Interdisciplinary Journal of Environmental and Science Education
2021, 17(2), e2238
ISSN: 2633-6537 (Online)
https://www.ijese.com

VNOS: A Historical Review of an Instrument on the Nature of Science

Luis-Alfonso Ayala-Villamil[1,2*], Álvaro García-Martínez[1]

[1] Doctorado Interinstitucional en Educación-Universidad Distrital Francisco José de Caldas, COLOMBIA
[2] Secretaría de Educación de Bogotá, COLOMBIA
[*]**Corresponding Author:** laayalav@correo.udistrital.edu.co

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

ARTICLE INFO

Received: 10 March 2020

Accepted: 1 September 2020

ABSTRACT

This paper studies four key aspects of the instrument "Views of Nature of Science" (VNOS); a) its general characteristics, b) the particular characteristics of the forms VNOS-A, VNOS-B, VNOS-C, VNOS-D; VNOS-D+ and VNOS-E, c) the modifications of its open-ended questions, and finally, d) the scope and limitations of the VNOS forms from the new conceptualizations of the Nature of Science (NOS) construct. The methodology is based on documentary research. The criteria of validity and reliability of Scott (1990) are followed. The open-ended questions of VNOS are analysed from four identified inductive categories: extension, reduction, substitution and fragmentation. The main contributions of the article are: 1. Delve into the characterization of VNOS, and its forms, allowing future NOS researchers to interpret the data obtained from the VNOS forms. Thus, each VNOS form identifies open-ended questions focused on various aspects of NOS (direct questions) and open questions focused on a specific context. The VNOS-C form presents more open-ended questions in a specific context and may be of greater interest for research in some populations. Explicit and implicit questions are also identified. The VNOS-D + form has more open-ended questions. Researchers are probably able to find units of analysis to characterize NOS views more easily in the VNOS-D+ form. 2. Relate the open-ended questions and NOS aspects characterize in each VNOS form. 3. Group open-ended questions by characterized NOS aspects, which is of interest for research focused on a particular NOS aspect. 4. Finally, the possibility of characterizing views on "scientific methods" is highlighted, especially when VNOS is used in conjunction with monitoring interviews, as well as with the "Views About Scientific Inquiry" (VASI) instrument. Similarly, it relates to the potential of VNOS forms to characterize some aspects coming from other NOS conceptualizations, especially from "features of science" (FOS) raised by Mathews (2012). All of the above, contributes conceptually and methodologically, to the identification of NOS views of primary and secondary students and their teachers. This is necessary to carry out diagnoses of NOS views in different communities, to propose evaluations of the impact of different teaching strategies and to relate NOS with other constructs, which together allow for the development of skills for informed socioscientific decision-making in the population in general.

Keywords: nature of science, VNOS forms, NOS views

INTRODUCTION

Contribution to scientific literacy has been an objective of education reforms in many countries (Cofré et al., 2014; Deboer, 2000; McComas & Olson, 1998; Ministry of Education [MOE], 2007; National Research Council [NRC], 1996; Sarkar & Gomes, 2010; Wang & Zhao, 2016). Understanding of NOS is considered a structural facet of scientific literacy (Akerson et al., 2010; Izquierdo-Aymerich et al., 2016; Ozgelen et al., 2013; Sarkar & Gomes, 2010); moreover, it has become one of the main objective of science education in the schools (Akerson et al., 2010; American Association for the Advancement of Science [AAAS], 1993; Ayala-Villamil, 2019; Celik & Bayrakceken, 2012; Mesci & Schwartz, 2016; Sarkar & Gomes, 2010; Vázquez-Alonso et al., 2013; Wang & Zhao, 2016) and is supported on utilitarian, democratic, cultural, axiological and educative reasons (Adúriz-Bravo & Ariza, 2013; Driver et al., 1996; Izquierdo-Aymerich et al., 2016; McComas et al., 1998; Sarkar & Gomes, 2010; Vázquez-Alonso et al., 2013). Consequently, it is necessary to consider the central role of teachers in the improvement of student learning (Lederman, 2007; Matthews, 1990; McComas et al., 1998; Mesci & Schwartz, 2016; Rennie et al., 2001; Aikenhead & Ryan, 1992). Because they play an essential role in helping their students to understand NOS. In this way, to characterise NOS understanding, many instruments have been created in the second half of the 20th century, including VNOS.

Purpose of the Research

The purpose of this study is to describe each form of the "Views of Nature of Science" (VNOS) instrument and compare them to identify modifications, scopes, and limitations of the VNOS forms. This article focuses on the following questions:

1. What are the characteristics of VNOS-A, VNOS-B, VNOS-C, VNOS-D; VNOS-D+ and VNOS-E?
2. What questions have been modified, removed or included in the VNOS forms?
3. What are the scope and limitations of the VNOS forms?

This article focuses on the VNOS since it is a widely used instrument in NOS empirical research (Aflalo, 2014; Allchin, 2011; Hodson & Wong, 2014; Kampourakis, 2016). This document does not include the comparison of different NOS instruments since it is the subject of another document that we hope to make available soon.

Significance of the Research

The article delves into the characteristics of VNOS, its origin, and the transformation of its questions through its forms. It is a contribution to NOS research because it recognizes the general and specific characteristics, scope, and limitations of each form of the VNOS. This provides future NOS researchers with:

(a) Analytical tools to choose the form of VNOS relevant to their research.

(b) To facilitate the analysis and interpretation of the data obtained with VNOS forms.

(c) To identify perspectives of the NOS that are not characterized by the forms of VNOS, and that are relevant from the recent conceptualizations of the NOS.

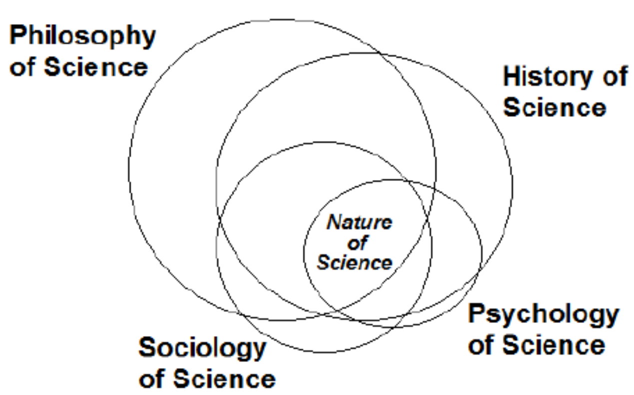

Figure 1. Representation of the contribution of four meta-sciences to the understanding of NOS (McComas & Olson, 1998, p. 50).

LITERATURE REVIEW

Conceptualization of NOS

Nature of Science or Nature of Scientific Knowledge is a multifaceted and complex construct, as much as science itself. In the literature there are several definitions of NOS; for example, McComas et al. (1998) define it as:

"a fertile hybrid arena which blends aspects of various social studies of science including the history, sociology, and philosophy of science combined with research from the cognitive sciences such as psychology into a rich description of what science is, how it works, how scientists operate as a social group and how society itself both directs and reacts to scientific endeavors." (p.4)

In this way, different meta-sciences contribute to a greater or lesser degree to the NOS construct. McComas and Olson (1998), in their review of international standards on science education, indicate that NOS is not synonymous with the Philosophy of Science; on the contrary, the History of Science, Sociology of Science and Psychology of Science also make contributions to the understanding of how science works. In Figure 1, the areas of the circumferences represent the contribution of each meta-science.

In the last two decades, interesting debates have arisen about the conceptualization of NOS (Ayala-Villamil, 2020). Two approaches are clearly identifiable, called by Abd-El-Khalick (2012), the general domain approach, and a specific domain approach. In the present document, under the denomination of the general domain approach, there are the "consensus" views or general aspects of NOS, thought for the scientific literacy of citizens, and to be developed in previous levels of education to the university. Among the researchers who have conceived NOS from this approach are Lederman et al. (2002), McComas (1998), Niaz (2009), Osborne et al. (2003).

Lederman and his collaborators have proposed a theoretical framework for researching and teaching NOS. They argue that the Nature of Science (NOS) and Scientific Inquiry (SI) constructs are different but converge in research because they are closely related (Bartos &

Lederman, 2014; Lederman et al., 2012; Lederman et al., 2014a). For these authors, NOS "refers to the characteristics of scientific knowledge that are inherently derived from how it is produced, that is scientific inquiry" (Lederman, Antink & Bartos, 2014b, p. 286). Specifically, they present a list of aspects, called tenets, that describe NOS in the context of K-12 (kindergarten through Grade 12 in a US context) science education, and this list is not intended to be exhaustive (Lederman, 2007). That said, tenets are:

1) Tentativeness of Scientific Knowledge: Both scientific laws and theories are subject to change.

2) Observations and inferences: Science is based on both observations and inferences. Scientists present their observations as statements that describe the world's natural phenomena. They are generated through the senses or with extensions of the senses. In contrast, inferences are statements obtained from manifestations or effects. Inferences allow the development of models and explanations about the observations.

3) Scientific Theories and Laws: The laws of science are statements about relationships observed in the natural world, in contrast to scientific theories, which are inferences that explain observations. Scientific theories and laws are different types of knowledge. Scientific theories and laws do not present a hierarchical relationship, which means that theories are not created to become laws.

4) Creativity and imagination: The development of knowledge requires human creativity and imagination to design research methodologies, analyse data, raise ideas, and create explanations.

5) Subjectivity in science (theory-laden): Scientific knowledge is subjective because scientists have theoretical commitments, beliefs, prior knowledge, training, experiences, and expectations. This generates different perspectives, which intervene in the problems that scientists investigate, the methodologies employed, the interpretations of the data, and the conclusions obtained.

6) Social and cultural integration in science: Science as human action takes place in cultural and social contexts. Scientists are products of these contexts. Science follows influences and is affected by elements of culture and society. Some of these elements are the social fabric, power structures, politics, socio-economic factors, philosophy, and religion.

7) The empirical nature of scientific knowledge: Science is not only based on observations of the natural world. (Lederman et al., 2012; Lederman et al., 2014a).

In addition, there is interdependence between the tenets (Schwartz, Lederman, & Crawford, 2004).

On the other hand, SI "refers to characteristics of the processes through which scientific knowledge is developed, including the conventions involved in the development, acceptance, and utility of scientific knowledge" (Bartos & Lederman, 2014, p. 4) and consider aspects such as; a) scientific investigations always begin with a question, b) there is no single set or sequence of steps in a scientific investigation, c) the procedures followed in an investigation are invariably guided by the question(s) asked, d) scientists following the same procedures will not necessarily arrive at the same results, e) the procedures undertaken in an investigation influence the subsequent results, f) conclusions drawn must be consistent with collected data, g) data are not the same as evidence, and h) scientific explanations are developed through a combination of evidence and what is already known (Bartos & Lederman, 2014, p. 5).

General domain approach has been the most used conceptualization in the empirical research of NOS (González-García, Blanco-López, España-Ramos, & Franco-Mariscal, 2019), and in Table 1 are presented the proposals of McComas (2008), Niaz (2009) and Osborne, Collins, Ratcliffe, Millar and Duschl (2003). McComas' list arises from the high correlation between content analysis of a group of books focusing on the nature and/or philosophy of science (McComas, 2005) and the convergence of key ideas appropriate for inclusion in the K-12 curriculum, constructed by Lederman (1998), McComas (1998); McComas et al. (1998) and Osborne et al. (2003).

Marin et al. (2013) analyse the NOS consensus of McComas and Olson (1998), Lederman et al. (2002), Osborne et al. (2003), Fernández et al. (2002), Vázquez-Alonso et al. (2004) and establish consensus between these different research groups through inductive and deductive processes, which are interrelated through a network of categories called context systematics ("sistemática de contextos" in Spanish). The contexts and their inductive categories (consensuses) are:

Sociological context: a) science emerges from the historical and social context of the moment, b) science has strong social and cultural implications, and c) there are strong interactions between Science, Technology, and Society (STS).

