The nature of science in the Spanish literature on science education: a systematic review covering the last decade

La naturaleza de la ciencia en la bibliografía española sobre educación científica: una revisión sistemática de la última década

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Antonio García-Carmona
Universidad de Sevilla

Abstract

The understanding of the nature of science (NOS) constitutes a key pillar of citizens' scientific literacy. However, no sufficient and detailed information on the state of NOS teaching in Spain is as yet available. Consequently, it was decided to conduct a systematic review of the topic in the Spanish literature on science education corresponding to the last decade. The study was guided by the following research questions: (1) What attention has NOS received in research and innovation articles published in Spanish Education journals during the period 2010-2019? (2) What types of studies about the teaching of NOS are covered in these articles? (3) What are the educational stages and (student and teacher) populations studied in regard to the teaching of NOS? (4) What aspects of NOS are addressed in its teaching? And (5) what are the contexts or settings used in teaching NOS? The object population of this systematic review was the set of 230 Spanish Education journals indexed in 'Dialnet Métricas' (2018), and the standard PRISMA statement procedures and qualitative content analysis methods were applied in carrying it out. The final sample analysed comprised 88 articles published in 17 journals. The results indicate that NOS has been under-served in Spanish science education in general, especially in Primary Education, even though its understanding is part of the scientific competence assessed in PISA tests. It is concluded that NOS teaching is still at a quite incipient stage in science education in Spain, and there is a significant gap between research and practice

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in this respect. Finally, some recommendations are made in order to foster and improve NOS teaching from the basic levels of education onwards.

Keywords: epistemic and non-epistemic aspects, nature of science, PRISMA, science education, scientific literacy, systematic review

Resumen

La comprensión de la naturaleza de la ciencia (NDC) constituye un pilar fundamental en la alfabetización científica de la ciudadanía. Sin embargo, aún no se dispone de información suficiente y detallada sobre el estado actual de la cuestión relativa a la enseñanza de la NDC en España. En consecuencia, se decidió hacer una revisión sistemática del asunto en la bibliografía española sobre educación científica de la última década. El estudio se concretó en las siguientes preguntas de investigación: (1) ¿Qué atención ha recibido la NDC en artículos de investigación e innovación, publicados en revistas españolas de Educación durante el periodo 2010-2019? (2) ¿Qué tipos de trabajos sobre enseñanza de la NDC se abordan en esos artículos? (3) ¿Qué etapas educativas y población (estudiantes y profesorado) son objeto de estudio, en relación con la enseñanza de la NDC? (4) ¿Qué aspectos de NDC son abordados en su enseñanza? (5) ¿Qué contextos o escenarios son empleados en la enseñanza de la NDC? La población seleccionada para el estudio fue el conjunto de 230 revistas españolas de Educación, indexadas en 'Dialnet Métricas' (2018). La revisión sistemática se hizo aplicando los procedimientos estándares de la declaración PRISMA y métodos de análisis cualitativo de contenido. La muestra final analizada estuvo conformada por 88 artículos, publicados en 17 revistas diferentes. Los resultados indican que la NDC ha sido infra-atendida en la educación científica española, en general, y especialmente en Educación Primaria, pese a que su comprensión forma parte de la competencia científica en las pruebas PISA. Se concluye que la enseñanza de la NDC es aún bastante incipiente en la educación científica del país, y que existe una brecha significativa entre investigación y práctica al respecto. Se finaliza con algunas recomendaciones para promover y mejorar la enseñanza de la NDC desde los niveles educativos básicos.

Palabras clave: alfabetización científica, aspectos epistémicos y no-epistémicos, educación científica, naturaleza de la ciencia, PRISMA, revisión sistemática

Introduction

Understanding the nature of science (NOS) is considered to be a fundamental pillar of citizens' scientific literacy (Lederman, 2007; McComas, 2020). Shamos (1995) stresses the importance of learning about NOS, arguing that when people assess public affairs that are related to science they tend to turn to their personal knowledge about science, regardless of how adequate that knowledge is. This perspective has become especially relevant in the present situation, given the information overload in the media, on social networks, etc. as the primary sources of scientific information for most citizens (Höttecke & Allchin, 2020). One can say, therefore, that there are utilitarian, democratic, cultural, axiological, and educational reasons to justify the integration of basic NOS knowledge into the school science curriculum (Driver, Leach, Millar & Scott, 1996).

All of this points to the need to promote basic NOS knowledge starting at the early levels of education (Akerson et al., 2011). There are two principal reasons for this. One is that it is convenient to start developing basic scientific literacy from an early age, and the other is that various studies have demonstrated the viability of learning about basic aspects of NOS in Primary Education (Akerson & Donnelly, 2010; Cakici & Bayir, 2012).

Aware of the need to achieve a scientifically literate society, some framework programs of innovation and research, such as the European Horizon 2020 project,[1] have as an objective the promotion in citizens of the desire to take an interest in science and to interact actively, critically, and responsibly with the different agents and institutions fostering scientific-technological development. These interactions will no doubt occur with better judgement and responsibility if there is a good understanding of NOS (Laherto et al., 2018). The importance of this is recognized explicitly in the PISA tests (OECD, 2019). These include the understanding of basic NOS notions in their evaluation of scientific competence – in this case, under the label of epistemic knowledge. The justification given in the theoretical framework of the PISA program about the evaluation of scientific competence (OECD, 2019) is: "*… understanding science as a practice also requires "epistemic knowledge", which refers to an*

(1) Available at https://ec.europa.eu/programmes/horizon2020/en/h2020-section/science-and-society

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understanding of the role of specific constructs and defining features essential to the process of building scientific knowledge" (p. 100).

