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Theoretical-Methodological Perspectives of the Debate about Nature of Science in Science Education: Contrasts and Approximations between the Consensus View and Renewed Tendencies

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ABSTRACT

Background: in science education, teachers and researchers are concerned with a teaching practice that enables an understanding of the nature of science and the principles of scientific research that considers aspects such as the purpose of scientific work, the nature of scientific knowledge, and the idea that science is a social enterprise, valuing the perception of science as human activity, permeated and conditioned by ethical, economic, political, and cultural values. Some proposals represent advances to the contributions to these discussions, which are taken as reference in science classes. **Objectives**: in this work, we identify and systematise contrasts and approximations between classical theoretical-methodological perspectives and renewed tendencies for the nature of science in science education. **Design**: the research developed was of a qualitative documentation analysis type. **Setting and Participants:** given the type of research, they were considered relevant publications on the nature of science in science education. **Data collection and analysis:** five texts considered nature-of-science theoretical-methodological references were researched. The analysis was carried out based on the criticisms and opinions of authors looking for alternatives to their teaching. **Results**: part of the theoretical-methodological perspectives that have been renewed may not be able to overcome some of the criticisms on the classic view in the debate about the nature of science in science education. **Conclusions:** deeper and more reflective discussions about the nature of science in teacher education can contribute to the production of more effective actions to improve teachers' and students' understanding.

Keywords: Nature of science; Science education; Science teacher education; Views of the nature of science; Scientific knowledge.

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Perspectivas Teórico-Metodológicas do Debate sobre a Natureza da Ciência na Educação em Ciências: Contrastes e Aproximações entre a Visão Consensual e as Tendências Renovadas

RESUMO

Contexto: no ensino das ciências, professores e investigadores preocupam-se com uma prática pedagógica que possibilite a compreensão da natureza da ciência e dos princípios da investigação científica que considere aspectos como a finalidade do trabalho científico, a natureza do conhecimento científico e a ideia de que a ciência é um empreendimento social, valorizando a percepção como atividade humana, permeada e condicionada por valores éticos, econômicos, políticos e culturais. Há propostas que representam avanços nas contribuições para essas discussões, as quais são tomadas como referência nas aulas de Ciências. **Objetivos:** neste trabalho, identificamos e sistematizamos contrastes e aproximações entre perspectivas teórico-metodológicas clássicas e tendências renovadas para a natureza da ciência no ensino de ciências. **Design:** a pesquisa desenvolvida foi de natureza qualitativa do tipo análise documental. **Cenário e participantes:** dado o tipo de pesquisa, foram consideradas publicações relevantes sobre natureza da ciência na área de ensino de ciências. **Coleta e análise de dados:** foram pesquisados cinco textos considerados referenciais teórico-metodológicos sobre a natureza da ciência e a análise foi realizada com base nas críticas e opiniões de autores que buscam alternativas ao seu ensino. **Resultados:** parte das diferentes perspectivas teórico-metodológicas renovadas podem não ser capazes de superar algumas das críticas à visão clássica no debate sobre a natureza da ciência no ensino de ciências. **Conclusões:** discutir natureza da ciência na formação de professores a partir de referenciais renovados pode contribuir para a produção de ações mais efetivas para melhorar a compreensão de professores e estudantes.

Palavras-chave: Natureza da ciência; Educação científica; Formação de professores de ciências; Visões sobre a natureza da ciência; Conhecimento científico.

INTRODUCTION

The debate about the nature of science in science education is not recent. Since the mid-twentieth century, teachers and researchers worldwide have expressed concern about students' conceptions and, more recently, about the conceptions of science teachers about the nature of scientific knowledge. Studies have pointed out the insertion of the subject in basic and higher education, intending to promote better conceptions and visions about scientific work and practice.

This concern arises, to a large extent, as a reflection of the understandings about shared sciences in classrooms, given the excessive emphasis on 'what is known' to the detriment of 'how it is known'. Generally, in their didactic practices, Science teachers are concerned with the context of epistemological justification, which prevails in relation to the context of historical discovery and elements that go beyond the content. This process hardly ever results in a science education that enables students to justify their ideas or produce explanations about sciences based on historical, philosophical, and epistemological context aspects. The justifications and explanations about sciences produced by students are often permeated by the authoritative discourses of textbooks and teachers. Thus, the students do not exhibit a functional understanding of scientific processes and practices, whether to explain, evaluate, or act on science (Forato, Pietrocola & Martins, 2011; Forato, Martins & Pietrocola, 2012).