"Private phase" context: a) the importance of creativity in discovery, and b) the scientist is affected by his interests.

"Private-public interaction phase" context: a) individual contributions are socially regulated by the expert community.

"Justification phase" context: a) empirical data are

Table 1. Some versions of the “general domain approach” conceptualization of NOS

(McComas, 2008)	(Niaz, 2009)	(Osborne et al., 2003)
Science produces, demands and relies on empirical evidence	Scientific knowledge relies heavily, but not entirely, on observation, experimental evidence, rational arguments, and scepticism	Science and questioning
Knowledge production in science shares many common factors and shared habits of mind, norms, logical thinking and methods such as careful observation and data recording, truthfulness in reporting, etc. Science and its methods cannot answer all questions	There is no one way to do science and hence no universal, recipe-like, step-by-step scientific method can be followed	Analysis and interpretation of data
	Scientists require accurate record keeping, peer review, and replicability	Scientific method and critical testing
Scientific knowledge is tentative, durable and self-correcting	Science is tentative/fallible	Science and certainty
	Development of scientific theories at times is based on inconsistent foundations	
Laws and theories are related but distinct kinds of scientific knowledge. Hypotheses are special, but general kinds of scientific knowledge	Laws and theories serve different roles in science and hence theories do not become laws even with additional evidence	Hypothesis and prediction
Science has a creative component	Scientists are creative and often resort to imagination and speculation	Creativity
Science has a subjective element (theory-laden)	Observations are theory-laden	
	Different scientists can interpret the same experimental data in more than one way	Diversity of scientific thinking
There are historical, cultural and social influences on the practice and direction of science	Scientific ideas are affected by their social and historical milieu	Historical Development of scientific knowledge
	Scientific progress is characterized by competition among rival theories	Cooperation and collaboration in the development of scientific knowledge
Science and technology impact each other, but they are not the same		Science and technology

not neutral, b) science is both durable and tentative, c) progress is sometimes evolutionary and sometimes revolutionary, d) there is no one “scientific method” for doing science, e) science combines induction and deduction, and f) the role of hypotheses is important in empirical contrast (Marin et al., 2013).

Critics of the general domain approach argue that: 1) science cannot be adequately characterized from simple statements, 2) the NOS characteristics of the general domain approach are not exclusive to science, they are aspects of human knowledge, 3) it does not recognize the distinctive differences in the development of knowledge from different scientific disciplines (biology, chemistry, physics, etc.) (Kampourakis, 2016). Thus, the general focus domain produces a restrictive, static, timeless NOS view. Also, there is no evidence that the listings help to make personal and social decisions. But, they can generate declarative teaching of NOS, when their teaching should be functio,nal (Allchin, 2011). As an alternative, the specific domain approach emerges, which attempts to overcome the criticism made to the general domain approach. Some NOS conceptualizations that are part of the specific domain approach are “Classical meta-theoretical questions on NOS” by Adúriz-Bravo (2001), “understanding scientific practice” by Hodson (2009), “Family Resemblance Approach” (FRA) by Irzik and Nola

(2011), "Features of Science" (FOS) by Matthews (2012), "Whole Science" by Allchin (2011), "Reconceptualised Family Resemblance" by Erduran and Dagher (2014), and conceptualization of Nature of Science & Technology (NoS&T) for science and technology education, called "4-World model and VOSTS taxonomy" by Vázquez-Alonso and Manassero (2017). In this article, we only present some of these conceptualizations to contextualize part of the current debate. A more detailed review is in Ayala-Villamil (2020).

Matthews (2012) proposes that recent NOS research presents the following philosophical and educational errors: a) The confused jumbling together of epistemological, sociological, psychological, ethical, commercial and philosophical features into a single NOS list, b) The privileging of one side of what are contentious and much-debated arguments about the methodology or 'nature' of science, c) The assumption of particular solutions of the demarcation dispute, and d) The assumption that NOS learning can be judged and assessed by students' capacity to identify some number of declarative statements about NOS. As an alternative, he proposes a theoretical framework to conceptualize and investigate NOS, based on a change of terminology and research approach, arguing a shift from "Nature of science (NOS) to a more relaxed, contextual and heterogeneous 'Features of Science' (FOS)" (Matthews, 2012, p. 4).

For Matthews, it's best to think of the seven aspects of Lederman and his collaborators as FOS to arise, consult, discuss and analyse; and not as elements of NOS to learn and evaluate in class. Besides, Experimentation, Idealization, Models, Values and Socioscientific issues, Mathematization, Technology, Explanation, Worldviews and Religion, Theory choice and rationality, Feminism, Realism, and Constructivism should also be considered, because they are also epistemological, historical, psychological, social, technological and economic. These are part of the scientific effort, and also meet the criteria of accessibility, consensus, and utility, which Lederman and his collaborators consider pertinent to choose NOS issues in K-12 teaching.

Allchin (2011) proposes to rethink NOS from the reliability in scientific practice. This conceptualization, called Whole Science, conceives a set of dimensions (Table 2) on how the scientific community achieves and preserves reliability as it develops scientific

Table 2. Partial inventory of dimensions of reliability in science

Dimension epistemic	**Dimension**	**Categories**
Observational	Observation and measurements	Accuracy, precision; role of systematic study (versus anecdote); completeness of evidence; robustness (agreement among different types of data).
	Experiments	Controlled experiment (one variable); blind and double-blind studies; statically analysis of error; replication and same size.
	Instruments	New instruments and their validation; Models and model organisms; Ethics of experimentation on human subjects.
Conceptual	Patterns of reasoning	Evidential relevance (empiricism); verifiable information versus values; role of probability in inference; alternative explanations; correlation versus causation.
	Historical dimensions	Consilience with established evidence; role of analogy, interdisciplinary thinking; conceptual change; error and uncertainly; role of imagination and creative syntheses.
	Human dimensions	Spectrum of motivations for doing science; spectrum of human personalities; confirmation bias/role of prior beliefs; emotional versus evidence-based perceptions of risk.
Sociocultural	Institutions	Collaboration and competition among scientists, forms of persuasion; credibility; peer review and response to criticism; resolving disagreement; academic freedom.
	Biases	Role of cultural beliefs (ideology, religion, nationality, etc.), role of gender bias; role of racial or class bias.
	Economics/ funding	Sources of funding; personal conflict of interest.
	Communication	Norms for handling scientific data; nature of graphs; credibility of various scientific journals and news media; fraud or other forms of misconduct; social responsibility of scientist.

Adapted from (Allchin, 2017).

Table 3. Subscales of some NOS instruments

Student Understanding of Science and Scientific Inquiry (SUSSI) (Liang et al., 2008)	Nature of Scientific Knowledge Scale (NSKS) (Rubba, 1977; Rubba & Andersen, 1978)	Conceptions of scientific Theories Test (COST) (Cotham y Smith, 1981)	Views on Science-Technology-Society (VOSTS) (Aikenhead & Ryan 1992)	Modified Nature of Scientific Knowledge Scale (M-NSKS) (Meichtry, 1992)	Students' Ideas about Nature of Science (SINOS) (Chen et al., 2013)
Observations and inferences	Amoral	Ontological implications of theories	Science and Technology	Creative	Theory-laden
Tentativeness	Creative	Testing of theories	Influence of Society on Science/ Technology	Developmental	Coherence and objectivity
Scientific theories and laws	Developmental (tentative)	Generation of theories	Influence of Science/ Technology on Society	Testable	Creativity and imagination
Social and cultural embeddedness	Parsimonious	Choice among competing theories	Influence of School Science on Society	Unified	Tentativeness
Creativity and imagination	Testable		Characteristics of Scientists		Durability
Scientific methods	Unified		Social Construction of Scientific Knowledge		Science for girls
			Social Construction of Technology		Science for boys
			Nature of Scientific Knowledge		

Source: Own devising.

knowledge. The dimensions with their categories can be overwhelming, so one must be selective. It is enough to choose some historical or contemporary cases that present science in its social, cultural, and research context. From Whole Science, the important thing is to verify that students reflect on a broad spectrum of NOS "Whole Science" dimensions, using the inventory of dimensions of reliability in science and their categories (Allchin, 2017).

Thus, what is important from this perspective is functional scientific literacy, which allows students to understand how science works, to interpret the reliability of scientific statements and to make decisions in personal and public situations. This reflects the relevance given in the NOS conceptualization of "why NOS" over "what NOS."

Irzik and Nola (2014) propose to assume science from the Family Resemblance Approach (FRA) with the intention of thinking NOS in a more systematic and unifying account. From this perspective, NOS is assumed with two systems: science as a cognitive-epistemic system and science as a social-institutional system. Each system is structured by four categories. Cognitive-epistemic system considers the categories: a) processes of Inquiry, b) aims and values, c) methods and methodological rules and d) scientific knowledge. Science as a social-institutional system considers the categories: a) professional activities, b) the scientific ethos, c) the social certification and dissemination of scientific knowledge and d) social values of science. In reconceptualising the idea of FRA (reconceptualising Nature of Science for Science Education), Erduran and Dagher (2014) add three categories of how science is performed and aspects of scientific work, which are relevant to the science curriculum, these categories are: a) social organizations and interactions, b) political power structures and c) financial systems.

Instruments

In literature, there is an abundant production of NOS instruments, because of the different conceptualizations that the construct has had since the middle of the last century. Lederman et al. (2014a) present a list of 29 NOS instruments developed between 1952 and 2006. Of these, 12 instruments present low validity according to the following three criteria: 1) most of the items deal with the ability and skill to engage in the process of science, 2) 50% or more of items deal with attitude toward or appreciation of science and scientists, or 3) they present little or no emphasis on epistemological characteristics of the development of scientific knowledge. The instruments that Lederman et al. (2014a) consider valid can be classified into those without subscales and those with subscales. The former, having no subscales, generate a single score. In this group are: Wisconsin Inventory of Science Processes (WISP), Science Process Inventory (SPI), Nature of Science Scale (NOSS), and Nature of Science Test (NOST).

Some instruments, which have subscales, are compared in Table 3. The tentative nature of scientific knowledge is a subscale of the SUSSI, NSKS, M-NSKS and SINOS instruments. Creativity is subscale on SUSSI, NSKS, M-NSKS and SINOS instruments. The social construction of scientific knowledge is a subscale of the SUSSI and VOSTS instruments. Finally, testable is a subscale of NSKS, COST and M-NSKS. While this is a basic comparison, there are subscales shared by some instruments.

Thus, the above theoretical framework outlines the broad debate on NOS conceptualization developed in recent years. In this way, we estimate that new instruments will be necessary to characterize NOS conceptions of different populations from the current NOS conceptualizations. So, the analysis of the present instruments from their scopes and limitations contributes to this purpose. In this particular case, we analyse the VNOS instrument.

METHOD

Design of the Research

The analysis took on a qualitative methodology (Hernández, Fernández, & Baptista, 2010) and a design based on documental research, which is useful to evince changes in situations over time (Cohen et al., 2007). With respect to the validity and reliability in the use of documents, the criteria suggested by Scott (1990) were used: credibility (which is guaranteed when primary sources are used or personal communication) and representativeness (which is guaranteed by the use of WEB published articles).