But what is the situation of teaching NOS in Spain? In the literature of educational research published in this country during the last decade, there are some reviews of the state of NOS in science education (Acevedo & García-Carmona, 2016; García-Carmona, Vázquez & Manassero, 2012; Marín, Benarroch & Niaz, 2013). Nonetheless, apart from not being in the form of systematic reviews, these studies were approached from an international perspective. They therefore shed no light on the particularities that might be characterizing the status of NOS in the science education carried out in this country. Consequently, it was decided to carry out a systematic review of the most recent decade's Spanish bibliographic production with regard to the teaching of NOS. The research questions that guided the study were the following:

(1) What attention has NOS received in research and innovation articles published in Spanish Education journals during the period 2010-2019?
(2) What types of studies about the teaching of NOS are covered in these articles?
(3) What are the educational stages and (student and teacher) populations studied in regard to the teaching of NOS?
(4) What aspects of NOS are addressed in its teaching?
(5) What contexts or settings are used in teaching NOS?

The Nature of Science in Science Education

What to teach about the nature of science

The NOS can be defined as a class of *meta-knowledge about science* (i.e., what science is, how it originates and develops, what its limits are, etc.) which arises from the interdisciplinary reflections made as part of the philosophy, history, and sociology of science (Acevedo & García-Carmona, 2016). But what to teach about NOS? The answer is not simple when it comes to bringing such wide and multifaceted meta-knowledge into the classroom. It is necessary on the one hand to select those aspects of NOS that may be more interesting, representative, and/or viable for scientific

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literacy at each educational level, and, on the other, to determine the degree of approximation or depth with which to address those aspects at each of those levels. Consequently, one is faced with a complex issue which is still heatedly debated within the international science education community (Acevedo & García-Carmona, 2016; Wallace, 2017).

One of the proposals for school content about NOS which has been predominant on the international scene during the last decade is that of Lederman (2007). Its focus is fundamentally on the understanding of *epistemic aspects of science*, i.e., cognitive or rational aspects of the construction and establishment of scientific knowledge (differences between law and theory in science, differences between observation and inference, that observations are theory-laden, that scientific knowledge is tentative but durable, subjectivity in science, science's methodological diversity, etc.). Thus, the contextual, social, and psychological aspects related to science and scientists (i.e., *non-epistemic aspects of science*) receive minimal or secondary attention. Indeed, Lederman only refers to them in a sparse and very generic way, alluding to the fact that the construction of scientific knowledge is influenced by cultural and social contexts.

Nonetheless, the history, philosophy, and sociology of science reveal the influence of multiple non-epistemic aspects on its development (Acevedo, García-Carmona & Aragón, 2017; García-Carmona, 2021a). Therefore, in order to achieve a basic and holistic teaching of NOS, the understanding of these aspects should receive similar attention to that given to those of an epistemic nature. This perspective is gaining momentum in the international field of science education. For example, Irzik and Nola (2014) propose that the understanding of NOS should include the *social and institutional dimension of science*, i.e., professional activities, certification and dissemination of scientific knowledge, scientific conduct, social values, etc. Dagher and Erduran (2016) suggest adding social organizations and interactions, public power structures, and science funding to this dimension. Martins (2015) argues that teaching about NOS should have an historical and sociological axis which integrates the role of scientists and the scientific community, intersubjectivity, scientific communication, and moral, ethical, and political issues of science, as well as the social and historical influences. García-Carmona and Acevedo (2018) propose a holistic form of NOS teaching that attends to both epistemic and non-epistemic aspects of science in a balanced way, viz.:

- *Epistemic aspects of NOS:* (*i*) nature of the processes of science (influence of scientists' beliefs and abilities on their research, observation vs inference, the roles of models and modeling, of questions and hypotheses, and of error, the relationships between research designs and empirical results, methodological diversity in scientific research, etc.); and (*ii*) nature of scientific knowledge (differences between scientific laws and theories, provisional nature of scientific knowledge, etc.).
- *Non-epistemic aspects of NOS:* (*i*) internal factors of the scientific community (role of scientific communication, personality of the scientists, gender in science, scientific collaboration and competitiveness, professional relationships among scientists, etc.); and (*ii*) factors external to the scientific community (political, economic, and cultural influences on science and vice versa, science and religion, the role of the media in the dissemination of science, etc.).

How to teach about the nature of science

There is a broad consensus deriving from empirical research results that the best way to learn about NOS is through a didactic approach that is explicit and reflective (Clough, 2018; Lederman, 2007). This means that NOS should be conceived of as (García-Carmona, 2021b): (*i*) a specific part of curricular content with its own learning objectives, whose implementation in the classroom requires (*ii*) the design of activities that encourage the students to reflect on and discuss aspects of NOS, as well as (*iii*) an appropriate evaluation process to determine the degree of understanding the students have reached, to detect their learning difficulties, and to decide on the feedback necessary to help them improve their understanding.

The teaching of NOS can be planned in an integrated manner with other school science content, as decontextualized from that other content, or through a combination of the two strategies (Acevedo & García-Carmona, 2016). Some studies indicate that the students' understanding of NOS is independent of whether or not it is integrated with other science curriculum content (Khishfe & Lederman, 2007). Nonetheless, the integration of NOS with the other content may have the advantage

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that it would require hardly any alteration of the programmed science class plan (Bell, Mulvey & Maeng, 2012).

In addition to the above, it is recommendable to select specific contexts or scenarios that help the students recognize, reflect on, and discuss certain aspects of NOS so as to improve their understanding of them. According to the international bibliography (Acevedo & García-Carmona, 2016; García-Carmona et al., 2012), the three commonest contexts used to foster the understanding of NOS are:

(i) *Learning about aspects of NOS within school science inquiries* (adaptation of the experimental procedure to the inquiry question; influence of the procedure chosen on the results obtained; difference between what is observed and what is inferred; effect of the instruments used to take the data; difference between data and evidence; etc.).
(ii) *Learning about aspects of NOS through the analysis of contemporary scientific and socio-scientific issues* (reliability indicators, internal and external sociology of science, etc.).
(iii) *Learning about aspects of NOS through the analysis of passages from the history of science* (development of scientific theories, science-society relationships in each historical period, etc.).