In this sense, considering the importance and insertion of the debate on the nature of science in science education in schools as a legitimate concern, based on the perspectives of consensus or renewed visions on the subject, both in theoretical-normative studies and in empirical studies, some investigations have been developed aiming to highlight elements and offer training to science teachers to equip them for the debate about the nature of science in school education (Martins, 1999; Almeida & Farias, 2011; Forato, Pietrocola & Martins, 2011; Forato, Martins & Pietrocola, 2012; Rudge, Cassidy, Fulford & Howe, 2014; García-Carmona & Acevedo-Díaz, 2016, 2017, 2018).

Supported by the justifications mentioned above, a significant number of empirical studies about students' conceptions of the nature of science have been developed (Lederman & O'Malley, 1990; Lederman, 1992; Matthews, 1994; Abd-El-Khalick & Lederman, 2000a, 2000b; Moss, Abrams & Robb, 2001; Teixeira, El-Hani & Freire Jr., 2001; Köhnlein & Peduzzi, 2005; Moreira, Massoni & Ostermann, 2007; Teixeira, Freire Jr. & El-Hani, 2009; Michel & Neumann, 2016; Alpaslan, Yalvac & Loving, 2017; Leblebicioglu et al., 2017; Pena & Teixeira, 2017). These studies reveal there are inadequate understandings about the nature of scientific knowledge in science education (assuming there is an adequate understanding), characterised and described by elements such as a) commitment to an absolutist epistemological view, according to which a form of knowledge can be understood as definitive and absolutely true; b) an empirical-inductive view of science, according to which scientific knowledge is obtained by inductive generalisation from data observation devoid of any theoretical and/or subjective influence, which would ensure the true nature of scientific propositions; c) belief in the existence of a unique method that would be able to assure the absolute truth of scientific statements about the world; d) lack of recognition of the role of creativity and imagination in the production of scientific knowledge; e) lack of understanding of meta-theoretical concepts such as ‘fact’, ‘evidence’, ‘observation’, ‘experimentation’, ‘models’, ‘laws’ and ‘theories’, as well as their interrelationships.

Another set of empirical research has focused on science teachers (Abd-El-Khalick & Boujaoude, 1997; Akerson, Abd-El-Khalick & Lederman, 2000; Gil-Pérez, Montoro, Alis, Cachapuz & Praia, 2001; Abd-El-Khalick, 2013; Lederman, Antink & Bartos, 2014; Massoni & Moreira, 2014; Vital & Guerra, 2014; García-Carmona & Acevedo-Díaz, 2016, 2017; Herman & Clough, 2016; Herman, Clough & Olson, 2013a, 2013b, 2017; Wan, Zhang & Wei, 2018). These studies reveal the predominance of empirical-inductivist and absolutist epistemological conceptions of the nature of science, which vary in relation to factors such as cultural context, teaching experience, level of performance, and training. Therefore, the concern for understanding the nature of science was focused on the initial teacher training courses, their curricula, and practices, also aiming to develop implicit and explicit methodological proposals on the nature of the sciences.

Admittedly, it is possible to differentiate two levels of scientific understanding and reflection, each with different goals. One of the levels refers to the knowledge of the contents and methods of science, i.e., “knowledge of science” (Cutrera, 2004). This is teaching through the final products of science, aiming to increase knowledge about scientific successes (Adúriz-Bravo, Izquierdo & Estany, 2002). Another level refers to knowledge about how science is made, how scientists develop, use, and deliberate about scientific knowledge, i.e., “knowledge about science” (Cutrera, 2004). This is teaching about the processes that led to the construction of science and the strengthening of the scientific statute. According to this distinction, science curricula generally address only the first level of reflection, rarely addressing the second level. A science education that is not concerned with “teaching about science” ends up being distorted from reality by not presenting a characterisation that is minimally honest and that can correspond to how science is constructed, including its problems and controversies.

Collins, Osborne, Ratcliffe, Millar and Duschl (2001) recognise the lack of knowledge among science teachers about effective strategies for teaching science and point out that these teachers remain relatively ignorant of the history of science and science itself. For the authors, “science teachers, themselves the products of such an archetypal education, are invariably left with a range of misconceptions or naïve understandings of the nature of science” (Collins, Osborne, Ratcliffe, Millar & Duschl, 2001, p. 5).