Retrieval of VNOS Forms

With the purpose to elicit the historical revisions of the VNOS instrument, the publications of Norman Lederman, who is co-author of the VNOS A, B, C and D+ forms, and Judith Lederman, also co-author of VNOS D, D+ and E are selected. It is started by chapter 28 of the Handbook of Research on Science Education (Lederman, 2007) and chapter 29 of the International Handbook of Research in History, Philosophy and Science Teaching (Lederman et al., 2014a). In all these documents, the authors revise the general features of some NOS instruments, doing a description of VNOS. In this way, the documents cited in these publications are sought. This allows to trace the origin and the characteristics of the VNOS instrument for each of its forms.

Norman Lederman (personal communication, April 30, 2018), shares the VNOS-D, VNOS-D+ and VNOS-E forms. However, the VNOS-A, VNOS-B, VNOS-C, VNOS-D+ and VNOS-E forms can be found on the web via the following links:

VNOS-A: https://science.iit.edu/sites/science/files/elements/mse/pdfs/VNOS(A).pdf

VNOS-B: https://science.iit.edu/sites/science/files/elements/mse/pdfs/VNOS(B).pdf

VNOS-C: https://science.iit.edu/sites/science/files/elements/mse/pdfs/VNOS(C).pdf

VNOS-D+:https://science.iit.edu/sites/science/files/elements/mse/pdfs/VNOS-D%2B.pdf

VNOS-E: https://science.iit.edu/sites/science/files/elements/mse/pdfs/VNOS-E-v2.pdf

Analysis of Data

In the presentation of the analyses, the numbering of the questions was taken based on the mentioned documents, since the same questions appear in other published documents, but with different numbering; such is the case of the following question of the VNOS-C:

> “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 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.” (Lederman et al., 2002, p. 509).

In this case, in Lederman et al. (2002), it is numbered as question 4, but in the VNOS-C form recovered from the WEB, it is question 6. On the other hand, the question’s codification has three components: a) the instrument, b) the form and c) the question. As an example, for VNOS- C form question 7, it is coded as VNOS-C-7.

The analysis is divided into three phases: 1) General characteristics of the VNOS, 2) Characteristics of each VNOS form, and 3) Comparison of Questions Among VNOS forms. To carry out the comparison of questions among VNOS forms, inductive analysis categories are identified, which allow describing the changes of the questions among VNOS forms. The categories are:

- Extension: Addition of words or phrases.
- Reduction: Elimination of words or phrases.
- Substitution: Change most of the words without changing the semantic meaning of the question.

- Fragmentation: Separation or division of a question into two new ones.

The two authors make the analysis of the questions independently, the percentage of agreement was 97.5% When there is no agreement in the inductive categories that describe the transformation of the questions, a second analysis is made, this time between the two researchers and 100% consensus is reached.

FINDINGS AND DISCUSSION

Phase 1: General Characteristics of VNOS

The VNOS is an open-ended question instrument. VNOS-B and VNOS-C forms are the improvements of the VNOS-A form, which was developed by Lederman and O'Malley. However, these are long forms, as respondents take between 35 to 45 minutes to complete the VNOS-B and between 45 to 60 minutes for the VNOS-C (Lederman et al., 2002), so students are not able to respond in a regular class period. The VNOS-D form adapts the language, is administered in less time and produces the same results as the VNOS-C (Lederman et al., 2014a). Finally, the VNOS-E form "has been designed for very young students (grades K-3)" (Lederman et al., 2014a, p. 986). In addition, VNOS is designed and also applied with a monitoring interview after the analysis of the answers (Lederman & O'Malley, 1990) for the purpose of clarifying and going into detail about the participants' views related to NOS (Abd-El Khalick, 1999).

In general, the tenets are the theoretical foundation of the instrument "Views of Nature of Science" (VNOS) and have been raised in the section conceptualization NOS. These aspects are characterised by attending the kindergarten through Grade 12 (K–12) students context (Lederman et al., 2002). The purpose of showing such NOS aspects is to contribute to K–12 teachers and education researchers in the development of a scientifically literate population, but not to give a list about science that scientists develop (Lederman et al., 2014a).

The students' responses to the above aspects of the NOS are classified into two categories of analysis: a) "naive views" and b) "informed views." Even the analysis of data reported in the annual summary of the second year of the Inquiry, Context, and Nature of Science project (Project ICAN) contemplates the third category of analysis called "transitional views" (Project ICAN, 2003). These categories are defined as follows:

- Naïve views: This happens when the answer given by teachers or students is not consistent with contemporary views of NOS aspect.
- Transitional views: This happens when the answer given by students or teachers is somewhat informed but not completely informed.
- Informed views: This happens when the answer of students or teachers is consistent and addresses all parts of NOS aspect (Project ICAN, 2003).

Moreover, unclear answers are classified as incomprehensible (Bartos, 2013). Table 4 shows some samples of NOS naïve and informed views.

According to Lederman (2007) and Lederman et al. (2014), VNOS-C has open-ended questions focusing on various NOS aspects and other open-ended questions in a specific context. To deepen this characterization, each of the open questions is classified into a) direct (without specific context and focused on several NOS aspects) and b) with specific context (Table 5).

VNOS-A-4, VNOS-A-5 and VNOS-A-6 do not contribute to the description of tentative nature of scientific knowledge (Lederman and O'Malley, 1990). For this reason, they are not included in the table. Source: Own devising.

The forms VNOS-B and VNOS-C have an equal percentage of direct questions and questions in context. In the forms, VNOS-A, VNOS-D, VNOS-D+ and VNOS-E direct questions prevail. The direct questions are short and recall the tenets. An example is VNOS-C-5: "Is there a difference between a scientific theory and a scientific law?" (Lederman et al., 2002, p. 509). Open-ended questions in context present the respondent with real situations or everyday examples that illustrate the NOS aspect being investigated. An example is VNOS-A-7:

> "Some astrophysicists believe that the universe is expanding while others believe that it is shrinking; still others believe that the universe is in a static state without any expansion or shrinkage. How are these different conclusions possible if all of these scientists are looking at the same experiments and data?" (Lederman & O'Malley, 1990, p. 228).

When comparing the two types of questions, it is plausible to think that questions with context exemplify the NOS aspect of interest. This makes it easier to establish a mental dialogue between that daily situation and your NOS view, which is expected to be reflected in the answers. This is especially important because VNOS forms are currently used not only in research with science teachers and their students, but also in other professionals, for example, VNOS-C has been used to characterize NOS views of special education teachers (Mulvey, Chiu, Ghosh, & Bell, 2016), first-year university students from different careers (pre-medicine, art major, biology major, forensic science major) (Carter & Wiles,

Table 4. Examples of naive and informed views taken with VNOS. Based on Lederman et al. (2002) and Abd-El-Khalick (1999)

NOS Aspect	More Naive Views	More Informed Views
The Tentative Nature of Scientific Knowledge	"If you get the same result over and over and over, then you become sure that your theory is a proven law, a fact" (Form B: Item 3) (Lederman et al., 2002, p. 515).	"Everything in science is subject to change with new evidence and interpretation of that evidence. We are never 100% sure about anything because...negative evidence will call a theory or law into question, and possibly cause a modification" (Form B: question 1) (Lederman et al., 2002, p. 515).
Empirical nature of scientific knowledge	"I believe science is different. . . because it uses concrete facts that have been proven! are observable/ can be repeated and seen by someone else to get . . . a right or wrong answer" (Abd-El-Khalick, 1999, p. 337).	"Much of the development of scientific knowledge depends on observation [But] I think what we observe is a function of convention. I don't believe that the goal of science is (or should be) the accumulation of observable facts. Rather, I think that . . . science involves abstraction, one step of abstraction after another" (Abd-El-Khalick, 1999, p. 339).
Difference and relationship between theories and laws	"A scientific law is somewhat set in stone, proven to be true...A scientific theory is apt to change and be proven false at any time" (Form C: Item 5) (Lederman et al., 2002).	"A scientific law describes quantitative relationships between phenomena such as universal attraction between objects. Scientific theories are made of concepts that are in accordance with common observation or go beyond and propose new explanatory models for the world" (Form C: item 5) (Lederman et al., 2002).
The Creative and Imaginative Nature of Scientific Knowledge	"I *don't* think [italics in original] scientific investigation is best characterized by creativity or imagination. I think a composer can be creative, a novelist can be imaginative, etc.... Scientific investigations are often tedious and repetitive, with the sole purpose of generating new data on the basis of previous data" (Abd-El-Khalick, 1999, p. 388).	"They use them [imagination and creativity] at all stages of an investigation: planning, design, data collection and after data collection. Because all of these stages are creatively *distorted* [italics added] to make the experiment reflect their preconceived notion as to how the experiment will turn out. They use their imagination to get published in scientific journals and, to receive monetary grant from the government and corporations" (Abd-El-Khalick, 1999, p. 388). "Yes, I think that scientists are imaginative and creative by nature. Look at Sir Isaac Newton. He created calculus. That definitely required creativity and imagination. To think of the "great" scientific theories and laws one must be creative and have a large imagination. I don't think that Albert Einstein would be considered uncreative or lacking in imagination after developing the theory of Relativity" (Abd-El-Khalick, 1999, p. 393).
Subjectivity in science (theory-laden)	"Scientists are very objective because they have a set of procedures they use to solve their problems. Artists are more subjective, putting themselves into their work" (Form B: Item 4) (Lederman et al., 2002, p. 516). "It is possible [to reach different conclusions] because the scientists were not around when the dinosaurs became extinct, so no one witnessed what happened. . . I think the only way to give a satisfactory answer to the extinction of the dinosaurs is to go back in time to witness what happened" (Abd-El-khalick, 1999, p. 409).	"Scientists are human. They learn and think differently, just like all people do. They interpret the same data sets differently because of the way they learn and think, and because of their prior knowledge" (Form B: Item 7) (Lederman et al., 2002, p. 516). "Different conclusions are possible for a number of reasons. It seems that the data is scarce; therefore, scientists are *forced* [italics added] to "flu in the gaps" using their imagination and creativity" (Abd-El-Khalick, 1999, p. 410).
Socially and culturally embedded	"Claims that science is universal and denies social and cultural influences on science" (Kartal et al., 2018, p. 5). "Science is about the facts and could not be influenced by cultures and society. Atoms are atoms here in the U.S. and are still atoms in Russia" (Lederman et al., 2002, p. 516).	"The needs of a society, personal needs, religious opinion and even the languages spoken have an effect on scientific studies" (Kartal et al., 2018, p. 7). "Of course culture influence the ideas in science. It was more than a 100 years after Copernicus that his ideas were considered because religious beliefs of the church sort of favored the geocentric model" (Lederman et al., 2002, p. 516).
Inference and theoretical entities in science	"They [scientists] are very certain, for they have observed the structure of atoms using powerful microscopes to actually peer at the structure of atoms of various elements and count the protons, neutrons, and electrons" (Abd-El-khalick, 1999, p. 397).	"Scientists have come upon the current model of an atom by testing, manipulating, and observing the "behavior"/properties of an atom based on charge properties and relationships with other atoms and molecules. Scientists are fairly certain about the structure, but again it is only a theory because scientists have never seen an atom and its orbitals" (Abd-El-khalick, 1999, p. 400).

Table 5. Classification of questions, whether direct or context of each form. Own devising

Form	Direct questions	Questions in context
VNOS-A	1, 2, 3	7
VNOS-B	1, 3, 4	2, 5, 6
VNOS-C	1, 2, 3, 5, 6	4, 7, 8, 9, 10
VNOS-D	1, 2, 3, 6	4, 5, 7
VNOS-D+	1, 2, 3, 8, 9, 10	4, 5, 6, 7
VNOS-E	1, 2, 3, 4, 7	5, 6

2017), prospective pre-school teachers (Aydemir, Ugras, Cambay, & Kilic, 2017) and VNOS-B to identify NOS views of preservice early childhood teachers (Akerson, Erumit, & Kaynak, 2019). Hence, the number of context-specific open-ended questions can help researchers choose the most appropriate form for their population.

