Teachers' Views on the Nature of Science: An Epistemological Analysis

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Abstract. This article presents results of research analysing the views on the nature of science (NOS) among primary and secondary teachers working in state schools in two different cities in Colombia. Previous studies have reported that science teachers maintain 'eclectic' epistemological perspectives on science; in this article, we test if such hypothesis holds when teachers' ideas are 'anchored' in specific periods and topics of the philosophy of science. Thirty-five teachers attending a postgraduate teaching course with emphasis on the natural sciences at the Universidad del Norte (Barranquilla, Colombia) were assessed with the use of quantitative, descriptive and parametric research methods. The most important conclusion of this study is that teachers' expressed views on NOS maintain their epistemological eclecticism even when examined with more detail in relation to specific periods and topics of the philosophy of science. Such results can have negative implications for teachers' professionalisation, since fragile or labile conceptions of NOS could restrict the possibility of presenting a coherent view on science in the classroom.

Key words: Epistemological views, nature of science, periods of the philosophy of science, topics of the philosophy of science, in-service science teacher education and professionalisation.

Introduction

Empirical research around teachers' professed ideas on the so-called nature of science (NOS) supports the construction of hypotheses on the possible relationships between teachers' epistemological views and actions; science teachers are known to subscribe to different epistemological views on science (Kang & Wallace, 2005; Linneman, Lynch, Kurup, Webb & Bantwini, 2003), and this 'eclecticism' is an important theoretical element to explain their practices. An eclectic conception of NOS refers to the case when the teachers' views can be linked to a diversity of epistemological conceptions, across different periods of the philosophy of science. One of the concerns in didactics of science is that each science teacher should elaborate an epistemologically robust image of science; such an elaboration has an effect both on science teaching and on the views on the nature of science taught in the classroom (Dogan & Abd-El-Khalick, 2008; Hodson, 1985; Reinoso, Delgado-Iglesias & Fernández, 2019). It is on the basis of the epistemological views of science that a teacher has built that he or she will teach the scientific theories and models and their construction; that is why it is important to map teachers' conceptions with particular periods of the philosophy of science, which may be more or less progressive in their depiction of the scientific activity.

For the purpose of the research reported here, NOS will be considered as a set of metascientific contents (Amador-Rodríguez & Adúriz-Bravo, 2018) selected due to their value for science education, and subject to didactical transposition (i.e., instructional adaptation). Such contents stem from distinct epistemological periods in 20th century philosophy of science. NOS 'key ideas' to be taught can be framed in paradigmatic episodes from the history of science (Adúriz-Bravo, 2007).

It has been proposed that mainstream research on NOS comprises four big themes: (1) understanding of NOS in teachers and students; (2) curriculum research, innovation and evaluation to improve students' understanding of NOS; (3) methodologies to improve the understanding of NOS among teachers; and (4) the connections between NOS understanding in teachers and students and NOS teaching and learning in the classrooms (Karaman, 2016). Previous qualitative research has indicated that teachers' views on NOS are in many cases *inadequate* for meaningful science teaching (e.g., Thye & Kwen, 2004).

In science education literature, the so-called VNOS questionnaire (in its variants A, B, C, D and E: Abd-El-Khalick, 2014) is often employed to determine views on NOS among science teachers. For over a decade now, a number of researchers have validated this questionnaire, while other authors have proposed theoretical and methodological alternatives to investigate views on NOS (see Allchin, 2013; Dagher & Erduran, 2017; Irzik & Nola, 2011). Most studies available analyse teachers' epistemological views in terms of their similarity with general ideas widely accepted by the community of philosophers of science. In contrast, this study is based on a set of epistemological statements that can be identified with five *distinct* periods from 20th century philosophy of science.

This study also analyses some specific aspects of the *scientific activity* (Amador-Rodríguez, 2018; Ospina-Quintero, 2019) with the aid of ten *specific* topics of the philosophy of science. In recent years, there has been a renewed interest in investigating science teachers' conceptions in general, and epistemological beliefs in particular (Lederman, 1992; Sahin, Deniz, & Topçu, 2016); however, very few studies have investigated those epistemological beliefs around specific epistemological topics, organised in a number of 'structuring theoretical fields' of the philosophy of science, as they will be called in this article.

Adúriz-Bravo (2008) suggests the construct of structuring theoretical fields of NOS defining them as *throughlines* that traverse meta-scientific reflection; this proposal has allowed us to identify key ideas in the philosophy of science that may suppose a contribution to science education.

A rich interaction between science education and the philosophy of science (iSE-PS) could let researchers generate key ideas about the main aspects of the scientific activity. In the present research, two constructs from iSE-PS have been employed in order to pinpoint valuable key ideas of NOS for science teacher education; those constructs are called *periods* and *topics* of the philosophy of science (Amador-Rodríguez & Adúriz-Bravo, 2021).

