Chapter #13

THE DEVELOPMENT, PILOTING AND ADMINISTRATION OF AN INSTRUMENT TO MEASURE NATURE OF SCIENCE UNDERSTANDING

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ABSTRACT
The study describes the development of an instrument to measure the Nature of Science (NOS) understandings in high school Science teachers. The instrument was initially piloted on two high school teachers in South Africa, one teaching Life Sciences and the other Physical Sciences. It was subsequently used to measure NOS understanding in 10 high school Science teachers in South Africa over 6 months in 2021. The objective of the study was to construct a questionnaire that could measure NOS understanding based on the Family Resemblance Approach (FRA) and the Consensus View (CV). The NOS is a construct that has been defined by various scholars and there exist multiple perspectives. For this study, two perspectives that define NOS, the CV of Abd-El-Khalick and the Reconceptualised Family Resemblance (RFN) approach to NOS of Erduran and Dagher were considered. To collect data on NOS understanding, the researcher compared the Views of Nature of Science (VNOS) instrument used to capture NOS understanding under the CV, and the RFN questionnaire used to capture NOS understanding under FRA and compiled an Integrated Family Views of Nature of Science (IFVNOS) questionnaire. The findings revealed that the IFVNOS questionnaire developed can be used as a reliable tool to measure NOS understanding.

Keywords: views of nature of science, family resemblance, consensus view.

1. INTRODUCTION

This chapter describes the development and administration of an instrument to measure Nature of Science (NOS) understandings in Science teachers. The study was carried out in two phases: phase 1, the development and piloting of the instrument; and phase 2, the administration of the instrument to 10 in-service Science teachers in South Africa over six months in 2021. The NOS is a construct that has been defined by various scholars and there exist multiple perspectives. For this study, two perspectives that define the NOS, the Consensus View (CV) (Abd-El-Khalick, 2013a) and the Reconceptualised Family Resemblance approach to NOS (RFN) (Erduran & Dagher, 2014) were considered. Based on these two perspectives, the researcher developed an analytical framework, the Integrated Family Views of Nature of Science (IFVNOS) and then developed a questionnaire based on this framework to assess views of NOS based on IFVNOS. The aims of the study are listed below.

Aims

- To design an instrument to measure views of NOS based on the CV and RFN.
- To pilot the use of the instrument to measure views of NOS of in-service Science teachers.
- To measure NOS understanding of 10 in-service Science teachers.

2. BACKGROUND

2.1. The nature of science

The NOS is a multifaceted construct that cannot be simply defined by one explicit definition. Rather, it is a concoction of attributes and a combination of at least seven aspects as defined by Lederman (1998), known as the tenets of NOS. The tenets are: Empirical; Inferential; Creative; Theory-driven; Tentative; Myth of The Scientific Method; Scientific theories; Scientific laws; Social dimensions of Science; and Social and cultural embeddedness of Science. NOS knowledge has been a goal of Science education reform for decades of years internationally and in South Africa where this study was conducted (Lederman & Lederman, 2019). Research has shown that understanding NOS is necessary for various attributes of an individual, including the promotion of responsible citizenship locally and globally (Smith & Scharmann, 1999), by ensuring that individuals can participate in decision making about socio-scientific issues through their acquired scientific knowledge (Driver, Leach, Miller, & Scott, 1996). Literature has, however, shown that the NOS is a concept that is naively understood globally. Akerson, Abd-El-Khalick, and Lederman (2000) have revealed that regardless of the level of education, there is an international inadequate realization of what the NOS is by Science teachers. Linneman, Lynch, Kurup, Webb, and Bantwini (2003) revealed that South Africa is no exception to the case and proposed that this naïve understanding of NOS can be attributed to a lack of formally acquired NOS knowledge by the teachers. Studies regarding NOS understanding have shown that explicit and reflective teaching is the most effective approach for improving teachers' NOS views (Akerson et al., 2000; Lederman & Lederman; 2019). However, this approach is not necessarily reflected in teacher education programs in South Africa (Ramnarain, 2017). The misconceptions of NOS could possibly be due to the complexity of defining what NOS is.