Besides questions without context and with context, open-ended questions can be classified into those that probe NOS aspects implicitly and explicitly (Table 6). The form with the highest number of explicit questions is VNOS-D+ (6 open-ended questions) and the form with the lowest number is VNOS-A (1 open-ended question). The NOS aspect with the largest number of explicit questions is the tentative Nature of Scientific Knowledge and is present in each VNOS form with at least one explicit open-ended question. Except for VNOS-A, creative and Imaginative asks explicitly at least once in the VNOS forms. Scientific theories vs. Laws is explicitly asked in the forms VNOS-B, VNOS-C and VNOS-D+. Social and cultural influences are explicitly asked in VNOS-C and VNOS-D+. In the VNOS forms, empirical nature of scientific knowledge, observation vs. inference and subjectivity in science (theory-laden) are not explicitly asked.

Consequently, during the analysis of the answers, "units of analysis" can easily be identified for the explicitly asked NOS aspects, which help to characterize the NOS views of the participants. In contrast, researchers will probably require more effort to recognize the NOS views of the participants in the case of empirical nature of scientific knowledge, observation vs. inference and subjectivity in science (theory-laden), and these NOS aspects should be clarified in the monitoring interview. This does not mean that the NOS aspects explicitly asked about do not need to be clarified in the monitoring interview, only that it is more likely to find in these aspects, units of analysis that facilitate the interpretation of the results. For this reason, VNOS-D+ can be considered an interesting form of VNOS for researchers who are beginning to study the NOS construct.

The explicit open-ended questions VNOS-D-6 and VNOS-D+ - 6 refer to the scientific models. These open questions appear in Table 6 in two NOS aspects closely related to scientific models: The creative and imaginative and observation vs inference; because, scientists infer models to explain observations, and this they do through their creativity, to obtain functional theoretical models

Table 6. Explicit open-ended questions for each NOS aspect in the VNOS forms

VNOS forms	**The Tentative Nature of Scientific Knowledge**	**Empirical nature of scientific knowledge**	**Observation vs inference**	**Social and cultural influences**	**The Creative and Imaginative Nature of Scientific Knowledge**	**Subjectivity in science (theory-laden)**	**Scientific theories vs. laws**	**Percentage of explicit questions**
A	1							25%
B	1				5		3	50%
C	6			10	8		5	40%
D	3		6		6, 7			42.8%
D+	3, 9		6	10	6, 7		8	60%
E	3				7			28.6%

Source: Own devising.

rather than faithful copies of reality (Lederman et al., 2014a).

Thus, the open-ended questions in combination with the interviews, allow the analysis of the complexity of the answers, recognizing if the respondent simply expresses the NOS aspects in a declarative way, or on the contrary, if they evidence NOS views that elicit a more structured understanding of the NOS aspect, leading to the recognition of science as a product and process.

Phase 2: Features of Each VNOS Form

VNOS-A of Lederman and O'Malley (1990). In 1990, the researchers Norman Lederman and Molly O'Malley designed a questionnaire of seven open-ended questions for the purpose of characterising the views of science that related to the category tentative nature of scientific knowledge. It was administered to sixty-nine students in secondary school (Lederman et al., 2002), thirty-three of whom were women, booked in Physical Science, Biology, Chemistry and Physics from grades 9-12 at a rural school in western Oregon in the United States. Data from pre-tests and post-tests of fifty-five students were obtained because fourteen of the students did not participate in the final test (Lederman & O'Malley, 1990).

Hence, the VNOS-A was created to be applied through a semi-structured interview, which allows validating the information and also eliminating any disadvantages of paper-and-pencil tests, as reported by Rubba in the use of the NSKS (as cited in Lederman, 2007; Lederman et al., 2014a). Nevertheless, the authors expressed difficulties in the redaction of some questions, which led the students to interpret a meaning differently from the one anticipated by Lederman and O'Malley (Lederman et al., 2002); therefore, the students' opinions were not precisely about the tentativeness of scientific knowledge. Even so, the authors indicated that the monitoring interviews reduced the problem (Lederman, 2007; Lederman et al., 2002; Lederman et al., 2014a). Thus, from the seven developed questions, Lederman and O'Malley (1990) considered that the VNOS-A-1, VNOS-A-2, VNOS-A-3 and VNOS-A-7, contributed to the description of the views about the tentative nature of scientific knowledge. Semi-structured interviews validated the questions.

The seven open-ended questions in VNOS-A attempted to address and improve the characterization of different aspects of tentatively raised in the VOSTS (Views on Science-Technology-Society) instrument (Lederman et al., 2014a), developed by Aikenhead, Fleming and Ryan (1987).Though Lederman and O'Malley do not mention such tentative aspects, in Aikenhead et al. (1987), the topics of the VOSTS instrument is given and among them "tentative nature of scientific knowledge" and "nature of the scientific models" which broach three of the four aspects considered in VNOS-A-1, VNOS-A-2, VNOS-A-3 and VNOS-A-7. Specifically, in Table 7, it is possible to associate the items 13.1, 15 and 18.1 of the VOSTS instrument with VNOS-A-1, VNOS-A-2 and VNOS-A-7.

VOSTS-15.2 inquires into the possibility of a change in scientific knowledge in the future, even if it comes from properly conducted research. Among the students' answers, views emerge where scientific knowledge will change in the future. These changes may be generated by a) competition between theories, b) the development of new technology, c) the emergence of new interpretations and explanations to empirical evidence, or d) by the accumulation of knowledge. VNOS-A-1 addresses this aspect with the question: "..., does the theory ever change?" (Lederman & O'Malley, 1990, p. 228).

VOSTS-13.1 is about changing scientific models. Among the students' views are that scientific models change as well as theories. VNOS-A-2 considers that scientific models change over time when asked about the certainty that scientists have of the model of the atom.

VOSTS-90511 focuses on the difference between theory and law. In its different response options, the item raises students' views. In option E, theories and laws are different forms of knowledge, and hypotheses can become either theories or laws. VNOS-A-3 asks specifically about the difference between theories and laws.

VOSTS-18.1 deals with the disagreement of scientists on the same problem. The students' views indicate that disagreement among scientists arises because each one infers a different interpretation of the facts or because they interpret from different theories. VNOS-A-7 addresses this aspect, when it asks the reasons that lead scientists to obtain different conclusions, despite observing the same experiments and data.

VNOS-B of Abd-El-Khalick, Bell, and Lederman (1998). The researchers Fouad Abd-El-Khalick, Randy Bell and Norman Lederman developed the VNOS-B, which consisted of seven open-ended questions applied to fourteen science teachers, five of whom were women, and all were enrolled in a teacher preparation program in a rural for the purpose of getting a science certification at the secondary school level. The categories that VNOS-B form allows to characterize are: 1) the tentative nature of science, 2) the empiric nature of science, 3) the creative nature of science, 4) the subjective nature of science, 5) the role of social and cultural contexts on science, 6) the observation versus the inference and 7) the functions and relation between theories and laws (Abd-El-Khalick et al., 1998). Table 5 presents the direct open-ended questions and the open-ended questions in context. In addition, explicitly in VNOS-B, the questions VNOS-B-1, VNOS-B-5

Table 7. Items and opinions of students about the VOSTS instrument which are related to three questions of the VNOS-A instrument and also can clarify some aspects of tentative nature of scientific knowledge

VOSTS	VNOS-A
Item 15 of VOSTS (VOSTS-15) , about tentative of scientific knowledge: "15.1 When scientific investigations are done correctly, scientists discover knowledge that will not change in future years. 15.2 Even when scientific investigations are done correctly, the knowledge that scientists discover may change in the future." (Aikenhead, 1987, p. 467). "A. Scientific knowledge has always changed with time. B. Scientific knowledge changes when new scientists disprove the theories of old scientists. C. Technological improvements in scientific apparatus will lead to changes in knowledge and theories. D. What seems to be a correct investigation may turn out later to contain errors. E. Correctly done experiments must yield absolute facts, but the interpretations and applications are subject to change. F. New knowledge is added onto old knowledge, but the old knowledge doesn't change" (Aikenhead, 1987, p. 467).	VNOS-A-1: "After scientists have developed a theory (e.g., atomic theory), does the theory ever change? If you believe that theories do change, explain why we bother to learn about theories. Defend your answer with examples. [Conclusive/Tentative]" (Lederman & O'Malley, 1990, p. 228).
Item 13.1 of VOSTS (VOSTS-13.1), about the nature of scientific models: "Many scientific models (such as a model of the atom or of DNA) are metaphors or useful stories; we should not believe that these models are duplicates of reality." (Aikenhead et al., 1987, p. 161 y Aikenhead, 1987, p. 463). Views from students got by saturation in the answers justification of the item: "…B. Models change with time and with the state of our knowledge, like theories do…" (Aikenhead, 1987, p. 463).	VNOS-A-2: "What does an atom look like? How do scientists know that an atom looks like what you have described or drawn? [Realist /Instrumentalist]" (Lederman & O'Malley, 1990, p. 228).
VOSTS-90511. "Scientific ideas develop from hypotheses to theories, and finally, if they are good enough, to being scientific laws. … E. Theories can't become laws because they both are different types of ideas. Laws describe things in general. Theories explain these laws. However, with supporting evidence, hypotheses may become theories (explanations) or laws (descriptions)." (Aikenhead et al., 1989, p. 99).	VNOS-A-3: "Is there a difference between a scientific theory and a scientific law? Give an example to illustrate your answer. [Induction/Invention]" (Lederman & O'Malley, 1990, p. 228).
From item 18.1 of VOSTS (VOSTS-18.1): "When scientists disagree on an issue (e.g. whether or not low-level radiation is harmful), they disagree mostly because one side does not have all the facts." (Aikenhead et al., 1987, p. 161). Views from students got by saturation in the answers justification of the item: "F. Disagreements occur mostly because scientists interpret the facts differently, or they interpret the significance of the facts differently. H. Disagreements occur because of different opinions, viewpoints or theories on the subject." (Aikenhead, 1987, p. 474 y 475).	VNOS-A-7: "Some astrophysicists believe that the universe is expanding while others believe that it is shrinking; still others believe that the universe is in a static state without any expansion or shrinkage. How are these different conclusions possible if all of these scientists are looking at the same experiments and data? [Subjectivist/ Objectivist]" (Lederman & O'Malley, 1990, p. 228).

and VNOS-B-3 inquire about the tentative nature, creativity and imagination and also about theories and laws, respectively (table 6).

An analysis of open-ended questions allows to associate in which a researcher can find units of analysis that allow interpreting the views of the participants. Thus, data on empirical nature of scientific knowledge are likely to appear in VNOS-B-2 and VNOS-B-4, observation vs inference in VNOS-B-2, social and cultural influence in VNOS-B-1, subjectivity in science (theory-laden) in VNOS-B-1 and VNOS-B-6 (table 8).

Finally, VNOS-B has seven open-ended questions (Lederman et al., 2002), but six open-ended questions have been classified in Table 5. The missing open-ended question is: "Is there a difference between scientific knowledge and opinion? Give an example to illustrate your answer" (Lederman et al., 2002, p. 505). It is not included in table 5, because in the form retrieved and used in the analysis, this question is not part of VNOS-B. Furthermore, the difference between scientific knowledge and opinion is not investigated in the following developed VNOS forms, probably because it does not contribute to eliciting

Table 8. Association between NOS aspects and open-ended questions of each form VNOS

VNOS forms	The Tentative Nature of Scientific Knowledge	Empirical nature of scientific knowledge	Observation vs inference	Social and cultural influences	The Creative and Imaginative Nature of Scientific Knowledge	Subjectivity in science (theory-laden)	Scientific theories vs. laws
A	1, 2, 3, 7						
B	1	2, 4	2	1	3, 5	1, 6	3
C	6	1, 4	4, 7	6, 10	5, 7, 8	2, 3, 6, 9	5
D	3, 6	1, 2, 4, 5, 6	4, 6	3, 6	5, 6, 7	3, 4, 6	5, 6
D+	3, 9	1, 2, 4, 5, 6	4	3, 9, 10	5, 6, 7, 8	3, 9	5, 6, 8
E	3	2, 4, 6	4	3	6, 7	3, 5	6

Source: Own devising.

the NOS views of the participants.