Periods of the Philosophy of Science to Model NOS Views

An alternative perspective on the study of NOS views is provided when a periodisation of the philosophy of science is introduced in order to map them. This proposal to relate teachers' ideas on NOS with specific philosophical formulations achieves higher degree of epistemological specificity than previous, more general studies. The periodisation used here proposes five periods, corresponding to well-established schools in the philosophy of science, and selected due to their relevance for the research community in didactics of science (Amador-Rodríguez, 2018; Amador-Rodríguez et al., 2021). The periods are as follows (Amador-Rodríguez, 2018):

Logical Positivism/Received View (LP/RV):

These two seminal schools of the philosophy of science (the first one developed in Austria between the two World Wars and the second one in post-war USA) emphasise the *methodological* aspects of scientific activity. They favour a 'syntactic' (or logical-linguistic) approach for studying scientific knowledge, employing formal tools to generate rigorous analyses of its structure and validity.

Critical Rationalism (CR):

This second period is well represented in the writings of the Austrian philosopher Sir Karl Popper. He sought to correct or refute the theoretical foundations of logical positivism, rejecting the principle of induction and stressing the value of theories while opposing the idea of *neutral* observation. In this period, scientific progress is interpreted as the recurrent rejection of theories by falsification and their replacement by more satisfactory theories through successive 'conjectures and refutations'.

The New Philosophy of Science (NPS):

During this third period of the philosophy of science, two significant interest foci emerged: the examination of the *historical* dimensions of science and the questioning of the foundational assumptions held by mainstream perspectives. These novel epistemological viewpoints gave rise to alternative methodological propositions. For example, theories ceased to be perceived as completed axiomatic systems fixed in time; instead, they were regarded as evolving conceptual entities of varying complexity. Furthermore, concepts such as 'paradigm' and 'programme of scientific research', among others, assumed the role of the new analytical units employed to comprehend, elucidate, and portray scientific knowledge.

Post-Kuhnian Philosophy of Science (PK):

This epistemological perspective challenges the assumed and unquestioned neutrality and objectivity of science. It acknowledges that scientific *terms* carry a theoretical 'load', and that every observation is influenced by the underlying theory used to perceive the world. Consequently, observational terms do not provide the meaning to theoretical concepts; rather, the latter shape the former. Furthermore, during this epistemological period, the existence of the renowned *scientific method* was refuted.

Contemporary Accounts (CA):

This last period in 20th century philosophy of science comprises a multitude of epistemological schools, which coexist with different degrees of harmony. One of those schools is the *semantic view of scientific theories*. Adepts to the semantic perspective focus on the meaning and use of scientific theories, and only secondarily on their form or structure. Semantic approaches postulate that the relationship between phenomena ('reality') and what science says about them *is mediated by scientific models* as abstract representations of the world. Theoretical models and empirical phenomena maintain a relationship of resemblance technically known as 'similarity'.

Topics of the Philosophy of Science: Aspects of the Scientific Activity

Our notion of epistemological topics refer to the variety of activities carried out by men and women in science. These topics studied by the philosophy of science allow for the analysis and evaluation of science as an activity; they can be considered structured bundles of philosophical ideas and questions adapted for didactical purposes. The reinterpretation of NOS themes into rigourously defined topics has demonstrated high theoretical and methodological value in science teaching and in didactical research (see, for example, Martínez-Rodríguez & Garay Garay, 2019; Vázquez Alonso & Manassero Mas, 2016).

Topic	*Definition*
Contexts	Refers to the contexts or domains where scientific activity takes place and is developed.
Correspondence	Describes how theoretical entities (theories, laws, models, hypotheses, among others) relate to reality.
Evolution	Refers to the proposed model of scientific change.
Intervention	Relates to experimentation, observation and other activities employed in science to generate knowledge about the world.
Judgement	Consists of the decisions taken by the scientific community regarding a given scientific theory or model.
Languages	Corresponds to how scientists employ symbolic, semiotic, expressive resources to define, describe, express and communicate scientific theories or models.
Methodologies	Refers to the possible existence of methods as normative rules to guide scientific activity.
Rationality	Relates to the criteria used by scientists to evaluate, justify and accept scientific theories or models.
Representation	Examines the intellectual tools that scientists construct to capture, represent or model phenomena.
Values	Refers to epistemic (and eventually non-epistemic) values guiding scientists' activity.

Table I. Topics of the philosophy of science for the study of different specific aspects of NOS.

Research Methodology
General Background

The present research was guided by two questions: which periods of the philosophy of science are linked to teachers' views on the nature of science (NOS)?, and with which topics are those views of NOS related? The investigation had an initial phase adjusted for a quantitative study using a number of statistical parameters. The central premise of this phase was to obtain information about the combined use of topics and periods of the philosophy of science in order to provide a more sophisticated description of science teachers' views on NOS. There was then a second qualitative phase for a more detailed characterisation of the epistemological profiles that emerge in the sample of teachers selected for the study.