Methods

According to Ferreira, Urrutia and Alonso-Coello (2011), a systematic review is a scientific research study in which the unit of analysis is the set of original primary studies which are selected by means of an explicit methodical process to respond to a research question. Consequently, in order to limit bias and random error, the present systematic review was designed in accordance with the following three general premises (Ferreira et al., 2011, p. 689):

- The systematic and exhaustive search for all potentially relevant articles.
- The selection, using explicit and reproducible criteria, of the articles to finally include in the review.

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- The description of the design and execution of the original studies, the synthesis of the data obtained, and the interpretation of the results.

The systematic process followed in the selection of the articles to be analysed was based on the guidelines of the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) statement (Moher, Liberati, Tetzlaff & Altman, 2009) as follows:

- *Identification*:
  - Publication period: 2010-2019 (both inclusive).
  - Search period: last quarter of 2019.
  - Journal population:
    - The base is the set of Spanish journals on Education, indexed in the Dialnet database, and with an accumulated impact factor in 'Dialnet Métricas' (2018)[2]: 229 journals.
    - Added as an exception is the journal *Ápice, Revista de Educación Científica*, specific to the didactics of experimental sciences, which, although it is indexed in Dialnet, still does not have an accumulated impact factor in 'Dialnet Métricas' because of its recent creation (2017). Thus, the final population under analysis comprised 230 journals.
- *Screening*:
  - Journals with specific didactics other than the didactics of experimental sciences, such as Physical Education, Language Didactics, Mathematics Didactics, Music Education, Educational Theory, Educational Orientation, etc. were discarded directly.
  - Articles with fewer than eight pages were discarded (ANECA, 2017), as also were editorials or monograph presentations.
- *Suitability*:
  - Articles about research and innovation, and essays of opinion and rationale, etc., that referred to NOS in the title, abstract, and/or keywords were selected.
  - It was also checked that the said allusions were not merely anecdotal.
  - To determine allusions to NOS topics, common terms in the bibliography were taken into account, such as: epistemic beliefs

(2) https://dialnet.unirioja.es/metricas/ambito/1/edicion/2018

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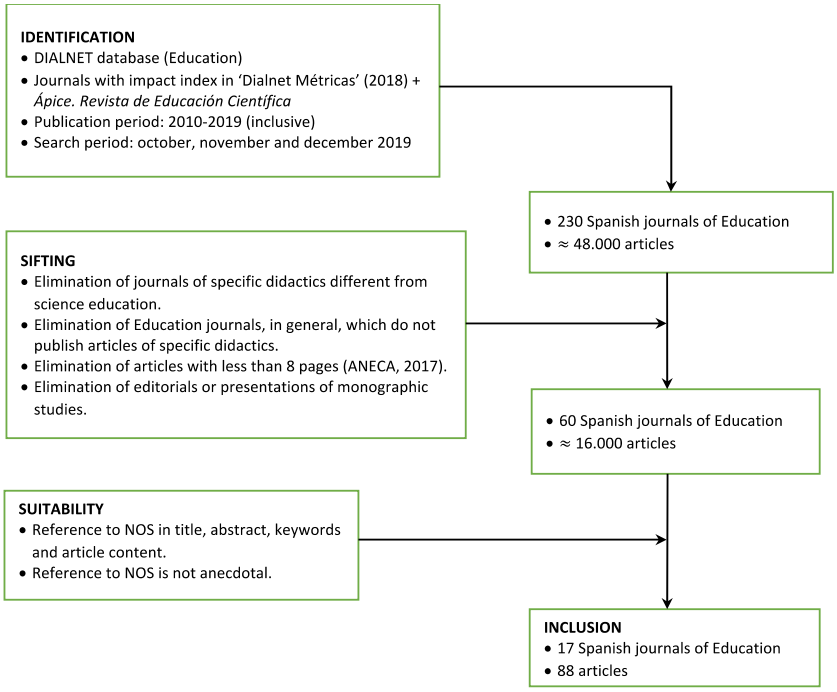
or conceptions, epistemology of science, nature of scientific activities, nature of science, nature of scientific knowledge, conceptions or ideas about science, image or views of science, history of science, sociology of science, science-technology-society relationships, etc.

- Since some of the journals reviewed also publish articles in English, Portuguese, Galician, or Catalan, the search for such terms was done in the corresponding language.

- *Inclusion*: 17 Spanish journals of Education and a total of 88 articles.

The application of these selection criteria is summarized in the flow chart of figure I.

FIGURE I. Flow chart of the process followed for the selection of articles.



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Content analysis of the articles

The content of the articles was analysed from a descriptive perspective, following the standard procedures for qualitative content analysis (Mayring, 2000). For this, an analysis protocol with different dimensions was used (table I), with its initial design taking into account the described theoretical framework and the research questions formulated. The analysis protocol was conceived of as a dynamic instrument (open and flexible), which was then refined throughout the course of the analysis in order to obtain the best possible responses to the said questions (Cáceres, 2003).

For the reliability of the study, the author analysed the sample in three successive phases, following customary procedures in intra-rater analyses (Padilla, 2002):

- *Phase I.* Approximately three months after preparing the first version of the protocol, a preliminary analysis of the sample of articles was made in which only the titles, abstracts, and keywords were examined. This made it possible to refine the initially designed protocol. For example, the initial version consisted of the following five dimensions: I. Types/purposes of the work; II. Educational stages; III. Study's object population; IV. Aspects of NOS addressed; V. Contexts used to teach NOS. After the preliminary analysis, it was decided to merge the "Educational stages" and the "Study's object population" into a single dimension (dimension II), as well as within this dimension to separate the studies about teacher training (dimension II.B) from the rest (dimension II.A).
- *Phase II.* A month later, the articles were re-analysed with the refined protocol, now including consultation of the Methods and Conclusions sections. Some further adjustments were made to the protocol. Basically, these consisted in making certain re-groupings and dis-aggregations in the types of studies, for example, integrating under a single indicator studies that analyse didactic materials (e.g., textbooks) and official curricular prescriptions, and separating from these the meta-analyses and literature reviews. In this phase, the definitive analysis protocol was obtained (table I) because, in the researcher's judgement, it already contained the appropriate dimensions and indicators needed to respond reasonably to the research problems that had been set (Bengtsson, 2016).