VNOS–C of Abd-El-Khalick and Lederman (2000). In the Doctoral Thesis of Fouad Abd-El Khalick (1999) and in the article which presents some parts of it (Abd-El-Khalick & Lederman, 2000), it is used as an instrument with nine questions; it is adapted from Lederman & O'Malley (1990) and Abd-El-Khalick et al. (1998) that is from the VNOS-A and VNOS-B. Five expert university teachers proved this instrument, three of whom were science educators, one was a science history expert and one was a scientist. The authors adopted comments from the panel (Abd-El-Khalick & Lederman, 2000). Another question about the social and cultural integration of science was added, which is in Lederman et al. (2002).

Thus, the questions VNOS-C-6, VNOS-C-10, VNOS-C-8 and VNOS-C-5 explicitly evaluate the tentative nature, the influence of culture and society on science, creativity and imagination as well as theories and laws (table 6). To facilitate the interpretation of the VNOS-C answers, Table 8 lists the open-end questions and NOS aspects that could be characterized, and where the researcher is likely to find units of analysis to reveal the NOS views of the participants.

Also, units of analysis to interpret NOS views related to nature of scientific theories, functions of scientific theories and logic of testing scientific theories can be obtained in the responses to VNOS-C-3, VNOS-C-5 and VNOS-C-6. While most research using VNOS-C does not address these three aspects, it does demonstrate the potential of the form to recognize the views of participants, especially when combined with the monitoring interview. Similarly, VNOS-C form is the only that addresses the definition of an experiment (VNOS-C-2) and the relationship between experiments and the development of scientific knowledge (VNOS-C-3). Surely these questions are not in other VNOS forms, because more questions also address the empirical nature of scientific knowledge (Table 8).

On the other hand, although Lederman and his collaborators differentiate the NOS and SI constructs, as commented in the theoretical framework, when designing VNOS-C "also aimed to assess views of the social and cultural embeddedness of science and the existence of a universal scientific method" (Lederman et al., 2002, p. 509). Although the "Views About Scientific Inquiry" (VASI) instrument (Lederman et al., 2014c) allows to characterize SI views at present, it is possible to find in the answers of VNOS-C-1 and VNOS-C-6 some reference to "the existence of a universal scientific method." In this regard, Abd-El-Khalick (2006) says that in VNOS-C there is no reference to the scientific method, however, in one of his investigations using this form, he reports that:

> "10% of participants indicated that science differs from religion and philosophy in that it has the scientific method… An additional 14% noted that science is typified by a set of orderly steps and rules or a systematic, structured, rigid, standardized, or logical method: Science is different from other disciplines… because there is a very structured and methodical way that scientists follow. The particular steps that participants assigned to this common method, logical standardized method,

rigid process, or The Scientific Method" (p.400).

VNOS–D of Lederman and Khishfe (2002). VNOS-D form is a modification of the VNOS-C that was created to reduce administration time because it requires about 45 to 60 minutes (Lederman et al., 2002), although it can be an hour and a half (Lederman et al., 2002). Language and composition were modified during the process (Lederman, 2007). It was validated with a group of ten secondary school teachers and their students (Lederman, 2007; Lederman et al., 2014a). As a result, a new form was obtained, which is solved by teachers in less than an hour (Lederman, 2007). The VNOS-D has seven open-ended questions. In 2010, Norman Lederman and Judith Lederman presented the VNOS D+ form (PhysPort, Supporting Physics Teaching with Research-Based Resources, 2020), which consists of 10 open-ended questions. Despite the VNOS-C and VNOS-D+ forms have the same number of open-ended questions, VNOS-D+ is less extensive than VNOS-C. This is possible, because VNOS-D+ has more direct questions than VNOS-C.

The VNOS-D-3, VNOS-D-6 and VNOS-D-7 questions explicitly evaluate the tentative nature, scientific models, and creativity and imagination (table 6). The questions VNOS-D+-3 and VNOS-D+-9 explicitly evaluate the tentative nature, while VNOS-D+-6, VNOS-D+-10, VNOS-D+-7 and VNOS-D+-8 explicitly evaluate scientific models, social and cultural influence on science, creativity and imagination and theories and laws, respectively (table 6). To facilitate the interpretation of the VNOS-D and VNOS-D+ answers, table 8 lists the open-ended questions and the NOS aspects that could be characterized, and where the researcher is likely to find units of analysis to reveal the NOS views of the participants.

An interesting adjustment in these VNOS forms are VNOS-D-6 and VNOS-D+-6, because they explicitly address scientific models. Eventually, it is possible that in VNOS-B-2 or VNOS-C-4 the participants mention the scientific models, but if you want to analyse this NOS aspect, the VNOS-D and VNOS-D+ forms are recommended from the present analysis.

Similar to what happened in VNOS-C-1 and VNOS-C-6, in VNOS-D-1, VNOS-D-2, VNOS-D+ -1, VNOS-D+ -2 some reference to "the existence of a universal scientific method" could be found, although if the objective is to analyse SI, the researcher should use the VASI instrument.

VNOS–E of Lederman and Ko (2004). VNOS-E form was validated with a group of ten primary teachers and their students (Lederman, 2007; Lederman et al., 2014a) and it is the first instrument developed K–3 students who are very young. It consists of seven open-ended questions with a more straightforward language than the previous forms, considering the population under study. As table 6 shows, the VNOS-E-3 and VNOS-E-7 questions explicitly deal with the tentative nature and the creativity and imagination in scientific knowledge. To facilitate the interpretation of the VNOS-E answers, table 8 lists the open-ended questions and the NOS aspects that could be characterized, and where the researcher is likely to find units of analysis to reveal the NOS views of the participants.

Similar to what happened in VNOS-C-1, VNOS-C-6, VNOS-D-1, VNOS-D-2, VNOS-D+ -1 and VNOS-D+ -2, in VNOS-E1 and VNOS-E2 some reference could be found to "the existence of a universal scientific method", although if the objective is to analyse SI, an adaptation of the VASI instrument should be used according to the population.

Phase 3: Comparison of Questions among VNOS Forms

The VNOS-A-1 considers the change in theories through time; Figure 2 shows the VNOS-A-1 changing

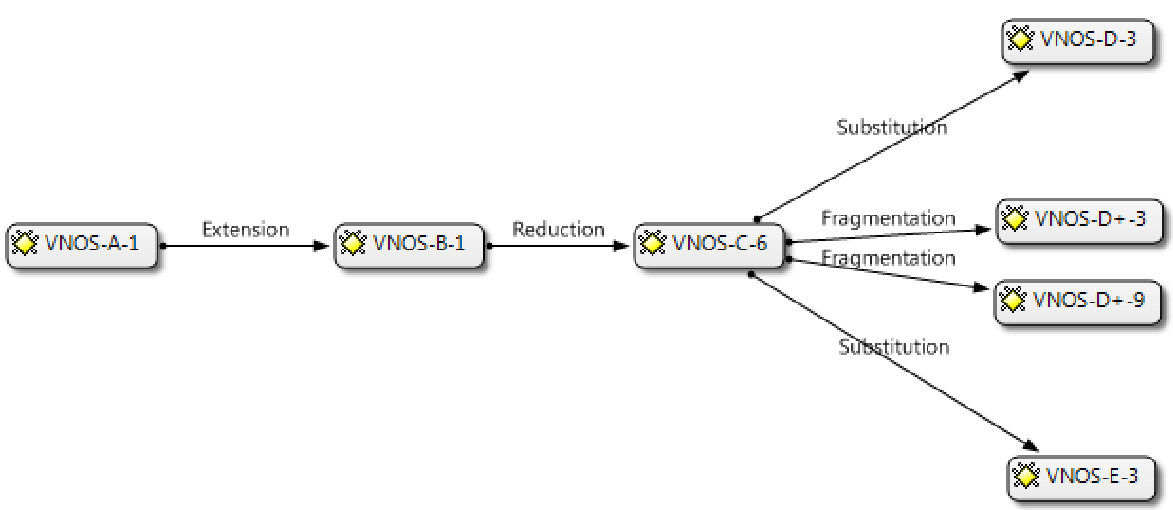

Figure 2. Transformations of the VNOS-A-1. Source: own devising

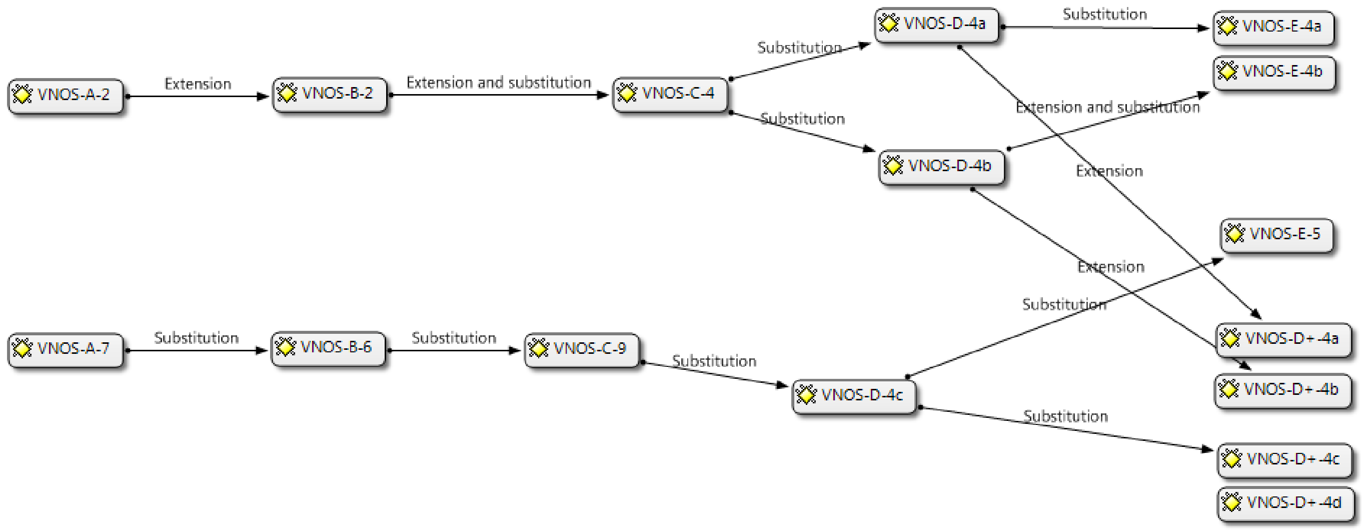

Figure 3. Transformations VNOS-A-2 and VNOS-A-7. Source: Own devising

Figure 4. Transformations VNOS-A-3. Source: Own devising

through time; it starts with the extension in VNOS-B adding some examples from the theories and clarifying that it is with respect to the scientific theory. Despite this, in VNOS-C-6 the question "explain, why theories change?" is explicitly presented. As an example, it introduces the theory of evolution and the atomic theory. VNOS-D-3 presents a substitution; here it has changed the concept of scientific knowledge to scientific theory, which does not ask for reasons as to why we do need to learn scientific theories. The VNOS-C-6 is fragmented into VNOS-D+-3 and VNOS-D+-9, both of which focused on the tentative nature, the first one of the scientific knowledge and the second one of scientific theories. The VNOS-C-6 is replaced in VNOS-E-3 and specifically asks about the change in knowledge in the future.