Data was collected using a 50-item Likert-scale survey that was previously designed and validated for large, comprehensive studies (Amador-Rodríguez et al., 2022). This piece of research was conducted on a sample of 35 primary and secondary teachers (22 women and 13 men) from state schools in the city of Santa Marta and the municipality of Ciénaga (in the Department of Magdalena, Colombia). All teachers were enrolled in a Master's programme in education with emphasis on science teaching at the Universidad del Norte (Barranquilla, Colombia).

During the programme, participant teachers took three seminars on science teaching methods that were formulated in consistence with current theoretical principles of the philosophy of science. Specifically, the seminars discussed the scientific activity under the light of the *semantic view of science* (Adúriz-Bravo, 2013). During those seminars, the possible relations between NOS and science teaching was the central element of discussion with teachers. Specific content of biology, physics and chemistry was analysed in order to examine its relations with different epistemological issues of importance.

The theoretical and methodological characteristics of the graduate course at the Universidad del Norte make it clear that the following metascientific aspects guide the education of graduate students (i.e., in-service science teachers):

- Explicit and updated training in NOS issues.
- Metascientific content offered in specific courses of didactics of science.
- Metascientific content organised through the inclusion of key epistemological topics into science teachers' reflections and discussions.

Instrument and Procedures

The objective of this study was to characterise, as richly as possible, ideas about the nature of science among a group of primary and secondary school teachers. In it, we operationalised the questions as follows: in the group, which particular period of the philosophy of science is linked with the teachers' view on a concrete aspect of the nature of science and with which topic can that view be related?

At the end of the three seminars on science teaching methods in which our participant teachers were enrolled, a 5-point Likert-type questionnaire was applied to them in order to assess their understanding of a series of 50 epistemological statements (see questionnaire in Amador-Rodríguez, 2018). These statements in the Likert questionnaire refer *at the same time* to the ten topics and the five periods of the philosophy of science presented above; thus, there is one statement for each topic as it is conceptualised in each period (making a total of 50).

This method provides indirect information on the views that teachers maintain regarding NOS through their adhesion to sample statements. The approach used in this study seeks at grouping teachers according to how they relate to a certain attribute -in this case, the ten epistemological topics in Table I (Amador-Rodríguez & Adúriz-Bravo, 2021). The objective was to determine, among the investigated teachers, the degree of consensus in their choices for distinct periods of the philosophy of science when considering various topics (Table II).

In the administered questionnaire (Amador-Rodríguez et al., 2022), teachers evaluated each epistemological statement according to a classical scale of alternatives: I strongly agree (SA); I agree (A); I do not know what to say (NS); I disagree (D); I strongly disagree (SD). The options were ascribed a numerical score ranging from 1 (SD) to 5 (SA). Since data was grouped in relation to the decisions of each teacher, the resulting conglomerate does not allow to establish distances between teachers who select "agree" and "disagree". Our use of the Likert scale permits sorting the overall trends in the decisions of the teacher sample.

Reliability of the questionnaire was tested through Cronbach's alpha. The questionnaire was considered reliable ($\alpha=0.875$), with the factorial score being obtained through the summative scoring procedure. A factor score using the summative scoring procedure is a measure obtained by summing the responses of an individual on a set of items or questions. In the context of factor analysis, statistical techniques are used to group related items and determine a composite score that reflects the individual's overall tendency with respect to the construct being evaluated. This factor score can be used to quantify or compare characteristics or attitudes on a numerical scale (Chakrabartty & Chakrabartty, 2019).

Research Results

The mean values of each teachers' responses to the questionnaire (Figure 1) show that 28 of them manifested an intermediate ('temperate') position (between 3 and 4), that moves between no formed opinion (NS) and agreement (A). Six teachers are closer to strongly agreeing (SA) with most statements (> 4); these are highlighted in the red dotted box. One single teacher expressed opinions largely disagreeing with the statements (< 3); he is highlighted in the green dotted box.

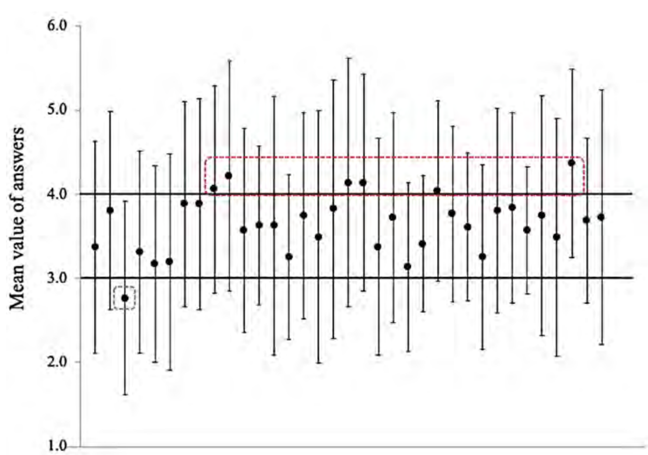

Figure 1. Mean value of opinions in each teacher regarding the 50 statements of the questionnaire.