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- *Phase III.* Some two weeks later, the article sample was again re-analysed, applying the definitive version of the protocol. In order to estimate the intra-rater reliability, the percentage agreement between the data taken on the two occasions was calculated.[3] Of a total of 352 data, 94,3% agreement was achieved. The few discrepancies between the two consecutive analyses (5,7% of the data) were due in part to labeling mistakes in the coding. Hence, it was only necessary to make the pertinent corrections. In the other cases, differing classifications had been considered. These were therefore reviewed again until a decision could be made as to their definitive cataloguing in accordance with the final version of the analysis protocol.

TABLE I. Protocol for the content analysis of the sample of selected articles.

I. Types of studies	1. Design of didactic proposals for NOS teaching	A. Explicit reflective approach	a. Contextualized within other school science contents
			b. Non-contextualized
	2. Testing of didactic proposals for NOS teaching	B. Implicit approach	a. Contextualized within other school science contents
			b. Non-contextualized
	3. Analysis of curricula, resources, materials, programmes, reports, etc. focused on NOS teaching		
	4. Design and validation of instruments to assess conceptions about NOS		
	5. Analysis of conceptions about NOS		
	6. Meta-analysis, literature reviews, etc. about NOS teaching		
	7. Essays of opinion, reflection and theoretical position, etc. about NOS teaching		

(3) It was not considered necessary to calculate a kappa index because, since this is an intra-rater type of analysis, the requirement that would justify the use of such a statistic (i.e., the possibility that agreements were due to chance) did not apply as would instead have been the case for an inter-rater analysis.

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II. Educational stages/ Study's object population	A) Student education:	B) Teacher education	
	1. Primary Education (6-12 years)	1. Primary Education	
	2. Lower Secondary Education (12-16 years)	2. Secondary Education	
	3. Upper Secondary Education (16-18 years)	3. University	
	4. University	4. Mixed	
	5. Mixed, longitudinal		
III. Aspects of NOS addressed	1. Epistemic		
	2. Non-epistemic		
	3. Both types		
IV. Contexts/ settings for NOS teaching	1. History of science 2. Contemporary scientific and socioscientific issues		
	3. School scientific inquiry		
	4. Others (mixes of the above types, non-specific, science fiction, etc.)		

Results

Attention paid to the nature of science in Spanish journals of Education: a first overview

It was found that 17 Spanish journals of Education (7,6% of the 230 journals considered) had published some article about NOS during the period 2010-2019 (table II). The total number of articles on the subject was 88, which constitutes just a tiny 1,4% of the total of the articles (6242) published by the said journals during that period. One also observes in the table that most of these articles (72 of the 88 articles) were published in journals specific to the didactics of experimental sciences (i.e., REEDC, REEC, EC, ALB, APICE, and DCES). Nonetheless, these only account for 4,4% of the total articles on science education that were published in those journals, with REEC having the greatest proportion of articles dedicated to NOS (6,9%).

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TABLE II. Number and proportion of articles about NOS published in Spanish journals of Education during the period 2010-2019.

Journals	No. of articles published in the period 2010-2019	No. of articles focused on nature of science (%)
Revista Eureka sobre Enseñanza y Divulgación de las Ciencias (REEDC)	418	23 (5,5%)
Revista Electrónica de Enseñanza de las Ciencias (REEC)	276	19 (6,9%)
Enseñanza de las Ciencias (EC)	354	17 (4,8%)
Alambique: Didáctica de las Ciencias Experimentales (ALB)	426	9 (2,1%)
Revista Iberoamericana de Educación (RIE)	1133	4 (0,4%)
Ápice. Revista de Educación Científica (APICE)	34	2 (5,9%)
Didáctica de las Ciencias Experimentales y Sociales (DCES)	139	2 (1,4%)
Profesorado. Revista de Curriculum y Formación de Profesorado (PROF)	788	2 (0,3%)
Revista de Educación (REDU)	603	2 (0,3%)
Qurriculum. Revista de Teoría, Investigación y Práctica Educativa (QURR)	90	1 (1,1%)
Campo Abierto. Revista de Educación (CAB)	171	1 (0,6%)
Journal for Educators, Teachers and Trainers (JETT)	233	1 (0,5%)
Educar (ED)	207	1 (0,5%)
Revista Española de Pedagogía (REP)	265	1 (0,4%)
Educatio Siglo XXI (EDUSGXXI)	345	1 (0,3%)
Educación XX1 (EDUXX1)	300	1 (0,3%)
Revista Electrónica Interuniversitaria de Formación del Profesorado (REIFP)	460	1 (0,2%)
Total	6242	88 (1,4%)

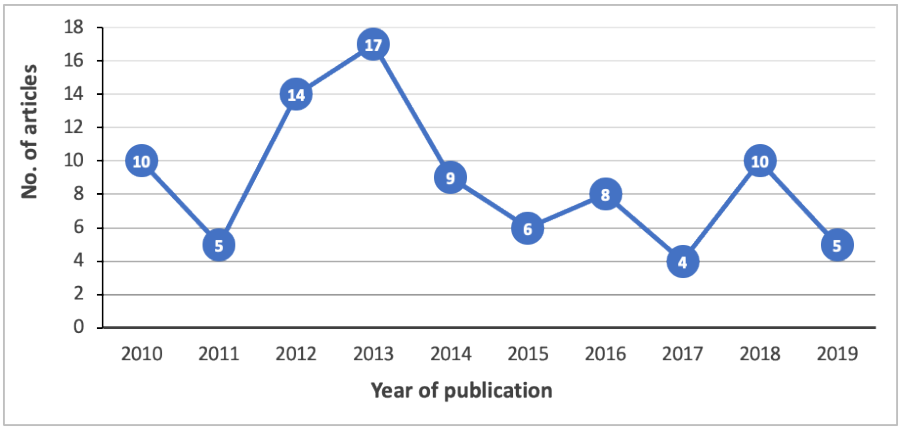
Graphic I shows the distribution of NOS articles by year of publication within the period considered. Except for 2012 and 2013 when 14 and 17 articles were published respectively, in the rest of the years the number of such articles did not exceed 10. In general, this is an ostensibly low

quantity if one takes into account that in the years 2011, 2017, and 2019, for example, no more than a single article was published in any of the journals specifically dedicated to the didactics of experimental science.