The NOS tenets defined by Lederman are widely accepted to be a representation of the CV of NOS and have been used as the framework for analysing NOS pedagogical views in Science students and their teachers (Kruse, Easter, Edgerly, Seebach, & Patel, 2017), for a representation of NOS in textbooks (e.g., Abd-El-Khalick, 2013b; Ramnarain & Chanetsa, 2016), and for the analysis of curriculum documents worldwide (Lederman, 2007) to name but a few. Reliable and valid instruments for NOS analysis based on the CV have been developed and used by researchers over decades such as the Views of Nature of Science Questionnaire (VNOS) developed by Lederman, Abd-El-Khalick, Bell, and Schwartz (2002). It is for these reasons of reliability and validity that the CV contributed to formulating the framework used to analyse the views of NOS in this study.

In more recent times, scholars have challenged the CV of NOS and highlighted shortcomings in its tenets as not encompassing economic, political, philosophical, social, and financial systems of Science (Erduran & Dagher, 2014). The Family Resemblance Approach to Science (FRA) has been developed to depict Science in a holistic system with dynamic interactions. This view of Science by Irzik and Nola (2010) adopted the generic definition of family resemblance coined by Wittgenstein in 1958. They proposed four categories of the FRA that reflect NOS as: a) activities; b) aims and values; c) methodologies and methodological rules; and d) products, which they substantiated had none of the shortcomings of the CV of NOS. Dagher and Erduran (2016) added categories of 'social organizations and interactions', 'political power structures', and 'financial systems' to FRA. This addition was made to highlight that Science is impacted by societal and cultural factors. The FRA has several authors but the work of Erduran and Dagher, who developed RFN, was considered in this study as their terminology appeals to science education and applies to the Science curriculum. The RFN defines NOS using categories of aims and values; methods; scientific practices; scientific knowledge; social certification and dissemination; scientific ethos; social values; professional activities; social organizations and interactions; financial systems; and political power structures.

2.2. Conceptual framework

In designing the integrated aspects of the NOS conceptual framework, the researcher analysed both the CV tenets and RFN categories. Ideally, the framework used in this study should comprise explicit statements such as those in the CV, as the researcher found these to be user friendly in content analysis of textbooks. This study formed part of larger research aimed at improving NOS understanding amongst teachers through the use of textbook analysis. It was found that the CV makes use of explicit tenets descriptive of independent NOS aspects, while the RFN represents a holistic interactive dynamic system of NOS categories. Research on RFN is limited and not widely spread at the time of writing this chapter. There is, however, sufficient evidence and reliable sources to validate the use of its instruments in Science education. Studies have been carried out in pre-service teacher education courses on NOS in Turkey using the RFN approach (Kaya, Erduran, Aksoz, & Akgun, 2019), and findings from this study have contributed to the understanding of how NOS can be incorporated into Science teacher education using RFN. The RFN has also been used in analysing the content of USA and Turkey curricula (Kaya & Erduran, 2016) and in investigating coherence about the NOS in Science curriculum documents of Taiwan (Yeh, Erduran, & Hsu, 2019).

The researcher found that within RFN categories, tenets of the CV on NOS are embedded. In analysing the RFN, the researcher found that two categories of RFN have no CV tenet representation, that is, in the scientific ethos category and social values category. Scientific ethos is defined as the norms that scientists employ in their work as well as in interactions with colleagues, while social values are values such as freedom, respect for the environment, and social utility. In the framework that was developed, it was necessary to represent these two RFN categories using keywords in order to match the format of the CV. Keyword analysis was the approach used by the authors of RFN when they conducted content analysis of Turkish curriculum statements (Kaya & Erduran, 2016). Keyword analysis involves the selection of indicative words from the descriptors of categories. From the two categories of scientific ethos and scientific values not represented in the CV, the researcher developed the keywords "ethical practices" derived from the definitions provided by the two categories. Ethical practices as keywords were thus included in the conceptual framework for this study. This framework was termed the IFVNOS and comprises (from the CV tenets): empirical, inferential, creativity, tentative, theory-driven, methods, scientific knowledge, social dimension of Science, social and cultural embeddedness of Science, Science vs pseudoscience and derived from RFN, ethical practices.