Black dots represent the mean value for each of the 35 teachers, and vertical bars represent standard deviations around the mean. Horizontal lines correspond to threshold values in the Likert-scale around NOS views.

These mean values of opinions suggest the existence of three groups of teachers, but they do not allow inferring their epistemological tendencies regarding NOS. Exploratory analysis of each teacher, however, supports the pertinence of the idea of epistemological eclecticism among the group of science teachers under study; such assumption is based on the observation that the most frequent choices by teachers regarding each statement (Table II) are agreeing or strongly agreeing with formulations that, in principle, are partially incompatible in the philosophy of science.

On the other hand, statements presenting the lowest variability in answers between teachers are 12 (*SD* = 0.554), 28 (*SD* = 0.554) and 50 (*SD* = 0.560) (Table II), which means that most teachers are aligned in their opinions to those specific formulations. Statements 12 and 50 refer to aspects of NOS as conceptualised in Contemporary Accounts, while statement 28 stems from the New Philosophy of Science.

The following statements exhibited SD values greater than one: 2 (*SD* = 1.402), 10 (*SD* = 1.546), 13 (*SD* = 1.423), 17 (*SD* = 1.414), 22 (*SD* = 1.437), 46 (*SD* = 1.431) and 48 (*SD* = 1.496). This indicates greater variability in epistemological trends related to these particular aspects of NOS. Statements 13, 46 and 48 relate to Logical Positivism/Received View, statements 10 and 17 to Critical Rationalism, and statements 2 and 22 to Post-Kuhnian Philosophy of Science.

As measured by the coefficient of variation (CV), the statements with the highest dispersion in terms of epistemological trends regarding NOS are: 1 (*CV* = 0.510), 4 (*CV* = 0.563), 10 (*CV* = 0.551), 35 (*CV* = 0.535) and 42 (*CV* = 0.502). Those values indicate that teachers are not consistent in their answers. Statement 1 relates to Logical Positivism/Received View, statement 10 to Critical Rationalism, statements 35 and 42 to the New Philosophy of Science, and statement 4 to the Post-Kuhnian period. Those statements exhibit higher disagreement regarding the selected answers.

Statement	*Mean*	*SD*	*CV*	*Statement*	*Mean*	*SD*	*CV*
1	2.278	1.162	0.510	26	3.722	1.003	0.270
2	2.917	1.402	0.481	27	3.083	1.317	0.427
3	3.917	0.996	0.254	28	4.583	0.554	0.121
4	1.944	1.094	0.563	29	4.306	0.710	0.165
5	3.583	1.273	0.355	30	4.333	0.632	0.146
6	3.444	1.297	0.377	31	4.278	0.815	0.190
7	4.000	1.069	0.267	32	4.306	0.920	0.214
8	4.306	0.710	0.165	33	4.528	0.654	0.144
9	4.028	1.108	0.275	34	3.861	1.099	0.285
10	2.806	1.546	0.551	35	1.972	1.055	0.535
11	4.278	0.615	0.144	36	3.722	0.882	0.237
12	4.583	0.554	0.121	37	4.167	0.910	0.218
13	3.556	1.423	0.400	38	3.667	1.287	0.351
14	4.333	0.632	0.146	39	3.444	1.182	0.343
15	2.611	1.271	0.487	40	4.361	0.639	0.147
16	4.194	0.951	0.227	41	3.778	0.989	0.262
17	3.000	1.414	0.471	42	2.583	1.296	0.502
18	4.083	0.906	0.222	43	3.722	1.111	0.299

19	3.556	1.252	0.352	44	3.639	1.175	0.323
20	3.917	0.996	0.254	45	3.361	1.376	0.410
21	3.722	1.301	0.349	46	3.194	1.431	0.448
22	3.639	1.437	0.395	47	4.333	0.676	0.156
23	3.389	1.076	0.318	48	3.361	1.496	0.445
24	3.667	1.069	0.292	49	3.417	1.360	0.398
25	3.694	1.037	0.281	50	4.472	0.560	0.125

Table II. Descriptive statistics for answers from each statement (N = 50).

Table III shows the most favoured statements regarding each epistemological topic. Selection is based on SD and CV values, which must be ≤ 1.