In regard to authorship, 55,2% of the NOS articles were written by authors affiliated with a Spanish centre or institution, 11,5% corresponded to foreign authors (Brazil, Argentina, Colombia, Mexico, Chile, USA, etc.), and 33,3% had mixed authorship, i.e., Spanish and foreign authors conjointly. With respect to this last group of articles, seven (8% of the total sample) referred to or focused on the Spanish educational context. Consequently, only 62,2% of the NOS articles published in Spain were framed within the contextual reality of science education in that country.

As additional data of this overview of the analysis, it can be observed that the most prolific authors on the subject during the period analysed were, in descending order, Ángel Vázquez (22 articles), María A. Manassero (18 articles), Antonio García-Carmona (9 articles), and José Antonio Acevedo-Díaz (4 articles). Also, 85,1% of the articles were written in Spanish, and the rest (14,9%) in Portuguese.

GRAPHIC I. Evolution of the production of articles about NOS in Spanish journals during the last decade (2010-2019).



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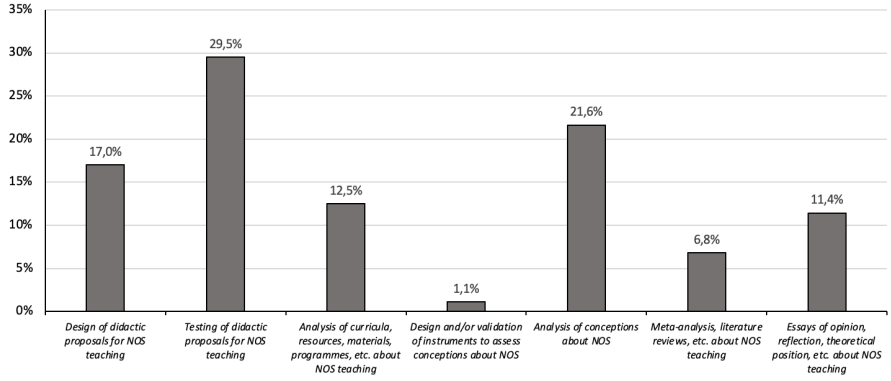
Types of studies about teaching the nature of science

The variety of studies about teaching NOS is represented in graphic II. No type reaches a third of the sample of articles. The most abundant is that referring to experimentation with didactic proposals about NOS (29,5%). This is followed by diagnostic analyses of ideas about NOS (21,6%), then, at a certain distance, by studies about the design of didactic proposals for teaching NOS (17%), analysis of related curricula, materials, and resources (12,5%), and opinion, reflection, and/or theoretical position essays in regard to NOS (11,4%). There were far fewer literature reviews and meta-analyses (6,8%), and the presence of works concerning the design and validation of instruments to evaluate ideas about NOS was almost insignificant (1,1%).

GRAPHIC II. Types of studies about teaching NOS in the sample of articles analysed.



Studies that diagnose the conceptions that Spanish students and science teachers have about NOS (n=19; 21,6%) revealed that those ideas are generally poorly informed. The commonest instruments used to analyse these conceptions were Likert-type or closed multiple-choice response questionnaires (13 of the 19 articles), followed at a distance by the interview method (3 of the 19 articles), open-response questionnaires (both textual and pictorial) (3 of the 19 articles), and analyses of spoken and written discourse (2 of the 19 articles). Of all these, the most

popular and robust instrument in terms of passing validity and reliability tests on an Ibero-American scale was the Questionnaire on Opinions about Science, Technology, and Society (COCTS in its Spanish language acronym) (Vázquez, García-Carmona, Manassero & Bennàssar, 2013).

With regard to the studies of design proposals to teach NOS and of experimentation with them in the classroom (graphic III), it was found that, in both types, there predominated explicit and reflective approaches. Nonetheless, there were certain differences in the way of integrating NOS into the school science curriculum. While the studies that were limited to design didactic proposals to teach NOS mostly introduced NOS in a contextualized way together with the rest of the school science curriculum content (10 of the 15 articles), those on testing in the classroom of didactic proposals about NOS took both contextualized and decontextualized approaches in the same proportion (13 articles in both cases).

With regard to the studies about experimentation with didactic proposals to teach NOS in the classroom (29,5%), it has to be noted that they all can be framed in what is known as design-based research (Guisasola & Oliva, 2020). This is in general characterized by the implementation and assessment of the didactic design of some specific curricular content in a particular educational context (and, therefore, on a small scale), with a view to making proposals to improve future teaching actions in such contexts. Within this framework of education research, most of the studies used mixed analytical methods, i.e., combining quantitative and qualitative techniques through processes of action research, quasi-experimental methods, case studies, etc.

With regard to the studies that analysed the attention to and treatment of NOS in didactic resources (textbooks, scientific news from the press, advertising, etc.) and curricular prescriptions (12,5%), it was found that, in general, NOS was addressed in quite limited and inappropriate ways in many respects. This was either because conceptual errors are introduced (e.g., existence of an algorithmic and universal scientific method in scientific research, distorted image of professional scientific activity and, in general, of the development of science), or due to important omissions of aspects of NOS, both epistemic (e.g., the role of error in the development of science) and non-epistemic (e.g., the sociological dimension of science is not alluded to) in their didactic treatment or curricular suggestion.