Figure 3 shows the VNOS-A-2 and VNOS-A-7 transformations. The first one is formed by two questions, one of them about how the atom looks and the other about the scientists' certainty about the appearance described by the respondent. The other question is about scientists' certainty about the appearance of atoms. In VNOS-B-2 a context replacing the first question is added, it explains how the textbooks represent the atoms; it also formulates two questions which ask about: 1) the scientist' certainty with respect to the atom structure and 2) the specific evidence that respondents believe scientists used to determine the atom structure. In VNOS-C-4, the context and the first question are identical; however, the second question is widened and substituted, as it questions specific evidence or types of evidence and modifies some words without changing the semantic sense of the question. The VNOS-C-4 is similar to VNOS-C-7 since it searches about the certainty that scientists have, firstly about the atom structure and secondly about the characterisation of "what a species is?"

In VNOS-A-7, it seems a context about the predictions of the final destiny of the universe. In VNOS-B-6, a substitution is made, both in the context and in the question. VNOS-C-9 substitutes the context and the question. Thus, the context is framed in two hypotheses about the extinction of dinosaurs, and the question continues to focus on how scientists reach different conclusions if they use the same data.

The VNOS-D-4 has three questions, the first and second inquire about: a) how scientists know that dinosaurs existed? and b) how sure are scientists about what dinosaurs look like? These questions resulted from a substitution from VNOS-C-4 that refers to the certainty of the scientists about the structure of the atom and the evidence about its aspect. The third question from VNOS-D-4 is a substitution from VNOS-C-9. VNOS-D+-4a and VNOS-D+-4b are considered amplifications of VNOS-D-4a and VNOS-D-4b, as they ask the respondent to generate an explanation of the answer. VNOS-D+-4c presents a substitution in the conjugation of a verb. VNOS-D+-4d appears for the first time and refers to the interaction between scientists to persuade each other to accept a theory. VNOS-E-4a and VNOS-E-4b are

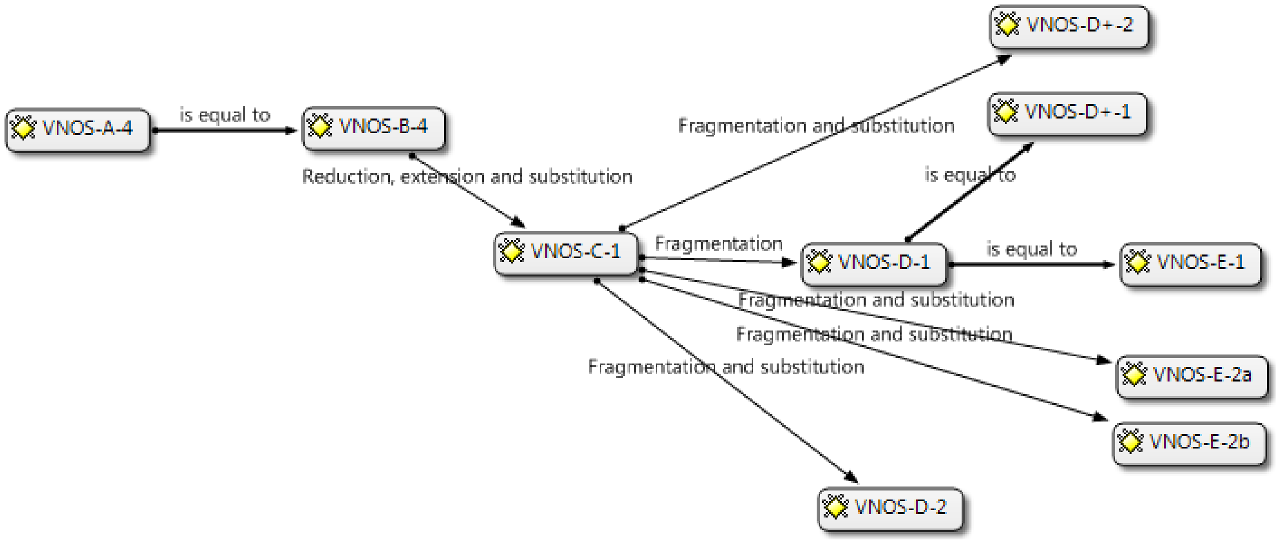

Figure 5. Transformations of VNOS-A-4. Source: own devising

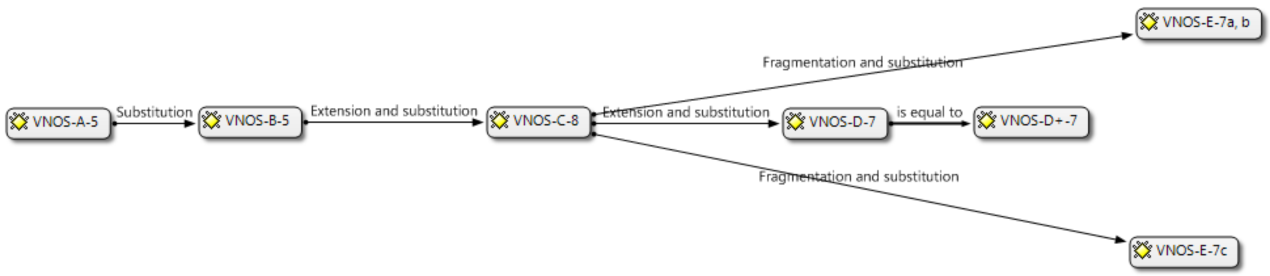

Figure 6. Transformations of VNOS-A-5. Source: own devising

substitutions of VNOS-D-4a and VNOS-D-4b, according to the K3 population age. Finally, VNOS-E-5 is a substitution for VNOS-D-4c, both in the context and in the question; like the previous one, it is an adaptation in language to improve the understanding of a young population.

VNOS-A-3 includes the difference between theory and scientific law. Figure 4 shows a few transformations of VNOS-A-3. Thus, VNOS-B-3 is identical to VNOS-A-3; VNOS-C-5 shows substitution due to changes in some words when it requests an example in order to illustrate the answer, and VNOS-D+-8 is identical to VNOS-C-5. About this aspect, there are no explicit questions in VNOS-D nor in VNOS-E.

These questions involve the difference between science and other disciplines. Figure 5 shows the transformations VNOS-A-4, so VNOS-B-4 is identical to VNOS-A-4, and they are conformed by two questions that compare science and art, the first question about their similarities and the second about their differences. VNOS-C-1 is a reduction, extension and substitution of VNOS-B-4 due to the fact that it eliminates the questions related to how similar are science and art and a question about what is science is added; on the other hand, the question about the difference between science and art is changed by one related to the difference between science or scientific discipline and other inquiry disciplines, such as religion or philosophy. VNOS-D-1 and VNOS-D-2 emerge from the fragmentation, reduction, and substitution of VNOS-C-1. Thus VNOS-D-1 is a minimal reduction because it omits the words "in your view" from the question, and VNOS-D-2 is a substitution that inquiries about the difference between science and some other subjects taken by the respondent. VNOS-D+-1 and VNOS-E-1 are identical to VNOS-D-1. The VNOS-D+-2 is a substitution of the second question of VNOS-C-1; it focuses on the difference between science or scientific disciplines with other subjects or disciplines, including art, history and philosophy. VNOS-E-2a and VNOS-E-2b emerge from fragmentation and substitution of the second VNOS-C-1 question because they ask K3 students about the other subjects they learn (different from science) and how science is different from these.

The next questions explicitly cover the creativity and imagination of scientists. Figure 6 shows these transformations. Thus, VNOS-B-5 is a substitution of VNOS-A-5 because it inquiries about the experiments/research stages (besides planning and designing) that are where scientists use their creativity and imagination. VNOS-C-8 is a substitution and addition of VNOS-B-5, it is a substitution because VNOS-C-8 indicates that scientists conduct experiments/research to find answers to the

Figure 7. Transformations of VNOS-C-10. Source: own devising

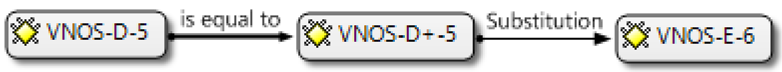

Figure 8. Transformations of VNOS-D-5. Source: own devising

questions asked, and VNOS-B-5 says that experiments/ research are conducted to try to solve problems. On the other hand, it is an addition because it adds some other stages where scientists use creativity and imagination. VNOS-D-7 is a substitution and addition from VNOS-C-8 since the question is reorganised, but it keeps its semantic meaning, adding stages such as experimentation, observations, data analysis, interpretation and results reported. VNOS-D+-7 is identical to VNOS-D-7. VNOS-E-7a, b and VNOS-E-7c are a result of the fragmentation and substitution of VNOS-C-8 since they inquire about how scientists use imagination while they work and, if they do, when do they use it.

The following questions explicitly inquire about the influence of social and cultural values on science. Figure 7 shows the transformation of these questions. VNOS-D+-10 is a reduction and substitution of VNOS-C-10 since it omits the context and the question is reorganised by asking about the existence of relationships between science, society and cultural values. When the answer is affirmative, it asks about how that relationship is. If the answer is negative, it asks why the relationship does not exist. In VNOS-A, B, D and E, there are no specific questions about this relationship.

Figure 8 shows the questions that explicitly inquire about models. VNOS-D-5 and VNOS-D+-5 are identical, in their context they consider that in order to make weather predictions, meteorologists collect many types of information, and then they create models of different weather patterns using computers. The question asks about safety in weather patterns, what people who predict the weather have and asks for an explanation of the answer. The VNOS-E-6 is a substitution of VNOS-D-5; here, the language is adapted to K3 students without changing the semantic meaning.

VNOS-D+-6 is an extension and replacement of VNOS-D-6 and also questions some aspects of the models. Thus, VNOS-D-6 directly asks, what is a scientific model? As opposed to VNOS-D+-6, which presents a context about the model of the interior of the earth and asks about the similarity of the model and reality.

Finally, VNOS-C-2 and VNOS-C-3 present the question, what is an experiment? and whether or not experiments are necessary for the development of scientific knowledge; these aspects are not explicitly found in other forms of the instrument. Similarly, the explicit question about the difference between scientific knowledge and opinion is only found in VNOS-A-6.

CONCLUSIONS

This article facilitates the approach of future NOS researchers to VNOS forms, because elements to facilitate the interpretation of VNOS forms are presented from the three phases of results and discussion. This instrument has been used in the characterization of the NOS views of pre-service and in-service teachers, both elementary and secondary, as well as their students.

Thus, in the phase "general characteristics of VNOS":

1. Presents the categories of analysis and some examples of each NOS aspect classified in naive views and informed views.

2. It deepens the distinction made by Lederman et al. (2014a) about: a) open questions focused on various NOS aspects (direct questions) and b) open questions focused on a specific context. Thus, table 5 classifies each question of the VNOS form set into these two types of open questions. This classification identifies VNOS-C as the form with the most open questions in context. This can be of great interest, because the training in epistemology that teachers receive varies greatly among training programs, especially among teachers at different levels of education (Aydemir et al., 2017; Duruk, Akgün, & Tokur, 2019). Of course, this depends on the characteristics of teacher training in each country. For this reason, these reflections contribute to NOS researchers making better methodological decisions.

3. Furthermore, a distinction is made in the set of forms VNOS between explicit and implicit questions. The VNOS-D+ form has more explicit open-ended questions, and in whose answers researchers are likely to find units of analysis to characterize NOS views more easily. Table 6 relates the NOS aspects to these open-ended questions.