Period from the philosophy of science	*Topic*	*Most favoured statement*	*SD*	*CV*
Contemporary Accounts	Context	12. In the scientific activity, four contexts are established: a) Education: related to teaching and dissemination of scientific activity. b) Innovation: related to inventions and innovation in scientific activity. c) Assessment: related to progress and improvement of scientific activity. d) Application: associated with changes in scientific production and artefacts with the purpose of transforming the environment of scientific activity.	0.554	0.121
	Evolution	8. The choice of a model over another is based not only on the similarity of the model to the real system, but also on the interests of scientists.	0.710	0.165
	Intervention	14. Experimental designs proposed by scientists as their observations are mediated by their scientific models, which also guide decision-making.	0.632	0.146
	Languages	50. Models can be represented through different symbolic media, allowing us to think, speak and act on the world or phenomena.	0.560	0.125
New Philosophy of Science	Correspondence	28. A paradigm constructs an interpretation of the world, thus becoming a possible truth in science, but paradigms can be modified or replaced by another one providing better solutions to scientific problems.	0.554	0.121
	Methodologies	31. Scientists working in a scientific field share assumption including: theoretical frameworks, experimental designs, methodological procedures, among others.	0.815	0.190
	Rationality	30. It cannot be said that a new paradigm in scientific activity is superior to the previous one for solving more or better problems. A paradigm shift implies not only change in theories, but also in norms and research methods.	0.632	0.146
	Representation	29. Scientific theories are structurally complex entities consisting of general principles supporting research and innovation, and of a set of experimentally tested assumptions derived from the general principles.	0.710	0.165
	Values	11. Scientific activity is governed by a plethora of	0.615	0.144

		values such as: precision, accuracy or approximation; consistency or constancy; universality, generality or breadth; simplicity, elegance or beauty; adjustability or adaptation to nature or data and social value.		
Logical Positivism / Received View	Judgement	32. In a mature scientific discipline, a new theory does not only replace the previous one, but retains what is true in it, perfecting, enriching and extending it.	0.920	0.214

Table III. Most favoured statements regarding each topic of the philosophy of science.

It is observed that participant science teachers' views on the topics of Context, Evolution, Intervention and Languages tend to refer to Contemporary Accounts. Regarding Correspondence, Methodologies, Rationality and Representation, epistemological views refer to the New Philosophy of Science, and regarding Judgment, views relate to the period of Logical Positivism/Received View. Most of the eclectic statements are related to the meanings that teachers give to the notions of Context, Evolution, Intervention and Languages. More specifically, there can be seen a tendency towards a *semantic* approach, which postulates that the relationship between phenomena and what science says about them is model-mediated of the world (Adúriz-Bravo, 2013). In addition, positions from the New Philosophy of Science only have particular impact on teachers' representations of the status of scientific knowledge in the topics of Correspondence, Method, Rationality, Representation and Values. Teachers may be considering that both hypotheses and experimentation are *theory-laden* (Hanson, 1971).

The so-called structuring theoretical fields of the nature of science (Adúriz-Bravo, 2008) postulate a relationship between a conglomerate of aspects of the scientific activity that belong in the same metascientific issue or problem. Such theoretical relationship is expressed by coupling the 10 topics of the philosophy of science in 5 pairs (Amador-Rodríguez & Adúriz-Bravo, 2021). In this study, we also wanted to test whether that relationship of coupling between topics was confirmed by research data; in order to do this, we calculated Kendall's correlation coefficient (τ), a non-parametric method applicable to samples with non-normal distributions. Bivariate Kendall correlations were estimated for the following pairs of topics, in accordance with the original proposal of structuring theoretical fields by Amador-Rodríguez (2018): Correspondence/Rationality, Languages/Representation, Methodologies/Intervention, Judgement/Evolution, and Values/Context (Table IV).

Correlations may range from -1 to 1, where values near zero indicate a very weak association between the two variables. The sign indicates the direction of the association (a negative sign indicates an inverse relationship, and a positive sign indicates a direct relationship). Only correlations with values of p equal to or less than 0.05 are considered significant (shown in bold in Table IV).

	LPRV		*CR*		*NPS*		*PK*		*CA*	
	τ	P	τ	P	τ	p	τ	p	τ	p
Correspondence / Rationality	0.19	0.18	0.11	0.46	0.35	0.033	0.28	0.059	0.066	0.67
Languages / Representation	-0.046	0.75	0.017	0.90	0.098	0.51	0.25	0.093	0.27	0.075
Methodologies / Intervention	0.32	0.026	0.11	0.45	-0.18	0.22	0	1	0.11	0.48
Judgement / Evolution	0.39	0.011	-0.01	0.94	0.36	0.0099	0.34	0.021	0.36	0.019
Values / Context	-0.45	0.0014	0.19	0.19	0.22	0.16	0.2	0.18	0.59	0.00034

Table IV. Kendall correlations between pairs of aspects of the scientific activity for each of the five epistemological periods. Significant values (p<0.05) shown in bold.

Our correlational analysis shows that the associations between epistemological topics proposed by Amador-Rodríguez (2018) do not appear in the empirical results for all pairs of topics and all periods. Where the association is observed, the correlation is rather low, the strongest being between Values and Context in the period of Contemporary Accounts (Table IV).