2.2.1. IFVNOS questionnaire

To collect the NOS views of the participant teachers, the researcher made use of the VNOS questionnaire version C, VNOS(C) developed by Lederman et al. (2002). The VNOS(C) has been validated by its authors and there exists a high level of confidence in it, thus making it an instrument of choice in this research. It has undergone an intensive validation process and revisions from VNOS(A) to VNOS(B) to this version of VNOS(C). The authors have provided crucial logistical and conceptual issues for consideration by researchers using VNOS(C) to ensure its correct administration with minimal errors, thus increasing the validity of the research process. Although the VNOS(C) can be regarded as valid and verified, shortcomings have been identified by the authors due to the aforementioned limitations of the CV. The need then arose to incorporate aspects of the FRA into VNOS(C) that were found to be lacking in the CV.

The authors of the RFN developed a questionnaire to assess views about the NOS (Kaya et al., 2019) reflecting the five RFN categories and incorporated educational applications in the questionnaire. The RFN questionnaire comprises 70 questions with five options of responses, which are ‘totally agree’, ‘agree’, ‘not sure’, ‘disagree’, and ‘totally disagree’ from which respondents select one option. One of the limitations of this 5-Likert scale is that the opinion and alternative responses of the respondents are not captured. Kaya et al. (2019) acknowledged the oversimplification of the instrument for the nature of data to be collected and argued that their interest was in developing an instrument for RFN. Given this oversimplification as noted above, the author of this research opted for open-ended questions extracted from the VNOS(C) questionnaire; numbers 1-9 below. Questions relating to family resemblance that were not represented in VNOS(C) were added to the questionnaire; numbers 10-12 below. This formed the IFVNOS questionnaire. These open-ended questions that comprised IFVNOS are:

1. What, in your view, is Science? What makes Science (or a scientific discipline such as physics, biology, etc.) different from other disciplines of inquiry (e.g., religion, philosophy)?

2. Do all scientific disciplines such as physics, astronomy, biology, and chemistry use the same scientific method? Explain your answer.

3. Define what an experiment is. Does the development of scientific knowledge require experiments?

If yes, explain why. Give an example to defend your position. If not, explain why. Give an example to defend your position.

4. After scientists have developed a scientific theory (e.g., atomic theory, evolution theory), does the theory ever change? If you believe that scientific theories do not change, explain why. Defend your answer with examples. If you do believe that scientific theories do change: a) explain why theories change b) explain why we bother to learn scientific theories. Defend your answer with examples.

5. Describe the purpose of theories, laws, and models in producing scientific knowledge.

6. Science textbooks often represent the atom as a central nucleus composed of protons (positively charged particles) and neutrons (neutral particles) with electrons (negatively charged particles) orbiting that nucleus. How certain are scientists about the structure of the atom? What specific evidence do you think scientists used to determine what an atom looks like?

7. Scientists perform experiments or investigations when trying to find answers to the questions they put forth. Do scientists use their creativity and imagination during their investigations? If yes, then at which stage of the investigations do you believe scientists use their imagination and creativity: planning and designing, data collection, or after data collection? Please explain why scientists use creativity and imagination during their investigations. If you believe that scientists do not use imagination and creativity, please explain why. Provide examples if appropriate.

8. It is believed that about 65 million years ago dinosaurs became extinct. Of the hypotheses formulated by scientists to explain the extinction, two enjoy wide support. The first, formulated by one group of scientists, suggests that a huge meteorite hit the earth 65 million years ago and led to a series of events that led to extinction. The second hypothesis,

formulated by the second group of scientists, suggests that massive and giant volcanic eruptions were responsible for the extinction. How are these different conclusions possible if scientists in both groups have access to and use the same set of data to derive their conclusions?