The phase "characteristics of each version" contextualizes the reader in the particularities of each form, specifically, in VNOS-A the researcher will find some aspects, such as "tentative scientific knowledge" and "the nature of scientific models" of the VOSTS instrument considered by Lederman and O'Malley (1990), and some of the answers that Aikenhead et al. (1987) obtained and that the NOS researchers at present could also find, either when using VNOS -A or in the similar questions found in other VNOS forms.

Also, the analyses of VNOS-B, VNOS-C, VNOS-D, VNOS-D+ and VNOS-E identify the NOS aspects that the researcher could characterize from each open-ended question.

The phase called "Comparison of questions between the VNOS forms" establishes relationships between the questions that evaluate the same aspects NOS through the VNOS forms. Thus, researchers can follow the questions that evaluate one or more aspects NOS through the VNOS forms. We suggest that researchers who need to evaluate a specific aspect NOS could take the question or the set of questions that evaluate that aspect from the most appropriate VNOS form, according to the objectives of their research.

Thus, the researchers can choose the most appropriate VNOS forms for their respective research, depending on the proposed objectives. For this, they can use the tables that classify the items indirect questions or with the context in each NOS form (table 5), identifying the explicit questions for each NOS aspect in the VNOS forms (table 6), the association of NOS aspects and questions of each form VNOS (table 8), and the analysis of the questions through the NOS forms according to the NOS aspect.

The above contributions are important, because it allows making diagnoses, evaluating the transformations in NOS views of students and teachers when applying teaching strategies and associating NOS views of respondents with other constructs. Consequently, approaching the field of identification of ideas about NOS is of vital importance for science teaching. In that sense, recognising its conceptual structures and how these ideas could be investigated in school contexts becomes very relevant, while at the same time knowing what VNOS form could be used depending on the type of population and the objectives of the research.

Of course, the VNOS forms have been developed from the general domain conceptualization and it is undeniable that from this approach, several investigations have been developed, which have put teachers and students of different levels to talk about NOS. In this sense, the VNOS forms are widely used, and future researchers must know their general and specific aspects, as well as the interpretation of the set of VNOS forms.

Finally, it is necessary to recognize some scopes and limitations of VNOS. Among the scopes, we consider that the questions that make up the VNOS forms (open questions), have the potential to gather detailed information from the participants' views, which will be increasingly sophisticated according to the level of depth with which the NOS reflections are approached, from the teaching strategies that didactic research raises and rethinks through time. With this we do not indicate that the VNOS forms are appropriate to characterize the NOS views from all the existing NOS conceptualizations, but that they do have the potential to characterize some aspects (in addition to those already mentioned).

Among these, VNOS forms can help obtain information about Experimentation, Models raised by Matthews, experiments, models, role of imagination and creative syntheses raised by Allchin, and in conjunction with the VASI instrument, could characterize the scientific knowledge, processes of Inquiry, methods and methodological rules raised by Erduran and Dagher.

The following units of analysis are obtained from VNOS forms and their monitoring interviews, which exemplifies their potential in characterizing some of these aspects:

> From VNOS-C-2: "An experiment is a controlled way to test and manipulate the objects of interest while keeping all other factors the same" (Lederman et al., 2002, p. 514).

> From VNOS-C-2: "An experiment is a sequence of steps performed to prove a proposed theory" (Lederman et al., 2002, p. 514).

> From VNOS-C-3: "Experiments are not always crucial . . . Darwin's theory of evolution . . . cannot be directly tested experimentally. Yet, because of observed data . . . it has become virtually the lynchpin of modern biology" (Lederman et al., 2002, p. 514).

> From VNOS-D-6: "Scientific model are models formed by individuals as a result of research, experiments and use of imagination and creativity. For instance, we formed a scientific model during the black box activity. We did not know what was inside the box. Scientists cannot have all the data while forming models. For instance they do not know how the inner layers of the sun are. But they form it as a result of the data they obtain. They do not have the chance to open it up and see. I mean they model it with the help of the data they have. As I said, they do research, they make experiments, and they make many experiments to learn about the layers of the Sun and the Earth. They do research using various sources. As a result, they use their data and their imagination and creativity and interpretation to form a model" (Metin & Leblebicioğlu, 2015, p. 9).

So, among the limitations, other NOS aspects are outside the domain of the VNOS forms, such as idealisation, values and Socioscientific issues, mathematization, technology, explanation, worldviews and religion, theory choice and rationality, feminism, realism and constructivism proposed by Matthews, dimension observation and measurements, instruments, patterns of reasoning, historical dimensions, human dimensions, institutions, biases, economics/funding raised by Allchin, and aims and values, professional activities, the scientific ethos, the social certification and dissemination of scientific knowledge, social values of science, social organizations and interactions, political power structures and financial systems proposed by Erduran and Dagher.

In this respect, the VNOS forms cannot characterize many aspects NOS conceptualized in recent years, nor is it their objective. However, they are mentioned because NOS researchers must be aware of the scope and limitations. Surely, with time, instruments will be designed and validated that attempt to characterize these NOS conceptualizations, as well as teaching strategies for a construct that is as broad and complex as science itself. The academic production of the next few years will probably be as abundant, controversial and interesting as that of this century.

ACKNOWLEDGEMENTS

We thank the four anonymous reviewers of this journal for their constructive comments on an earlier version of this paper.

REFERENCES

Abd-El-Khalick,F. (1999). *The influence of history of science courses on students' conceptions of the nature of science (doctoral dissertation).* Oregon State University, Corvallis. Retrieved from https://www.researchgate.net/publication/35510771

Abd-El-Khalick, F. (2006). Over and over again: College students' views of nature of science. In *Scientific inquiry and nature of Science. Implications for teaching, learning, and teacher education* (pp. 389-425).

Abd-El-Khalick, F. (2012). Examining the sources for our understandings about science: Enduring conflations and critical issues in research on nature of science education. *International Journal of Science Education*, *34*(3), 353-374. https://doi.org/http://dx.doi.org/10.1080/09500693.2011.629013

Abd-El-Khalick, F., Bell, R., & Lederman, N. (1998). The nature of science and instructional practice: Making the unnatrual natural. *Science education*, 417–437. Retrieved from https://doi.org/10.1002/(SICI)1098-237X(199807)82:4<417::AID-SCE1>3.0.CO;2-E

Abd-El-Khalick, F., & Lederman, N. (2000). The infuence of history of science courses on students' views of nature of science. *Journal of Research in Science Teaching*, *37*(37), 1057–1095. Retrieved from https://doi.org/10.1002/1098-2736(200012)37:10<1057::AID-TEA3>3.0.CO;2-C

Adúriz-Bravo, A. (2001). *Integración de la epistemología en la formación del profesorado de ciencias (tesis doctoral).* Bellaterra: Universitat Autònoma de Barcelona.

Adúriz-Bravo, A., & Ariza, Y. (2013). Las imágenes de ciencia y de cientifico, una puerta de entrada a la naturaleza de la ciencia. En Adúriz-Bravo, Dibarboure, & Ithurralde (Eds.), *El quehacer del científico en el aula, pistas para pensar* (pp. 13–20). Montevideo, Uruguay: Fondo Editorial QUEDUCA.

Aflalo, E. (2014). Advancing the perceptions of the nature of science (NOS): Integrating teaching the NOS in a science content course. *Reseach in Science & Technological Education*, *32*(3), 298–310. https://doi.org/10.1080/02635143.2014.944492

Aikenhead, G. (1987). High-school graduates' beliefs about science-technology-society. III. Characteristics and limitations of scientific knowledge. *Science Education*, *71*(4), 459-487. https://doi.org/10.1002/sce.3730710402

Aikenhead, G., Fleming, R., & Ryan, A. (1987). High-school graduates' beliefs about science-technology-society. I. Methods and issues in monitoring student views. *Science Education*, *71*(2), 145-161. https://doi.org/10.1002/sce.3730710203

Aikenhead, G., & Ryan, A. (1992). The development of a new instrument: "Views on science-technology-society" (VOSTS). *Science Education*, 76(5), 477–491. https://doi.org/10.1002/sce.3730760503

Aikenhead, G., Ryan, A., & Fleming, R. (1989). Views on science-technology-society. From https://education.usask.ca/documents/profiles/aikenhead/vosts.pdf

Akerson, V., Cullen, T., & Hanson, D. (2010). Experienced teachers' strategies for assessing nature of science conceptions in the elementary classroom. *Journal of Science Teacher Education*, *21*, 723–745. https://doi.org/10.1007/s10972-010-9208-x

Akerson, V., Erumit, B., & Kaynak, N. (2019). Teaching nature of science through children's literature: An early childhood preservice teacher study. *International Journal of Science Education*. https://doi.org/10.1080/09500693.2019.1698785

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

Allchin, D. (2017). Beyond the consensus view: Whole science. *Canadian Journal of Science, Mathematics and Technology Education*, 17(1), 18–26. https://doi.org/10.1080/14926156.2016.1271921

American Association for the advancement of science [AAAS], A. (1993). *Benchmarks for science literacy: A Project 2061 report*. New York, USA: Oxford University Press.

Ayala-Villamil, L-A. (2019). Unidad didáctica para la enseñanza explícita de un aspecto de la Naturaleza de la Ciencia. *Latin American Journal of Science Education, 6*(1), 12002. https://lajse.org/may19/2019_12002.pdf

Ayala-Villamil, L-A. (2020). Conceptualización de naturaleza de la ciencia: El desarrollo de dos enfoques. *Noria Investigación Educativa, 2*(6), 105-128. https://doi.org/10.14483/25905791.16653

Aydemir, S., Ugras, M., Cambay, O., & Kilic, A. (2017). Prospective pre-school teachers' views on the nature of science and scientific inquiry. Üniversitepark Bülten, 6(2), 74–87. https://doi.org/10.22521/unibulletin.2017.62.6

Bartos, S. (2013). *Teachers' knowledge structures for nature of science and scientific inquiry and their classroom practice (doctoral dissertation).* Illinois Institute of Technology. Retrieved from http://repository.iit.edu/bitstream/handle/10560/3110/Bartos_Ph.D._Diss.pdf?sequence=1&isAllowed=y

Bartos, S., & Lederman, N. (2014). Teachers' knowledge structures for nature of science and scientific inquiry: Conceptions and classroom practice. *Journal of Research in Science Teaching*, 51(9), 1150–1184. https://doi.org/10.1002/tea.21168

Carter, B., & Wiles, J. (2017). A qualitative study examining the exclusive use of primary literature in a special topics biology course: improving conceptions about the nature of science and boosting confidence in approaching original scientific research. *International Journal of Environmental & Science Education*, 12(3), 523–538. https://doi.org/10.12973/ijese.2017.1245p

Celik, S., & Bayrakceken, S. (2012). The influence of an activity-based explicit approach on the Turkish prospective science teachers ' conceptions of the nature of science. *Australian Journal of Teacher Education*, *37*(4), 75–95.

Chen, S., Chang, W., Lieu, S., Kao, H., Huang, M., & Lin, S. (2013). Development of an empirically based questionnaire to investigate young students' ideas about nature of science. *Journal of Research in Science Teaching*, 50(4), 408–430. https://doi.org/10.1002/tea.21079

Cofré, H., Vergara, C., Lederman, N., Lederman, J., Santibánez, D., Jiménez, J., & Yancovic, M. (2014). Improving Chilean in-service elementary teachers ' understanding of nature of science using self-contained nos and content-embedded mini-courses. *Journal of Science Teacher Education*, *25*, 759–783. https://doi.org/10.1007/s10972-014-9399-7

Cohen, L., Manion, L., & Morrison, K. (2007). *Research methods in education* (Sixth edit). New York, USA: Routledge Taylor & Francis group.

