*I do not know*	

Any comment:

C. Scientists take opposition to their ideas seriously and aim to deal with them.

Strongly agree		*Agree*		*Disagree*		*Strongly disagree*		*I do not know*	

Any comment:

D. Scientists do not aim to be accurate as often scientific knowledge is formed from mistakes made by the scientist.

Strongly agree		*Agree*		*Disagree*		*Strongly disagree*		*I do not know*	

Any comment:

E. The interests and preferences of organisations that fund research often cloud scientists' design and their interpretation of the findings and consequently the results that are disseminated to the public can be also be clouded as a result.

Strongly agree		*Agree*		*Disagree*		*Strongly disagree*		*I do not know*	

Any comment:

F. Politics never influences scientific studies and scientists never have to follow the values of the politicians.

Strongly agree		*Agree*		*Disagree*		*Strongly disagree*		*I do not know*	

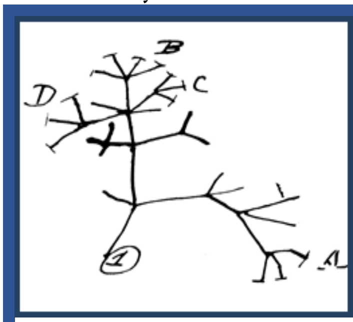
Any comment:

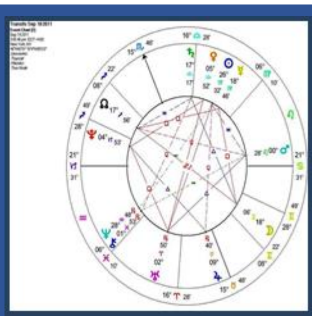
G. Scientists strive to conduct their inquiries in an objective way. Yet as with any human being, the scientists' personalities and social circumstances may influence their scientific investigations.

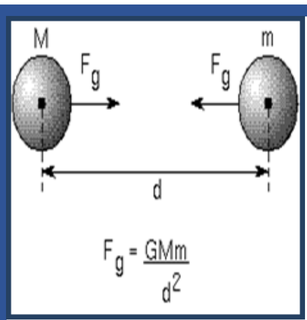
Strongly agree		*Agree*		*Disagree*		*Strongly disagree*		*I do not know*	

Any comment:

3.1. Which of the images DO NOT illustrate an example of scientific knowledge? Place a tick in the box(es) under the image. You may tick more than one box.







1. Darwin's tree of life	**2. Atlas**	**3. Astrological birth chart**	**4. Newton's explanation of gravity**

3.2. Please explain why/ how the image(s) you chose do not illustrate example(s) of scientific knowledge.

3.3. Why do you feel that the other images (which you did not tick) are examples of scientific knowledge?

3.4. There are different forms of scientific knowledge. Are the images above representing similar forms OR different forms of scientific knowledge? Please explain your answer.

4.1. Which of the following practices best characterises the practices of scientists (biologists, chemists, and physicists)? You may choose more than one characteristic for each scientist and you may choose the same characteristic for more than one type of scientist.

	Biologists	Chemists	Physicists
Experimenting			
Observing the world for interpretation			
Classifying data to produce scientific knowledge			
Disseminating research findings through conferences and journals			
Discussing and debating data to produce explanations with other scientists			

If you <u>DID NOT</u> tick a certain practice, please explain why it is <u>not</u> a practice undertaken by the particular scientist.
4.2. Biologists:
4.3. Chemists:
4.4. Physicists:

5.1. Do you think the aspects pictured here influence science? Tick YES or NO in the circle provided.

RACE	NATIONALITY	GENDER	POLITICS	RELIGION

5.2. **Race:** YES ◯ NO ◯. Please explain your answer.