Unexpected relationships actually found between pairs of specific topics (in contrast with the notion of structuring theoretical fields) point at the eclecticism in NOS views among teachers (Table V). For example, the pair Judgement-Evolution is significantly associated in four of the five periods of the philosophy of science. In the case of the pair Values-Context, it is interesting to observe that teachers' epistemological eclecticism is shown in their choice of the two most separate periods of the philosophy of science (LP-RV and CA). In the case of the pair Languages-Representation, results do not show any period in which a relationship between the two topics is recognised by participants in the sample.

Structuring theoretical fields	*Period of the philosophy of science*
Correspondence / Rationality	New Philosophy of Science
Methodologies / Intervention	Logical Positivism/Received View
Judgement / Evolution	Logical Positivism/Received View
Judgement / Evolution	New Philosophy of Science
Judgement / Evolution	Post-Kuhnian Philosophy of Science
Judgement / Evolution	Contemporary Accounts
Values / Context	Logical Positivism/Received View
Values / Context	Contemporary Accounts

Table V. Connection between pairs of epistemological topics in the data.

Based on the actually identified relationships, the statements determining some kind of epistemological pattern in teachers' views on NOS are presented in Table VI. It should be noted that data show negative correlation in the case of the pair Context-Values for the period of Logical Positivism-Received View, implying that teachers hold opposite views on these two epistemological topics. Teachers agree with the formulation of the idea of context that is provided by Logical Positivism-Received View while at the same time disagree with positivistic formulations in the case of values.

Period in the philosophy of science	*Topic*	*Most favoured statement*
New Philosophy of Science	Rationality	30. It cannot be said that a new paradigm in scientific activity is superior to the previous one for solving more or better problems. A paradigm shift implies not only change in theories, but also in norms and research methods.
	Correspondence	28. A paradigm constructs an interpretation of the world, thus becoming a possible truth in science, but paradigms can be modified or replaced by another one providing better solutions to scientific problems.
Logical Positivism-Received View	Intervention	41. Observation and experimentation provide a solid foundation for scientific enquiry.
	Methodologies	13. Scientists performing research start with the observation of phenomena, then proceed to formulate hypotheses, design and perform experiments, and finally draw conclusions containing more information than the original hypotheses. This method characterises the inductive logic.
Logical Positivism-Received View	Evolution	43. Scientific advancement is based on the accumulation of theories; whereby new theories incorporate previous ones both conceptually and methodologically.
	Judgement	32. In a mature science, a new theory does not only replace the previous one, but retains what is true in it, perfecting, enriching and extending it.
New Philosophy of Science	Evolution	39. After a scientific revolution, scientists see the world differently, meaning that although the world remains the same, scientists operate in it differently.
	Judgement	42. The acceptance of a new paradigm relies on persuasion techniques, arguments and counterarguments, in the absence of ‘proofs’.
Post-Kuhnian	Evolution	25. When a research tradition no longer solves certain scientific problems, it is replaced by another tradition. This substitution brings about changes in solutions to various problems, but a large fraction of problems to be solved remains the same.
	Judgement	9. Scientists accept a theory or research tradition if they provide a better solution to empirical and conceptual problems.
Contemporary accounts	Evolution	8. The choice of a model over another is based not only on the similarity of the model to the real system, but also on the interests of scientists.
	Judgement	37. Scientists choose theoretical proposals that best fit their models, a choice based on scientific, social and other interests, with the purpose of interpreting, describing and explaining the world.
Logical Positivism-Received View	Context	46. How the theories are discovered is irrelevant, since that depends on varied circumstances not subject to logical criteria. Instead, it is important to evaluate procedures by which scientists justify their theories, a task where logic plays a significant role.
	Values	48. Scientists must follow a single epistemic value: the truth.
Contemporary Accounts	Context	12. In scientific activity, four contexts are established: a) Education: related to teaching and dissemination of scientific activity. b) Innovation: concerning inventions and novelties in scientific activity. c) Assessment: related to progress and improvement of scientific activity. d) Application: associated with changes in scientific production and artefacts with the purpose of transforming the environment of scientific activity.
	Values	33. The social values of science relate to the following axiological criteria: The results of scientific activity must be public, communicable and teachable; Scientific knowledge must be accessible to any human being; Science must be objective; As far as possible, scientists must improve on the achievements of their predecessors.

Table VI. Most favoured statements for each period in the philosophy of science.

Discussion

On the principle that good quality science education must empower young people for critical thinking and decision-making, there is growing consensus over the explicit inclusion of NOS content in science curricula (McComas, 2004). But the fact is that NOS does not yet permeate in a truly effective way in science teaching. Thus, Hipkins, Barker and Bolstad (2005) have confirmed the existence of an incongruence between the rhetoric of reform in science education and real teaching practices in the classrooms. The absence of consensus around NOS within the community of science education, teachers' personal theories on teaching and learning, the scarcity of effective curriculum guidelines and the lack of adequate instructional materials, among other factors, are direct causes for that discrepancy. This diagnosis of stagnation in the implementation of NOS provides the background to the present investigation into the robustness of teachers' epistemological views, which are the key to changes at school.