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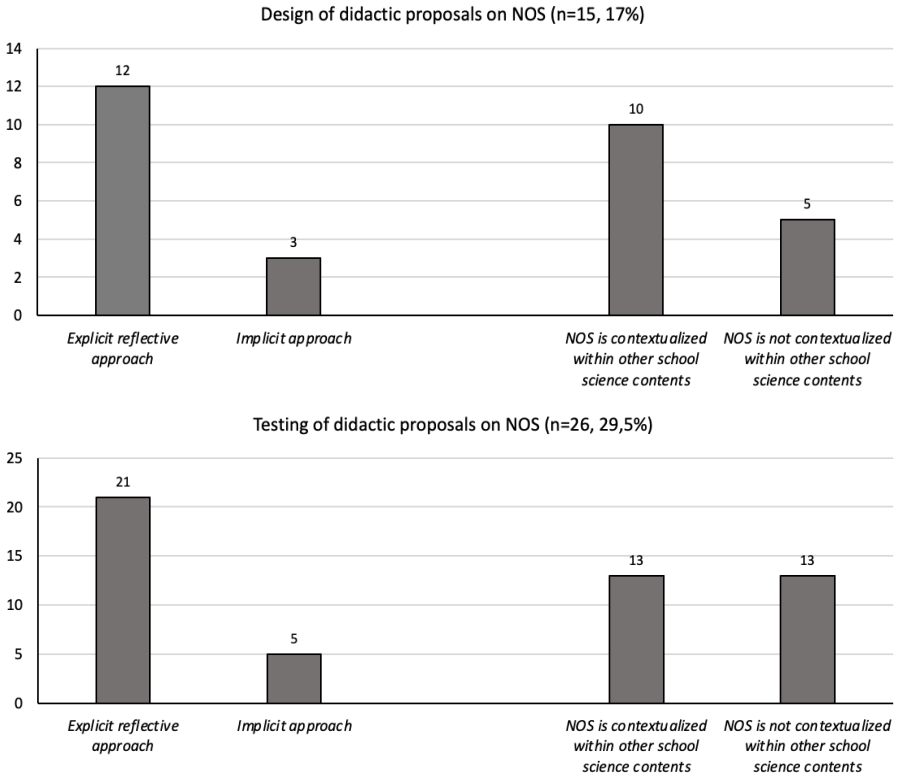
Finally, the meta-analyses and bibliographic reviews about understanding and teaching NOS (6,8%) focused, above all, on Spanish students' results on the PISA tests in relation to epistemic knowledge, and the determination of international consensuses on what to teach about NOS. Works of opinion, reflection, and theoretical positions related to teaching NOS (11,4%) are more varied, although there predominate those that promote, among other issues, explicit attention to both epistemic and non-epistemic aspects of NOS from a didactic perspective based on reflection.

GRAPHIC III. Approaches to teaching NOS and ways of integrating it into the curriculum in works on the design of didactic proposals and experimentation in the classroom.



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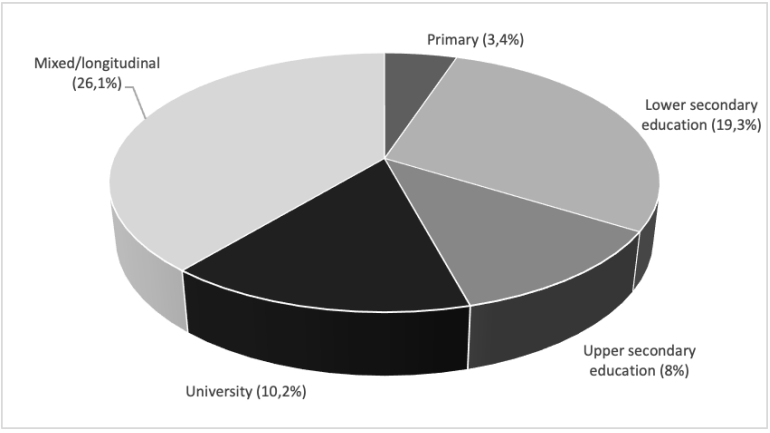
Educational stages and the study's object population in articles about teaching the nature of science

Considering studies focused specifically on the students and/or on resources and programs targeted at them (67,1%), and therefore excluding those on teacher training, the educational stage that received most attention was Lower Secondary (19,3%), and the least was Primary (3,4%). Nonetheless, the most abundant studies were those of a mixed or longitudinal nature (26,1%), i.e., studies that address more than one consecutive educational stage (e.g., Primary and Lower Secondary, or Lower and Upper Secondary). The distribution is presented in graphic IV.

GRAPHIC IV. Distribution of the articles with a focus on the students, according to the different educational stages.



When attention is centred on studies of experimentation with didactic proposals of NOS with students, the results in general show that:

- Classroom experiences that involve learning about NOS implicitly, i.e., without proposing activities specifically designed for the students to reflect on specific aspects of the topic, usually identify "learning about NOS" with participating in certain school-level scientific practices.

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- Students' direct interaction with science professionals encourages them to acquire a more realistic image of scientific activity.
- Reflective participation in school science inquiries helps students to become aware of the role of creativity in science, to understand the provisional nature of scientific knowledge, and in general to acquire a more realistic conception of science.
- The reflective and critical reading of passages from the history of science favours the students' understanding of aspects of NOS that are both epistemic (e.g., the provisional nature of scientific knowledge) and non-epistemic (sociological, contextual, etc.).
- In general, the implementation of activities about NOS with an explicit and reflective approach improves the students' understanding.