9. Some claim that Science is infused with social and cultural values. That is, Science reflects the social and political values, philosophical assumptions, and intellectual norms of the culture in which it is practiced. Others claim that Science is universal. That is, Science transcends national and cultural boundaries, and it is not affected by social, political, and philosophical values and intellectual norms of the culture in which it is practiced. If you believe that Science reflects social and cultural values, explain why. Defend your answer with examples. If you believe that Science is universal, explain why. Defend your answer with examples.

10. Scientists engage in professional activities such as attending conferences and doing publication reviews. Why do scientists engage in such activities?

11. Scientists work in organizations or establishments such as universities and research centers; how are they organized in these institutions?

12. Teaching epistemic, cognitive, social, and cultural values should be core components of the Science curriculum. Do you agree or disagree with this statement? Provide a reason for your opinion.

3. METHODOLOGY

As mentioned before, the study was carried out in two phases: phase 1, the development and piloting of the instrument; phase 2, the administration of the instrument to 10 in-service Science teachers in South Africa. The pilot study aimed at testing the IFVNOS questionnaire and its readability, and it adopted a structural content analysis approach. In phase 1 two participant teachers, one teaching Life Sciences and the other Physical Sciences were purposefully selected based on availability and access to online teaching of either Natural Sciences, Life Sciences, or Physical Sciences. In South Africa, Natural Sciences is taught in the first two years of high school, following which learners have the choice of taking either taking Life Sciences or Physical Sciences, or neither. Teachers were required to complete the IFVNOS questionnaire and return it via email within two weeks. It was recommended that the teachers take about 45 minutes to complete the questionnaire and that responses had to be their own and not researched. On receipt of each questionnaire, the researcher drafted an interview schedule aimed at clarifying aspects of the respondents' answers that may not have been clear or posed conflicting messages to an understanding of the NOS aspects. In phase 2 of the study, the questionnaire to document the NOS understanding was then distributed to 10 purposefully selected in-service Science teachers based on availability and willingness to participate.

3.1. Content analysis

According to Krippendorff (1980), "Content analysis has been defined as a systematic replicable technique for compressing many words of text (or other meaningful matter) into fewer categories based on explicit rules of coding" (p. 17). The qualitative data collected from the IFVNOS questionnaire and the interview for each teacher were coded for NOS aspects in a technique similar to Saldana's coding technique. According to Saldana (2009), a code serves to summarize or condense data rather than simply reduce it. The NOS aspects were assigned to every response provided by participants; in some instances, responses comprised more than one NOS aspect. IFVNOS responses and interview responses were assigned NOS aspects independently. The units of similar NOS aspects were then grouped for analysis to allocate a rating describing the degree of explicitness or implicitness of the NOS representation.

3.2. Scoring rubric

Points were allocated by the researcher from a scale of positive three points to negative three points based on Abd El-Khalick's scoring rubric (2013b). The allocation of points depended on the degree of explicitness or implicitness of the NOS represented in the units of analysis. A cumulative score ranging from -33 to +33 was then assigned to the NOS understanding of each teacher. The higher the cumulative score, the more explicit, informed, and consistent the representation of the NOS. The following scoring rubric was used:

- Three points = Explicit, informed, and consistent representation of the target NOS aspect.
- Two points = Explicit, partially informed representation of the target NOS aspect.
- One point = Implicit, informed, and consistent representation of the target NOS aspect.
- Zero points = The target NOS aspect is not addressed.
- Negative one point = Implicit misrepresentation of the target NOS aspect.
- Negative two points = The textbook materials convey mixed explicit and/or implicit messages about the target NOS aspect.
- Negative three points = Explicit, naïve representation of the target NOS aspect

  (Source: Abd-El-Khalick: NOS textbook analysis methods/ UIUC: April 20th, 2013/ Scoring rubric).