As said, the purpose of the present study was *not* to categorise teachers into a specific school or period of the philosophy of science. Instead, it aimed at determining which periods of the philosophy of science relate to specific teachers' views on the nature of science and with which topics within that periods those views are associated. Views on NOS among in-service teachers in our sample were assessed by relying on five markedly different periods of 20th century philosophy of science; this led to establishing a more detailed characterisation of their very eclectic epistemological tendencies. Teachers interpret the nature of the scientific activity and its products on the basis of a variety of epistemological views, ranging from classical schools in the philosophy of science to the most current perspectives.

With these methods, our interpretation of data suggests that teachers strongly associate the topic Rationality with the period NPS; this school of the philosophy of science considers that a paradigm shift implies not only a change in theories, but also *in scientific methods and norms*. This epistemological view sustained by teachers is complemented by their high agreement to the idea (in the topic of Correspondence) that scientists' interpretations of the world are built *from a paradigm* to which they adhere, but that such a paradigm can be modified or even substituted by another that generates better solutions to the scientific problems under study. These 'progressive' views of NOS in the topics of Rationality and Correspondence promote a non-positivistic account of the scientific activity, favouring an image of science and of scientists that is far more *productive* for science teaching, since it moves away from the belief of theories as absolute truths elaborated from observation.

Following the literature in our field, it can be safely considered that nowadays science teaching is being conceptualised from philosophical schools beyond LP/RV and CR. For instance, a construct from NPS, that of 'scientific revolution', implies considering that, even if the real world remains the same, scientists with different theoretical frameworks observe, understand and intervene it differently. Furthermore, scientists' acceptance of new theoretical systems relies on elaborate persuasion techniques, with arguments and counterarguments. Our foundings in this study about the *components*, or 'voices', in teachers' epistemological eclecticism allow us to infer changes in science teachers' professional knowledge that are in the right direction.

The analysis performed using pairs of epistemological topics inspired in the structuring theoretical fields of NOS by Adúriz-Bravo (2008) reveals some more details of the epistemological *patterns* that teachers hold in relation to NOS. Specifically, the period of Logical Positivism/Received View is associated by teachers to the relationships between Methodologies and Intervention (perhaps the two most typical themes in positivistic accounts). For the pair of Values and Context, something noteworthy is found: teachers agree to the positivistic reconstruction of contexts (à la Reichenbach) while they reject the simplistic assumption of truth as the governing epistemic value. The decoupling in this field is an indication of the increasing influence of NPS, PK and CA in some aspects of science education linked to an image of science *as a communitary endeavour deeply entrenched in its context*.

On the other hand, the teachers that we studied associate the New Philosophy of Science with the relationships between Correspondence and Rationality and, to a lesser extent, between Judgement and Evolution, showing more nuanced and moderate positions in these topics. Teachers pair the field of Judgement-Evolution with three different periods of the philosophy of science, which is a yet another strong sign of their epistemological eclecticism.

Implications

The results obtained in this research and in others that our group has conducted (Amador-Rodríguez et al., 2021; 2022) are very consistent with those reported in many previous studies on teachers' NOS, some of which have a larger scale than ours (e.g., studies with a larger sample size) (e.g., Dogan and Abd-El-Khalick 2008; Jun-Young and Lederman 2018; Lin and Chen 2002). We have found once again a strong eclecticism in the philosophical views on science among in-service primary and secondary teachers, but we have provided new insights to this now well-establisehd finding using the tool of periods and topics.

We were also able to identify, in accordance with already published results, a considerable number of teachers who hold a strongly traditional view of NOS (associated with positivism); but we here report that this adherence to conservative philosophies of science is not homongeneous across all topics.

As presented in the results, teachers' views on the topics of Context, Evolution, Intervention and Languages tend to refer to Contemporary Accounts; for Correspondence, Methodologies, Rationality and Representation, they adjust to the New Philosophy of Science; for Judgement, they relate to the period of Logical Positivism/Received View. These correlations suggest the need for further research. Most of the eclecticism in teachers' NOS is found when they face ideas around to notions of Context, Evolution and Intervention.

The question that then arises is: What can be done to contribute to a more appropriate NOS education *in pre-service science teacher education*?

We think that explicit training in updated topics related to the nature of science should be provided from the beginning of teacher education. And it is our suggestion that such a training should be included both in the educational and the disciplinary (i.e., biology, physics, chemistry, biology, etc.) components of teacher education.

If we take some of our most original results, for instance, the very weak correlation between the topics of Values and Contexts in the period of Contemporary Accounts (Table IV), this empirical evidence would allow us to design instances of teaching of very specific metascientific contents on the basis of selected notions, authors and text from the philosophy of science in formulations that are adequate for science teachers (e.g., Adúriz-Bravo, 2001). For the design and implementation of units and sequences of metascientific content, we propose to prioritise contributions from the New Philosophy of Science and then move towards more updated views.