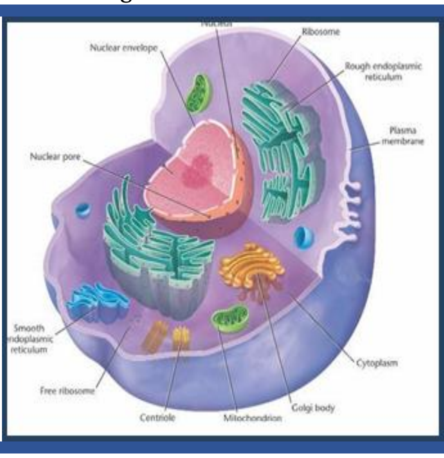
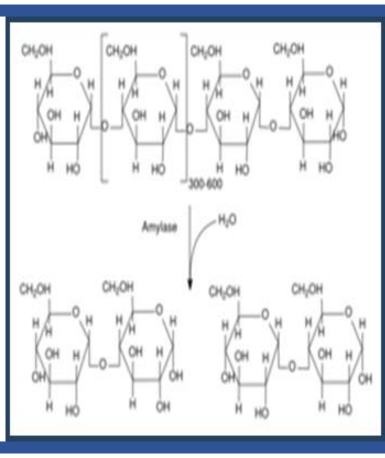
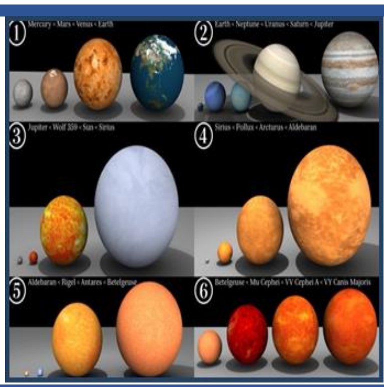
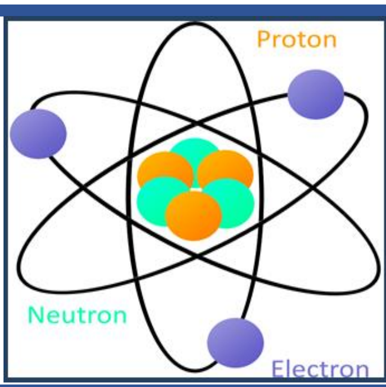
5.3. **Nationality:** YES ◯ NO ◯. Please explain your answer.

5.4. **Gender:** YES ◯ NO ◯. Please explain your answer.

5.5. **Politics:** YES ◯ NO ◯. Please explain your answer.

5.6. **Religion:** YES ◯ NO ◯. Please explain your answer.

6.1. Science is concerned with creating models to explain things. Which image(s) do you believe represents scientific models? Please indicate your answer with a tick under the image(s) you think represent scientific models. You may tick more than one image.

		
1. The cell	**2. The skeleton**	**3. Chemical reaction**
$\frac{dLs}{dt} = N * K_1 - (d_1 + r) * Ls + \delta_1$ $\frac{dLux}{dt} = \left(\frac{K_2}{1 + A * Ls1^2}\right) * N - (d_2 + r) * Lux + \delta_2$ $Z = Z_1 + Z_2$ $Z_1 = K_3 * Lux$ $Z_2 = \iint_{0,0}^{2\pi,D} e^{-K_4 s} * Z_{i,j} ds$ $\frac{dLs1}{dt} = Ls * \left(1 - \frac{Ls}{K5}\right) * Z * \left(1 - \frac{Z}{K6}\right)$ (1)		
4. Mathematical equation	**5. Solar system**	**6. The atom**

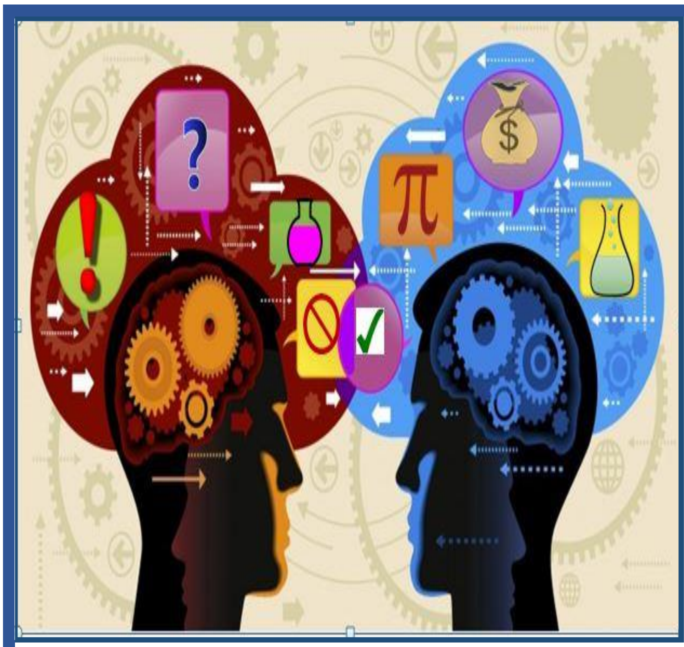
6.2. If there were any image(s) you DID NOT select, please explain why you believe it <u>does not</u> represent scientific model(s).

7.1. Scientific theories are a form of scientific knowledge. Read the statements below and select the statement(s) that best describes your thinking on scientific theories. You may tick more than one statement.

The knowledge we know today will not change. The theories and ideas we have are so rigorously tested by scientists that they will never change.	Our knowledge is always changing. When a theory has stood the test of time and is shown to be valid under all conditions that can be tested, it may be given status of a law.	Our knowledge is always changing as technology advances and scientists can get a better understanding of how the world works, however no matter how much our knowledge grows, a theory will never change into a law.