3.3. Reliability and validity

To ensure reliability in content analysis, Abd-El-Khalick (2013b) stipulated the use of more than one rater to achieve inter-rater reliability of the findings. Two raters were used in this study, and each one reviewed and analysed the data independently, assigning scores of the NOS understanding to the units of analysis. There was complete agreement between the findings of the two raters indicating a high level of reliability of the findings. Conducting an interview post-evaluation of IFVNOS responses and triangulation of findings from both questionnaires contributed to some level of validity in the findings.

3.4. Phase 1

3.4.1. Findings

Both in-service Science teachers were found to have an inadequate overall understanding of the NOS. The cumulative possible score of NOS understanding of +33 represents an explicit and informed understanding. Although the teachers in some instances displayed an explicit, informed understanding of some NOS aspects, these scores were lowered by mixed understanding or naïve understanding in other instances. The ensuing table displays some quotations from teacher responses and corresponding scores allocated by the researcher.

Table 1.
Excerpts of NOS responses of teachers and score assigned.

Teacher	Cumulative score /33	Example of excerpts	NOS understanding
Physical Sciences	+13	**Scientific theories:** "Theories do change, theories are developed on knowledge that are known, but often limited. Theories cannot always be proven wrong, but they can't be proven right either. The lack of concrete evidence proving a theory right means that a theory can change. Certain models have been adapted and changed, but older models can be useful to explain certain aspects."	explicit, informed +3
Life Sciences	+6	**Social and cultural embeddedness:** "So while *Science* may be affected by cultural practices, the prevailing desire to make it universal results in it being universal. It's not a field occurring in this vacuum, it has to be shaped to some extent by what surrounds those who build this knowledge. The way that we even build the knowledge and the people who build the specific type of knowledge is specific to their context."	mixed, explicit -2

3.4.2. Discussion of findings

The inadequate NOS understanding of the teachers is consistent with findings by other researchers in South Africa (Govender & Zulu, 2017). The small number of teachers used in the pilot does not provide enough indicative findings on the reliability of the instrument. The pilot aimed to test if the IFVNOS could be used to capture views of NOS, and this was achieved. No revisions were made to the questionnaire following the pilot. The pilot provided valuable insight into how data would be analysed to rate NOS understanding. The IFVNOS was then used to capture NOS understanding from a larger number of teachers who participated in the study to improve NOS understanding through textbook analysis. The reliability of the instrument could then be commented on after it had been used on a larger number of teachers.

3.5. Phase 2

3.5.1. Data collection of NOS understanding of 10 teachers

Ten in-service high school Science teachers, purposefully selected based on availability, access to the internet, and being in-service, partook in phase 2 of the study. To distribute the IFVNOS instrument, the researcher created a Google Form on which the questionnaire was loaded. The 10 teachers completed the Google Form online over six weeks and their responses to the questionnaire were automatically captured onto Google Drive. The authors of the VNOS form recommend that the questionnaire be administered under controlled conditions, such as in a classroom setting, typically requiring 45-60 minutes to complete. Due to the lockdown restrictions imposed because of COVID-19 in South Africa in 2021, researchers were not readily allowed to enter schools to collect data. The participant teachers, therefore, had to respond to the questionnaire in their own unique settings online after being notified by the researcher that completing the questionnaire would take about 45 minutes. The turnaround time from the release of the questionnaire on the Google Form to receipt of responses from the teachers varied from three days to six weeks. Teachers used various gadgets such as cell phones, laptops, and tablets to complete the forms online.