Similarly, little is known about how one can effectively communicate about science (Collins, Osborne, Ratcliffe, Millar & Duschl, 2001). Authors of this line of thought tend to defend an explicit teaching of the nature of science, its epistemic basis, and the meaning of its cultural achievements and accomplishments (Duschl, 1990; Millar & Osborne, 1998; Collins, Osborne, Ratcliffe, Millar & Duschl, 2001). The explicit approaches are directly focused on epistemological contents or employ elements of history and philosophy of the sciences when talking about specific contents. Other methodological proposals refer to an implicit approach to the nature of science, which uses instructions on skills related to scientific practice or engagement in research activities to improve views on the nature of science.

Finally, we agree with the argument that, among the implications of the debate on the nature of science in science education, it is important to explain why science is considered an ideal of rationality (Collins, Osborne, Ratcliffe, Millar & Duschl, 2001), or there is a risk of forming students who do not perceive science as rational (Duschl, 1990).

Based on the argument about the importance associated with the subject of the nature of science for science education, in this article, we present descriptions, approximations, and contrasts between the consensus view and renewed tendencies to characterise a desirable and fruitful approach to be used in science teaching.

METHODOLOGY

To constitute the analysis developed in this study, we carried out a narrative-type review selecting articles that present discussions about the consensual and renewed views of the nature of science, traditionally referenced in scientific education research, and that serve as a theoretical and methodological framework for proposals for classroom applications, with widespread use also because they bring general principles for the nature of science. In addition, and very importantly, the articles selected within a renewed perspective should not share theoretical and methodological assumptions with the consensual view, called the classic perspective.

Finally, from these renewed perspectives on the nature of science, we analysed and criticised the classical perspective. These same criteria for selecting analytical material were used in another study developed by Rodríguez and Adúriz-Bravo (2017).

It is necessary to emphasise that we do not intend in this article to be exhaustive in our review and analysis, rather, our aim is to illustrate the approximations and contrasts of different theoretical and methodological perspectives, to characterise a desirable and fruitful approach to be used in science teaching. To that end, our review includes approaches that consider the importance and implications of the debate on the nature of science for science education.

To do so, we first describe what is called the consensus view on the nature of scientific knowledge and some of the criticisms pointed to this aspect. After that, we present renewed perspectives around this debate, among which are: *Features of Science* (Matthews, 2012), *Nature of Whole Science* (Allchin, 2011), *Family Resemblance Approach* (Irzik & Nola, 2011), *Structuring Theoretical Fields* (Adúriz-Bravo, 2007) and *Subjects and Questions* (Martins, 2015). Therefore, we present a general overview of these perspectives, summarising the proposals, presenting the contrasts and approximations between them and showing that perhaps the different theoretical-methodological perspectives that have been renewed may not overcome part of the criticism to the classic view of the debate about the nature of science in science education. Finally, in addition to justifying the presence of this discussion in science education, supported by the literature of the area, we defend the importance and implications of these discussions in courses for initial and continuing training of science teachers.

THE CONSENSUS VIEW

In the studies on the nature of science, there are concerns about epistemological values and assumptions underlying science and scientific processes from the hybridity of several areas of knowledge. MacComas (2008) states that NOS is defined as a hybrid domain that blends aspects of various social studies of science, including the history, sociology and philosophy of science combined with research from the cognitive sciences, such as psychology, into a rich description of science; how it works, how scientists operate as a social group and how society itself both directs and reacts to scientific endeavours.

However, the intended "rich description of science" is a complex task. To the challenges in establishing this description, sociologists, philosophers, and historians of science disagree on the meanings of the nature of science (Lederman, Abd-El-Khalick, Bell & Schwartz, 2002; McComas, 2008).

Despite such disagreement, science education has continuously sought the construction of a consensual image or vision of what the nature of science is, with the justification that an idea of its processes and procedures and its epistemic basis can be taught (McComas & Olson, 1998; Abd-El-Khalik & Lederman, 2000a; Gil-Pérez, Montoro, Alis, Cachapuz & Praia, 2001, Osborne, Collins, Ratcliffe, Millar & Duschl, 2003; Dagher and Erduran, 2016; McComas, 2008, 2017). This view aims to "seek a pragmatic consensus around certain aspects that would be valid to think the insertion of the Nature of Science in schools" (Martins, 2015, p. 706).

Researchers clarify that elements about the nature of science may be controversial within the philosophical community because they represent a partial or simplified view of the nature of scientific knowledge. However, they argue that science education is often based on vulgarised or simplified reports, such as pedagogical heuristics for communicating a basic scientific understanding. They argue, therefore, that for science teachers to teach explicit aspects of the epistemic nature of science, the science education community must then reach a consensus on aspects of science that represent legitimate aspirations for the curriculum. It was in this sense that they sought elements that specialised groups considered acceptable as a description of the nature of science and practices of the scientific community and that could be offered to school education, although this description may still represent a reduced, contested and potentially vulgarised view.