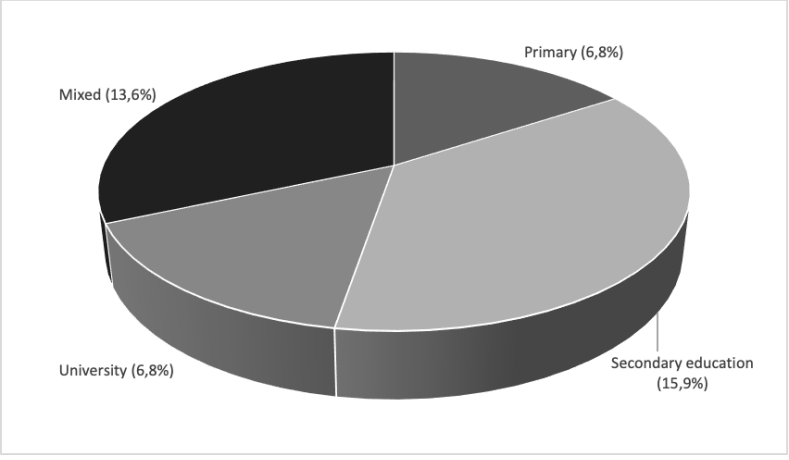
In regard to teacher training about NOS and its didactics (27,3%) (graphic V), the review carried out reveals that the group most studied is that of prospective Secondary Education science teachers (15,9%), and that those of Primary Education and University level are the least studied (both 6,8%). There are also mixed studies which include prospective teachers of different stages (13,6%). The following is a synthesis of the conclusions of the experimental studies about NOS with prospective science teachers:

- The use of the history of science helps prospective teachers to become aware of various aspects of NOS, such as the importance of women in science, or that, during the development of science, setbacks sometimes occur.
- When prospective teachers reflect on certain aspects of the nature of scientific activity (e.g., error and conflicts of interest), their understanding of it improves, as does their competence to educate citizens with criteria and capacities for decision.
- Meta-scientific reflection through cinema in the training of science teachers is a good resource with which to improve their understanding of NOS and how to teach it.
- An improved understanding of NOS in teachers broadens their pedagogical content knowledge to teach science.
- The iterative elaboration of concept maps, the result of reflection and discussion, favours the prospective science teachers' more

adequate conception of the process of the construction of scientific knowledge.

- The use in science teaching of analogies based on scientific modeling encourages prospective teachers to understand the nature of scientific models.
- In general, the implementation of activities about NOS with an explicit and reflective approach during the training of prospective science teachers improves their understanding of NOS and its didactics.

GRAPHIC V. Distribution of articles according to the group of science teachers whom they address.



Aspects of the nature of science addressed and the contexts used to teach it

Slightly more than half of the articles reviewed (51,1%) only addressed epistemic aspects of NOS (i.e., rational or cognitive aspects linked to the construction of science), while those that dealt exclusively with non-epistemic aspects constituted a meagre 4,5% (graphic VI). Likewise, a considerable portion of the studies (43,2%) dealt with both aspects,

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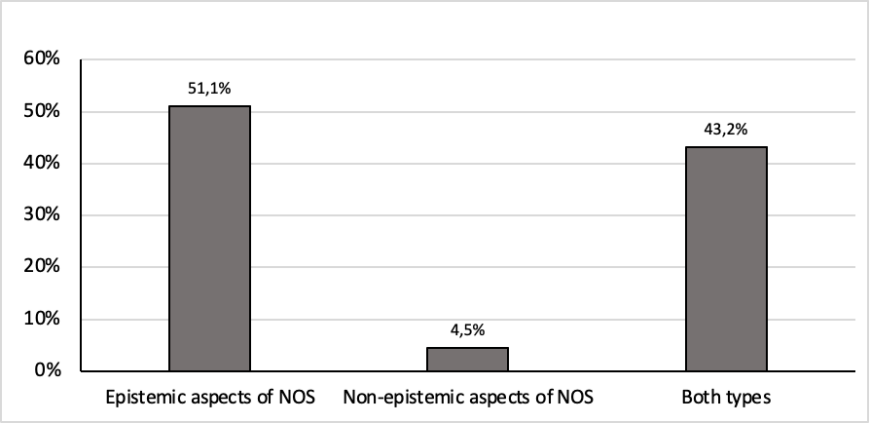
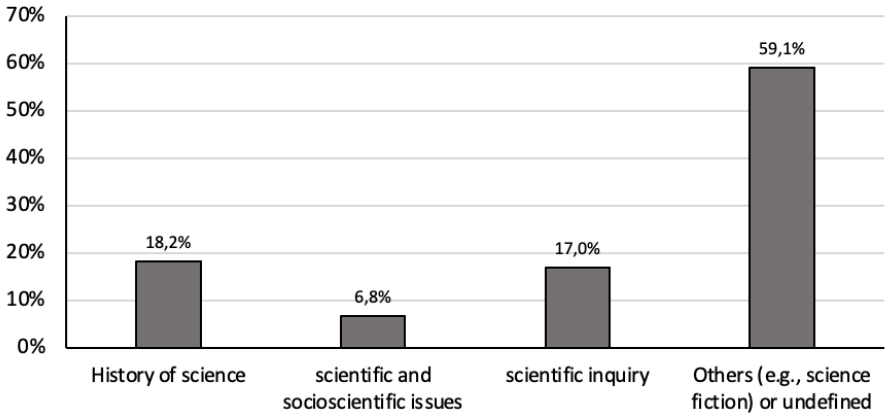
although the vast majority of these did so with a rather imbalanced proportion in favour of those of an epistemic type.

GRAPHIC VI. Aspects of NOS addressed in the articles.



In analysing the contexts/scenarios used to teach NOS (graphic VII), it was found that 18,2% of the sample did so by using passages from the history of science, 17% addressed it as part of school science inquiries, and 6,8% through the analysis of contemporary scientific and socio-scientific issues. Nonetheless, the most striking thing was that most of the studies (59,1%) either used no specific context or some other contexts different from the foregoing and which are less common in the international literature about NOS and its didactics (e.g., science fiction, science in films, etc.).