Cotham, J., & Smith, E. (1981). Development and validation of the conceptions of scientific theories test. *Journal of Research in Science Teaching*, 18(5), 387–396. https://doi.org/10.1002/tea.3660180502

Deboer, G. (2000). Scientific literacy: Another look at its historical and contemporary meanings and its relationship to science education reform. *Journal of Research in Science Teaching*, *37*(6), 582–601.

Driver, R., Leach, J., Millar, R., & Scott, P. (1996). *Young people ' s images of science by Rosalind Driver John Learch Robin Millar and*. Buckingham, UK: Open University Press.

Duruk, Ü., Akgün, A., & Tokur, F. (2019). Prospective early childhood teachers' understandings on the nature of science in terms of scientific knowledge and scientific method. *Universal Journal of Educational Research*, 7(3), 675–690. https://doi.org/10.13189/ujer.2019.070306

Erduran, S., & Dagher, Z. (2014). Family resemblance approach to characterizing science. In *Reconceptualizing the nature of science for science education* (p. 206). Dordrecht: Springer. https://doi.org/10.1007/978-94-017-9057-4

Fernández, I., Gil, D., Carrascosa, J., Cachapuz, A., & Praia, J. (2002). Visiones deformadas de la ciencia transmitidas por la enseñanza. *Enseñanza de Las Ciencias*, *20*(3), 447–488.

González-garcía, F., Blanco-lópez, Á., España-ramos, E., & Franco-Mariscal, A.-J. (2019). The nature of science and citizenship: A Delphi analysis. *Research in Science Education*. https://doi.org/https://doi.org/10.1007/s11165-018-9817-5

Hernández, R., Fernández, C., & Baptista, P. (2010). *Metodología de la Investigación.* (5ª. ed.). Mexico D.F, Mexico: McGraw-Hill.

Hodson, D. (2009). *Teaching and learning about science: Language, theories, methods, history, traditions and values*. Rotterdam, The Netherlands: Sense.

Hodson, D., & Wong, S. (2014). From the Horse's mouth: Why scientists' views are crucial to nature of science understanding. *International Journal of Science Education*, *36*(16), 2639–2665.

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

Irzik, G., & Nola, R. (2014). New directions for nature of science research. In M. Matthews (Ed.), *International Handbook of Research in History, Philosophy and Science Teaching* (pp. 999–1021). https://doi.org/10.1007/978-94-007-7654-8

Izquierdo-Aymerich, M., García-Martínez, Á., Quintanilla, M., & Adúriz-Bravo, A. (2016). Historia, Filosofía y Didáctica de las Ciencias: Aportes para la formación del profesorado de ciencias. Bogotá, D.C: Editorial Universidad Distrital. https://doi.org/10.14483/9789588972282

Kampourakis, K. (2016). The "general aspects" conceptualization as a pragmatic and effective means to introducing students to nature of science. *Journal of Research in Science Teaching*, *53*(5), 667–682. https://doi.org/10.1002/tea.21305

Kartal, E., Cobern, W., Dogan, N., Irez, S., Cakmakci, G., & Yalaki, Y. (2018). Improving science teachers' nature of science views through an innovative continuing professional development program. *International Journal of STEM Education*, 5(30), 1–10. https://doi.org/10.1186/s40594-018-0125-4

Lederman, N. (1998). The state of science education: Subject matter without context. *The Electronic Journal for Research in Science & Mathematics Education*, *3*(2). Retrieved from https://ejse.southwestern.edu/article/view/7602

Lederman, N. (2007). Nature of science: Past, present, and future. In S. Abell, & N. Lederman (Eds.), *Handbook of Research on Science Education* (pp. 831–880). New York, USA: Lawrence Erlbaum Associates, Inc.

Lederman, N., & O'Malley, M. (1990). Students' perceptions of tentativeness in science: Development, use, and sources of change. *Science Education*, *74*(2), 225–239. https://doi.org/10.1002/sce.3730740207

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

Lederman, J., Lederman, N., Kim, B., & Ko, E. (2012). Teaching and learning of nature of science and scientific inquiry: building capacity through systematic research-based professional development. In *Advances in Nature of Science Research: Concepts and Methodologies* (pp. 125–152). London New York: Springer. https://doi.org/10.1007/978-94-007-2457-0

Lederman, N., Bartos, S., & Lederman, J. (2014a). The development, use, and interpretation of nature of science assessments. In M. R. Matthews (Ed.), *International Handbook of Research in History, Philosophy and Science Teaching* (pp. 971–997). New York, USA: Springer. https://doi.org/10.1007/978-94-007-7654-8

Lederman, N., Antink, A. & Bartos, S. (2014b). Nature of science, scientific inquiry, and socio-scientific issues arising from genetics: A pathway to developing a scientifically literate citizenry. *Science and Education*, 23, 285-302. https://doi.org/10.1007/s11191-012-9503-3

Lederman, J., Lederman, N., Bartos, S., Bartels, S., Antink-

Meyer, A. & Schwartz, R. (2014c). Meaningful assessment of learners' understandings about scientific inquiry-The views about scientific inquiry (VASI) Questionnaire. *Journal of Research in Science Teaching*. https://doi.org/10.1002/tea.21125

Liang, L., Chen, S., Chen, X., Kaya, O., Adams, A., 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), 1–20

Marin, N., Benarroch, A., & Niaz, M. (2013). Revisión de consensos sobre Naturaleza de la Ciencia. *Revista de Educación*, (361), 117–140. https://doi.org/10.4438/1988-592X-RE-2011-361-137

Matthews, M. (1990). History, philosophy, and science teaching: The new engagement. *Asia-Pacific Forum on Science Learning and Teaching*, *10*(1), 1–14.

Matthews, M. (2012). Changing the focus: From nature of science (nos) to features of science (fos). in m. s. khin (ed.), *Advances in Nature of Science Research, Concepts and Methodologies* (pp. 3–26). London New York: Springer Dordrecht Heidelberg. https://doi.org/10.1007/978-94-007-2457-0

McComas, W. (1998). The principal elements of the nature of science: Dispelling the myths. In W. McComas (Ed.), *The Nature of Science in Science Education: Rationales and Strategies* (pp. 53–70). Netherlands: The Netherlands: Kluwer Academic Publishers.

McComas,W. (2005). Seeking NOS standards: What content consensus exists in popular books on the nature of science? In *Paper presented at the annual conference of the national association of research in science teaching*. Dallas, TX.

McComas, W. (2008). Seeking historical examples to illustrate key aspects of the nature of science. *Science & Education*, *17*(23), 249–263. https://doi.org/10.1007/s11191-007-9081-y

McComas, W., Clough, M., & Almazroa, H. (1998). The role and character of the nature of science in science education. In W. McComas (Ed.), *The Nature of Science in Science Education: Rationales and Strategies* (pp. 3–39). New York, USA: The Netherlands: Kluwer Academic Publishers.

McComas, W., & Olson, J. (1998). The nature of science in international science education. In W. McComas (Ed.), *The Nature of Science in Science Education: Rationales and Strategies* (pp. 41–52). New York, USA: The Netherlands: Kluwer Academic Publishers.

Meichtry, Y. (1992). Influencing student understanding of the nature of science - Data from a case of curriculum-development. *Journal of Research in Science Teaching*, 29(4), 389–407. https://doi.org/10.1002/tea.3660290407

Mesci, G., & Schwartz, R. (2016). Changing preservice science teachers' views of nature of science: Why some conceptions may be more easily altered than others. *Research in Science Education*, 1–23. https://doi.org/10.1007/s11165-015-9503-9

Metin, D., & Leblebicioğlu, G. (2015). Development of elementary 6th and 7th grade students' views about scientific model and modeling throughout a summer science camp. *Education and Science*, 40(177), 1-18. http://dx.doi.org/10.15390/EB.2015.1507

Ministry of Education [MOE], M. (2007). The Ontario curriculum grades 1-8: Science and technology. Retrieved 20 May 2019. Retrieved from http://www.edu.gov.on.ca/eng/curriculum/elementary/scientec18currb.pdf

Mulvey, B., Chiu, J., Ghosh, R., & Bell, R. (2016). Special education teachers' nature of science instructional experiences. *Journal of Research in Science Teaching*, 53(4), 554–578. https://doi.org/10.1002/tea.21311

National Research Council [NRC], N. (1996). *National science education standards*. Washington DC, USA: National Academic Press.

Niaz, M. (2009). *Critical appreisal of physical science as a human enterprise: Dynamics of scientific progress*. Dordrecht, The Netherlands: Springer.

Osborne, J., Collins, S., Ratcliffe, M., Millar, R., & Duschl, R. (2003). What 'ideas-about-science' should be taught in school science? A delphi study of the expert community. *Journal of Research in Science Teaching*, *40*(7), 692–720. https://doi.org/10.1002/tea.10105

Ozgelen, S., Yilmaz-Tuzun, O., & Hanuscin, D. (2013). Exploring the development of preservice science teachers ' views on the nature of science in inquiry-based laboratory instruction. *Research in Science Education*, *43*, 1551–1570. https://doi.org/10.1007/s11165-012-9321-2

PhysPort, Supporting physics teaching with research-based resources (2020, Juanary 20). Retrieved from https://www.physport.org/assessments/assessment.cfm?I=81&A=VNOS

Project ICAN. (2003). *ICAN Year 2 annual report summary. Project ICAN: Inquiry, Context , and Nature of Science.* Retrieved from https://science.iit.edu/sites/science/files/elements/mse/pdfs/Annual-report-y-2.pdf

Rennie, L., Goodrum, D., & Hackling, M. (2001). Science teaching and learning in Australian schools: Results of a national study. *Research in Science Education*, *31*, 455–498. https://doi.org/https://doi.org/10.1023/A:1013171905815

Rubba, P. (1977). User's manual for the nature of scientific knowledge scale.

Rubba, P. A., & Andersen, H. O. (1978). Development of an instrument to assess secondary school students' understanding of the nature of scientific knowledge. *Science Education*, 62(4), 449–458. https://doi.org/10.1002/sce.3730620404

Ryan, A., & Aikenhead, G. (1992). Students' preconceptions about the epistemology of science. *Science Education*, *76*(6), 559–580. https://doi.org/10.1002/sce.3730760602

Sarkar, M., & Gomes, J. (2010). Science teachers ' conceptions of nature of science : The case of Bangladesh. *Asia-Pacific Forum on Science Learning and Teaching*, *11*(1), 1–17.

Schwartz, R., Lederman, N., & Crawford, B. (2004). Developing views of nature of science in an authentic context: An explicit approach to bridging the gap between nature of science and scientific inquiry. *Science Teacher Education*, *88*(4), 610–645. https://doi.org/10.1002/sce.10128

Scott, J. (1990). *A matter of record: Documentary sources in social research.* Cambridge, U: Polity Press.

Vázquez-Alonso, Á., Acevedo-Díaz, J., & Manassero-Mas, M. A. (2004). Consensos sobre la Naturaleza de la Ciencia: Evidencias e implicaciones para su enseñanza. *Revista Iberoamericana de Educación*, 14, 1–36.

Vázquez-Alonso, Á., García-carmona, A., Manassero-Mas, A., & Bennàssar-roig, A. (2013). Science teachers' thinking about the nature of science: A new methodological approach to Its Assessment. *Research in Science Education*, *43*, 781–808. https://doi.org/10.1007/s11165-012-9291-4

Vázquez-Alonso, Á., & Manassero-Mas, A. (2017). An alternative conceptualization of the nature of science for science and technology education. *Conexão Ciência*, 12(2), 18-24.

Wang, J., & Zhao, Y. (2016). Comparative research on the understandings of nature of science and scientific inquiry between sciencce teachers from Shanghai and Chicago. *Journal of Baltic Science Education*, 15(1), 97-108.