Specifically, in order to teach to teachers ideas concerning the topics of Correspondence and Representation, where eclecticism and contradiction were found, emphasis can be placed on theoretical concepts derived from the semantic view of scientific theories (Giere, 1988), a philosophical line belonging to the periods of recent and current views.

It is our contention that this incorporation of notions from the extremely powerful semantic conception allows for rich and fruitful interaction between the nature of science and science teaching methods. Through the consisten use of the didactcal framework known as cognitive model of school science (Sanmartí, 2000; Adúriz-Bravo, 2014), the construct of school scientific activity could be presented to teachers.

As for discussion related to the topics of Contexts and Values, we propose to address them using proposals from post-Kuhnian philosophers of science, such as the Spanish philosopher Javier Echeverría (1995).

As a Conclusion

In this study, the combined use of topics and periods of the philosophy of science was introduced in order to provide a more sophisticated depiction of science teachers' views on NOS. This tool aimed at obtaining finer and more detailed analyses. Mapping teachers' ideas onto a periodised conceptual network permits introducing epistemological content that was not explicitly considered in previous research in NOS. Generally, the scope of the study involved exploring the perspectives on the nature of science held by teachers with experience in their teaching practice, with a type of analysis based on a periodisation and on specific themes or issues from the philosophy of science.

We were not able to construct generalised profiles for teachers, since a variety of views appeared for each topic and period. Depending on which of the 50 epistemological statements was considered, we located teachers near Logical Positivism/Received View or the New Philosophy of Science; in the case of a few epistemic aspects of the scientific practice, teachers even related to Contemporary Accounts. The fact that in this study teachers' views could not be homogeneously identified with philosophical ideas from traditional, positivistic philosophy of science conflicts with previous studies presenting their results more monolithically, and shows that teachers' images of science and of scientists are far more complex and multiple. This conclusion is also shared by the Spanish researcher Vicente Mellado (1997).

As for the systems of topics of the philosophy of science that we employed, these were shown to constitute a robust theoretical framework to characterise tendencies in teachers' NOS views and to organise content from the philosophy of science that should be taught to them.

A possible negative consequence of teaching science and the nature of science from an eclectic epistemological positioning is that it fails to satisfactorily manage the fact that students show a variety of *attitudes* towards standard NOS topics such as observation, scientific methodology and theory-world relationships. If teachers do not know or disregard which specific epistemological elements contribute to the status of validity of scientific knowledge (Koulaidis & Ogborn, 1989), this *en bloc* conception will negatively impact on the construction of a robust image of science in their students.

In order to address the problem of teachers' epistemological eclecticism, one possible strategy is to discuss with them the variety of positionings provided by the philosophy of science and their correlated reflexes in textbooks. Philosophical views could be then perceived by teachers as more coherent systems; teachers could also learn to assess students' ideas according to those disciplinary views as false (Koulaidis & Ogborn, 1989). In any case, an issue that needs urgent adjustments is the inclusion, as early as possible, of NOS discussion in pre-service teacher education programmes. A possible adaptation of curricula could be based on the following points: 1. explicit and up-to-date training of teachers in selected topics of the nature of science from the very beginning of their education; 2. introduction of a strong metascientific component in courses of didactics of science; 3. organisation of the metascientific content to be taught in terms of epistemological topics addressed from the point of view of the main periods of the philosophy of science; 4. sound relation between NOS and both instructional *and* disciplinary contents in teacher education.

Generating among science teachers an educationally adequate perspective on the nature of science implies including in their professional development a variety of epistemological issues to be discussed (hence our proposal of topics and, eventually, of structuring theoretical fields) and presenting them with the canonical technical solutions to those issues that different schools of the philosophy of science generated (hence the periodisation that we have proposed).

Possible biases are considered in this research: Expert teachers might tend to reaffirm their own pre-existing beliefs and conceptions about the nature of science, rather than considering alternative perspectives. This could affect the objectivity of the collected data (confirmation bias). Another bias could arise from the pressure on teachers to respond in a socially acceptable manner or in a way that reflects positively on themselves. This could lead to responses that do not accurately reflect their true conceptions (socially desirable response bias). Additionally, teachers' conceptions about the nature of science could be influenced by cultural and contextual factors. Teachers from different regions or cultures might hold diverse perspectives that might not be fully captured in the study (cultural bias).

Ethical Statement

All procedures in this study that involved human participants were in accordance with the ethical standards of the institution and were approved by the Institutional Review Board (IRB) before the implementation of the research procedures.

Consent Statement

Data in this piece of research comes from consenting adults. All subjects in this study are in-service science teachers who willingly responded to the surveys and were duly informed of the characteristics of the research and of the use of the information they provided.

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