Lederman et al. (2002) recommended conducting follow-up interviews to the questionnaire aimed at establishing the validity of the responses captured by the VNOS instrument and interpreted by the researcher. The authors of the VNOS instrument recommended that many interviews should be conducted until the researcher becomes an expert in analysing VNOS responses. Expertise would be evidenced by a high degree of correspondence between the inferences made by the researcher when analysing VNOS responses and the views clarified during interviews. In this study, most of the respondents (eight out of 10) were interviewed to clarify responses, thus ensuring the reliability of the findings. This was a large number of respondents, and it was necessary to conduct these interviews since the questionnaires were not administered in a controlled environment and under supervision. Interviews were typically conducted within two weeks of the researcher receiving the IFVNOS responses and were conducted online using platforms such as Zoom or Google Meet. These sessions were recorded online for the researcher to transcribe. Interviews typically took 18 to 30 minutes.

3.5.2. Findings

The 10 teachers showed varying levels of NOS understanding with cumulative scores ranging from -4 to +18. A more negative cumulative score represents a more explicit, naïve representation of NOS understanding, while a score of +33 represents an explicit, informed, and consistent NOS understanding across all NOS aspects.

Table 2.
Excerpts of NOS responses of teacher, corresponding interview question, responses and score assigned.

Teacher cumulative score /33	**IFVNOS response**	**Interview question**	**Interview response**	**NOS understanding**
-4	Scientific theories work within certain boundaries of the variables. If the variables reach extremes the theory may not work. The theory is useful to explain things within limits.	Would the theory ever change?	Yes, I do think it changes, it more develops than changes completely. …all scientific knowledge requires experiments.	Scientific knowledge (theories, laws) -2

	A theory is something a bit broader than a law. A theory still has to be tested. Out of the theory comes testing and out of testing comes laws.	So is there a hierarchy to a law and a theory or are they just different forms of scientific knowledge?	I wouldn't say one is better than the other, I would say something always starts off with a theory. It's probably as much work developing a theory as finding and testing in coming to a law, it's just the process.	

3.5.3. Discussion of findings

The findings of the study revealed a general naïve understanding of the NOS as has been found by other researchers in South Africa (Gwebu, 2015; Govender & Zulu, 2017). The instrument used was reliable in its use and can be used to collect IFVNOS views. Although the data collection process was not envisioned to be carried out completely online, the triangulation of follow-up interviews and IFVNOS responses contributed to making the findings valid. One of the difficulties encountered by the researcher in the data collection process was connectivity issues when carrying out interviews with respondents who were not in areas with strong internet connections. To overcome this challenge, the researcher turned on captions and shared the participant's IFVNOS responses and the interview schedule with each respondent. This aided the respondent to follow the questions that the researcher was asking while simultaneously reminding themselves of the responses they had given. Due to time-lapses and health, mental, and emotional challenges facing participants during the COVID-19 lockdown, some participants could not easily recall the initial responses that they had provided to the IFVNOS questionnaire. Sharing the submitted responses aided in reminding the participants of their initial thoughts and understandings.

4. FUTURE RESEARCH DIRECTIONS

The overall naïve understanding of the NOS presented by the teachers signifies the need for professional development programs to improve the NOS understanding. This study reported in this chapter forms part of a larger study in which the 10 participant teachers would attend a professional development program based on textbook analysis to improve their NOS understanding. Following the training, the IFVNOS questionnaire will be administered to capture their NOS views, and comparisons will be made to track any changes in understanding.

5. CONCLUSION

This chapter reported on the development of an instrument to measure views of the NOS that merged the CV and RFN. The piloting of the instrument, findings of the pilot study, and further administration of the instrument to 10 Science teachers were also reported. The entire data collection process and data analysis were carried out online, from

April to August 2021. This was during the COVID-19 lockdown period in South Africa where it was difficult to gain access to in-service Science teachers in person. Strategies had to be put in place to ensure that the data collection process was credible and valid. It can be concluded after analysing the data from the pilot and the main study that the IFVNOS questionnaire can be used to measure NOS understanding. There is still a need for professional development programs to improve the NOS understanding of in-service teachers. The teachers whose IFVNOS were captured will attend training on NOS to improve their understanding, and the instrument will be used to document any changes in their NOS understanding.

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