7.2. Please explain why you have chosen the statement(s) you have.

8.1. Which of the following two explanations below best represents how science is conducted in the scientific community?



Science is not a linear process. Scientists conduct science in a variety of ways depending on the contexts and discipline, in order to produce new knowledge.

Science is a linear process and is conducted through the scientific method; the process that is used by scientists for testing ideas and theories by using experiments and the formulation and testing of hypotheses.

8.2. Please explain your choice above.

9.1. There are a variety of methods and approaches that scientists use to produce new scientific knowledge. There are four scientific approaches below. Match the *example approach* (in the first box) to the *explanation of the approach* (in the second box) in the table below.
Match the letter in the first box to the number in the second box in the table below.

Example approach	A	B	C	D
Explanation of the approach				

EXAMPLE APPROACH	EXPLANATION OF THE APPROACH
A. Testing if the insulating properties of Styrofoam are greater than that of fibre glass.	1. This scientific approach tests a hypothesis without changing dependent and independent variables.
B. Investigating if the wavelength of light emitted from a pulsar in space is radio, visible, x-ray or gamma.	2. This scientific approach does not test a hypothesis, but conducts an experiment to measure the outcome.
C. Breeding a labrador and a poodle together, to see the new breed's features.	3. This scientific approach has no hypothesis; it is an exploratory approach to measure or observe an outcome.
D. Deep sea-exploration.	4. This scientific approach tests a hypothesis by changing dependent and independent variables.

On a scale of 1- 10 with 1 being not very confident and 10 being very confident, how would you rate your confidence with the answers you supplied to this questionnaire

1 2 3 4 5 6 7 8 9 10
Not very confident Very confident

Thank you for completing this questionnaire

APPENDIX B: SCORING RUBRIC FOR R-NOS WORKSHEET

	0=Incorrect view/no view	1=Naïve/Emerging views of NOS	2= Transitional/Developing view of NOS	3= Informed view of NOS
Question 1: Philosophical views. Evidence for change in philosophical views.	No response.	Ticked one or two philosophical statements but did not elaborate as to why they selected these statements. Or have unclear or confused ideas in their response, or refer to science being black and white.	Ticked one or two philosophical statements but have some unclear/ confused views of science but mention science as a human activity open to human influence (science not being black and white).	Ticked one or two philosophical statements and have well-articulated inferences about science being a human activity open to human influence (science not being black and white).
Question 2: Aims and values. Assesses their knowledge of the various aims and values of scientists.	If they agreed with all statements that required disagreement or vice versa, or ticked all "I don't know" or didn't tick any answer. Had either no or incorrect elaboration of statements.	If they agreed with some statements that required an agreement or vice versa, or ticked "I don't know". And they didn't elaborate on their answers at all in the comment section.	If they agreed with many statements that required agreement or vice versa. And elaborated on some statements with some developing views of the statements.	If they agreed with all statements that required agreement or vice versa. And went on to elaborate on their answers with some informed views of the statements.
Question 3: Scientific knowledge: Assesses the difference between theories laws and models and the idea of pseudoscience not forming part of scientific knowledge.	3.1 No response or ticked the wrong image(s) and have no elaboration of the ideas	3.1 If they ticked multiple image including the Astrological image	3.1 If they ticked Astrological image and one other one	3.1 If they ticked the Astrological image only
	3.2 No response or completely incorrect response provided as to why the image does not illustrate an example of scientific knowledge	3.2 If they select the Astrological image and another image but there is no elaboration as to why they are not a form of scientific knowledge. Or a completely incorrect response is provided.	3.2 They tick the Astrological image but only partially articulation as to why the image is a form of pseudoscience not supported by scientific evidence and therefore does not illustrate an example of scientific knowledge.	3.2 Articulate well using proper terminology that the Astrological image is a form of pseudoscience not supported by scientific evidence and therefore does not illustrate an example of scientific knowledge.
	3.3 No response or completely incorrect response provided.	3.3 If they present some knowledge as to why the images are forms of scientific knowledge but it is unclear or confused	3.3 Articulate that there is scientific evidence to support them, or they are models of science knowledge	3.3 Articulate well using proper terminology that the other images are theories laws and models
	3.4 No response or completely incorrect response provided	3.4 If they said they were similar but did not fully articulate why they were similar.	3.4 If they said they were similar but articulated that they were all models or because they were supported by scientific evidence.	3.4 If they said they were different forms and knowledge and have articulated well that the images are different because they represent theories, laws and models and a form of pseudoscience.
Question 4: Practice Assesses the different practices of scientists by characterising which practices biologists, chemists and physicists do and if there are differences between them.	Did not tick any practice or provides incorrect reasons why it is not a practice undertaken by scientists	Ticked few of the practices but provide no reasons as to why it is not a practice undertaken by scientists or they are incorrect.	Tick most of the practices. but provide incorrect or partially incorrect reasons as to why it is not a practice undertaken by scientists	Tick all the practices (will not need to elaborate on a response).
Question 5: Assessed broad aspects of science in society: Race, nationality, gender, politics, religion and its influence on science.	Selected no or incorrect options or provided incorrect responses when asked to explain their answers as to why the aspects pictured influence science.	Selected yes to one to two aspects and provided somewhat complete or incomplete reasons as to why the aspects influence science.	Selected yes three to four aspects and provided partial or complete reasons as to why they influence science.	Selected all the aspects and provide well-articulated complete reasons as to why the aspects of society influence science.