GRAPHIC VII. Contexts/scenarios used to teach about NOS in the sample of articles analysed.



Discussion

This study reveals that NOS has been under-addressed in the Spanish literature on science education during the last decade (2010-2019). Even in the journals specialized in science education (6 of the 17 journals analysed), the studies about NOS constituted just a discrete 4,4% of the publications during that period. Likewise, a little more than a third of the sample analysed presented studies about the subject that did not emanate from (or were specifically oriented to) the Spanish educational context. Therefore, one can say that NOS is a part of school science content with very low impact in the science teaching promulgated in this country. This is especially striking if one takes into account that the PISA program (OECD, 2019), in which Spain has participated since its beginning, includes NOS content in the evaluation of scientific competence. Among other causes, this situation may be due to the fact that NOS is content that has been dealt with poorly in the official prescriptions for science teaching in Spain (Acevedo et al., 2017), especially in comparison with science curricula in other countries such as Australia, Canada, South Africa, Thailand, and the USA (Lederman, 2007; Olson, 2018).

It is also noteworthy that only slightly less than 30% of the articles presented studies of the effectiveness in the classroom of educational

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proposals for learning aspects of NOS. This is a clear indication that this content has little impact in Spanish science classrooms. Likewise, it highlights the continuing sparsity of knowledge about how the subject is being taught in the educational framework of this country. Together with the curricular perspective mentioned above, another reason for the situation may be the limited training science teachers get in regard to NOS and its didactics (Lederman, 2007; Vázquez et al., 2013). This was confirmed in the studies in the sample that analysed the conceptions of Spanish science teachers. This has two consequences that were also confirmed in this systematic review: (*i*) the introduction of NOS in Spanish science textbooks (prepared by science teachers) is in general quite deficient, and (*ii*) students show that they have poorly informed ideas about science.

Even so, it stands out that the few actual classroom studies, both with students and with prospective science teachers, that were proposed with an explicit and reflective didactic approach (Clough, 2018) showed mostly positive learning results. This fact is on the contrary not clearly verifiable in those studies which promoted NOS via an implicit approach, thus coinciding with the conclusions reached in this regard in the international literature (Lederman, 2007). Additionally, most classroom studies integrate NOS with other content of the science curriculum, which may favour its fitting into science curriculum programs (Bell et al., 2012) that in general are already quite overloaded. Nonetheless, in the studies limited to the design of didactic proposals about NOS, there stand out those that propose its introduction in the classroom in a way that is decontextualized from the rest of the curricular content.

Also noteworthy is that Lower Secondary Education was the stage that has received most attention in the studies about NOS, and Primary Education the least. A similar result in terms of proportion was obtained in relation to studies referring to the training of prospective science teachers on the topic. Science education in Spain thus does not seem to be in line with the suggestions emerging from the international literature that the basic notions of NOS need to begin to be presented at early ages (Akerson et al., 2011). Furthermore, this may in part explain why few Spanish students achieve high levels of epistemic knowledge in the PISA assessment tests (Ministry of Education, 2019).

Another fact found in this review was that slightly more than half of the studies addressed only epistemic aspects of NOS. Even those which

also dealt with non-epistemic aspects gave the latter much lower weight in quantity and depth. This reflects the great influence that Lederman's (2007) proposal still has on what to teach about NOS, despite the fact that, in recent years, other alternative approaches that advocate giving greater weight to non-epistemic aspects have been gaining in relevance (Acevedo et al., 2017; Dagher and Erduran, 2016).

It is also noteworthy that, unlike what had been found in the literature about the contexts and scenarios with which to teach NOS (Acevedo and García-Carmona, 2016), in Spain most of the studies made no resort to the history of science, school-level inquiries, or contemporary scientific or socio-scientific issues for learning about NOS. Among the few studies that did use one or more of these contexts, the most frequently used were, in this order, the history of science and participation in scientific inquiries.

Limitations and Implications

The overview that this study has offered of the current situation of NOS teaching in Spain has, of course, its limitations. The first has to do with the fact that the review was limited to works published in Spanish journals, ignoring articles by Spanish authors in foreign journals that also analyse teaching processes about NOS in this country. The second refers to the fact that any relationship found between what is published and what actually happens in Spanish science education with respect to NOS must be accepted with caution. Indeed, it is likely that there are science teachers who teach their students basic NOS notions but do not publish the results of their experience. Similarly, there may be science teachers who carry out specific work about the didactics of NOS when this is not part of their regular teaching practice.

Even with these limitations, the present study provides extensive and detailed information that may, to a large extent, be representative of the current state of the issue of teaching NOS in Spain. This shows, firstly, that the subject is still in a fairly incipient stage in science education in this country, and, secondly, that there is a significant gap between what is derived from international education research with respect to teaching NOS and what is (*i*) prescribed from this in school science curricula, (*ii*) developed in science textbooks, and (*iii*) actually done

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in classrooms. Narrowing this gap and fostering this content in Spanish science education would therefore require the following objectives to be addressed as priorities:

- Renewing the prescriptions of school science curricula in their treatment of NOS in terms of both explicitness and quantity, with educational propositions that balance the epistemic with the non-epistemic factors of science, that make use of the history of science, etc.
- Including NOS content in official evaluation tests such as those that some of Spain's Autonomous Communities set at the end of the Primary stage or during Lower Secondary Education, as well as the tests for access to University since, in general, what is not evaluated is not taught.
- Improving, in accordance with the results of education research, the treatment of NOS content in teaching materials, especially in textbooks since these continue to be the most used resource in Spanish classrooms.
- Giving greater importance to NOS in the teacher training plans for science teaching at the different levels of education.

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Contact address: Antonio García-Carmona. Universidad de Sevilla, Facultad de Ciencias de la Educación, Departamento de Didáctica de las Ciencias Experimentales y Sociales. C/ Pirotecnia, S/N. 41013. Sevilla. E-mail: garcia-carmona@us.es

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