5.1 Scoring notes: Race impacts on science in terms of different races seeing themselves as superior and not taking the work of other races they see as inferior seriously	5.2 Scoring notes: Nationality: similar to Race also it different nationality have worked together to develop scientific knowledge over time and in parallel	5.3 Scoring notes: Gender: Women not being taken seriously in science and credit for their work given to their male counter parts. F and M can see science differently and bring different perspectives	5.4 Scoring notes: Politicians personal beliefs influencing science in terms of the funding allocated to science, and policy makers etc.	5.5 Scoring notes: Religion impacted science in terms of stem cell research and historically has banned science innovation as it defied the teachings of the church.
Question 6: Knowledge This question examined the aspect of models in science. All the images represent scientific models.	If they selected none of the an images (and provide reasons as to why these images do not represent scientific models)	Selected one to two images and provided partial reasons as to why these images do not represent scientific models.	Selected three to four images and provided a reason why the one/ two image/s they didn't select did not represent scientific model.	If they selected all the images.
Question 7: Knowledge Assesses the concept of the tentative nature of science, and theories changing into laws by providing	If they selected no statement about scientific theories	Selected an incorrect statement but provide correct or partially correct explanation in their reasoning Or they select the correct statement about scientific theories but provide an incorrect reason.	Selected correct statement and provide a partially correct explanation in their reasoning as to why the statement about scientific theories is correct.	Selected the correct statement and provides a complete explanation as to why they selected them. E.g: that a law explains what we can see and usually has a mathematical formula to explain it, a theory explains what we can't see but has withstood the rigour of many scientific tests.
Question 8: Methods Assesses the idea of the scientific method and the non-linear approach and the misrepresentation of the scientific method image.	If they selected no image or provide an in accurate account of the scientific method.	If they selected the scientific method image but provided a partial explanation about how it guides science.	If they selected the non-linear method but provide a partially correct answer as to why the non-linear approach best represents how science is conducted in the scientific community	Selected the non-linear approach and provide a complete explanation as to why e.g. there are many ways to do science and the scientific method shows a misrepresentation of science as a linear process
Question 9: Methods Assess four methods presented in FRA and investigate can they chose which experiment goes with which example explanation.	If they selected no answer or selected all the incorrect answers.	They got two correct or provided information that they had guesses the answers	If they got the four correct (but may have provided information that they had guesses the answers.)	If they got all four correct and they were confident in their answering.

Question 1	The pre-test provided baseline for comparison with post-test to investigate if their philosophical view would change post intervention.
Question 2	A. This statement requires an agreement; B. This statement requires an agreement; C. This statement requires an agreement; D. This statement requires a disagreement; E. This statement requires an agreement; F. This statement requires a disagreement; G. This statement requires an agreement
Question 3	The astrological birth chart is correct image as this is classed a pseudoscience.
Question 4	This question has some potential flaws for analysis considering it did require an explanation if they selected all the practices to show if there were reasons why they thought that these were all practices engaged by scientists and not just that they wanted to write less material. They received a four if they ticked all the statements.
Question 5.1	Race impacts on science in terms of different races being subject to scientific racism, and history seeing some races as superior & not taking work of other races they saw as inferior seriously.
Question 5.2	Nationality: Similar to race, also different nationalities have worked together to develop scientific knowledge over time.
Question 5.3	Gender: Women not being taken seriously in science and credit for their work given to their male counter parts. Females and males can see science differently and bring different perspectives.
Question 5.4	Politicians' personal beliefs influencing science in terms of the funding allocated to science, and policy makers etc.
Question 5.5	Religion impacted science for many year as it centres around beliefs opposed to beliefs about deity, & historically religious institutions banned science innovation as it defied the teachings of religion.
Question 6	Similar to question 4, there was no opportunity to record their thoughts as to why they thought all the images were models, so they received a four if they ticked all the images
Question 7	A complete explanation would include that a law explains what we can observe and usually has a mathematical formula to explain it, a theory explains what we can't see but has withstood the rigour of many scientific tests.
Question 8	There are a variety of scientific methods and scientists use a variety of approaches to conduct their investigation.
Question 9	The answer to this is A:4 B:1 C:2 D:3 (The example experiments provided in the pre-test were altered for the post test.)