At a theoretical and normative level, and in line with the efforts of the science education reforms (AAAS, 1993; NRC, 1996) that aim to improve students' conceptions of the nature of science, McComas (2008), McComas and Olson (1998), McComas, Almazroa, and Clough (1998a), and McComas, Clough and Almazroa (1998b) draw up a list of tenets of the nature of science from a set of official documents on science education in the United States, Canada, Australia, New Zealand, England and Wales. This list, from theoretical-normative studies, when compared with principles of NOS presented in empirical studies such as in Collins, Osborne, Ratcliffe, Millar, and Duschl (2001), revealed a set of tenets for teaching the nature of science that may be consensual to the science education community:

- There is no one way to do science (therefore, there is no universal step-by-step scientific method). Scientists require accurate record-keeping, peer review, and replicability.

- Laws and theories serve different roles in science; therefore, students should note that theories do not become laws even with additional evidence.
- Scientific knowledge, while durable, has a tentative character.
- Scientific knowledge relies heavily, but not entirely, on observation, experimental evidence, rational arguments, and scepticism.
- Observations are theory-laden.
- Science is an attempt to explain natural phenomena.
- Science is part of social and cultural traditions. Scientific ideas are affected by their social and historical milieu.
- People from all cultures contribute to science.
- Science and technology impact each other.
- The history of science reveals both an evolutionary and revolutionary character.
- New knowledge must be reported clearly and openly.
- Scientists are creative.

This comparison suggests that some aspects of science are absent from discussions or debates, concluding that both methods do not seem to be enough to determine what should constitute an adequate curriculum for teaching about the nature of science and that, perhaps, there is no universal solution as to what should be the essential elements for a curriculum that addresses aspects of the nature of contemporary science. Collins, Osborne, Ratcliffe, Millar, and Duschl (2001) and Osborne, Collins, Ratcliffe, Millar, and Duschl (2003) argue that the omissions were either considered to be too complex or too controversial to be included. In any case, although it is a vulgarised description, it is considerably more sophisticated than the naive notions routinely taught in science classes.

In this same sense, Lederman, Abd-El-Khalick, Bell, and Schwartz (2002) systematise statements about the nature of science and propose some generalisations to be interpreted in the context of school education, although there may be different levels of depth and complexity depending on the situation. These generalisations are based on issues such as: provisional scientific knowledge; empirical basis of scientific knowledge; theoretical load of scientific knowledge; scientific knowledge as partially a product of inference, imagination and human creativity; scientific knowledge as socially and culturally incorporated; importance of the distinction between observation and inference; the lack of a universal reciprocity method of doing science; and, the functions and relations between scientific theories and laws.

However, many criticisms are addressed to this consensus view about the nature of science and scientific knowledge (Rudolph, 2000; Clough, 2006, 2007; Allchin, 2011; Irzik & Nola, 2011; Van Dijk, 2011; Matthews, 2012; Duschl & Grandy, 2013; Martins, 2015; Forato, Bagdonas & Testoni, 2017; Rodríguez & Adúriz-Bravo, 2017), mostly because it is not believed that it is possible to establish a general agreement. From the studies and research that defend it and criticise it, it is possible to perceive that "there are different routes, terminologies, starting points and conclusions" (Martins, 2015, p. 703).

Among the weaknesses, some problems are highlighted, like, for example, criticism of declarative statements about science (Clough, 2006, 2007; Allchin, 2011; Martins, 2015), which suggest a dogmatic aspect for approaching and learning about the sciences, disregarding the particularities of the different areas of science (Irzik & Nola, 2011), and lack of historical and philosophical refinement about the elements of the nature of science (Matthews, 2012; Martins, 2015).

The consensus view goes against a positivist, naive realistic, and common-sense view of science and deconstructing this view has been a not simple, but very important, part of the goal of science teaching. According to Martins' analysis (2015), the proposal of the consensual view seems to fall within the scope of a moderate relativism by pointing out the provisional aspect of knowledge, the lack of a single and rigid method, the existence of theoretical biases in observation and experimentation, the historical, social and cultural influences of scientific practice.

However, a very relevant concern is that a moderate relativist view as the one proposed by the consensus view can contribute to some kind of inadequate relativism, like exacerbated relativism. Martins (2015) presents a series of arguments (Feyerabend, 1993; Matthews, 1998; Clough, 2007) and, from them, concludes that "exacerbated relativism can lead to anti-scientific attitudes an irrationalism" (Martins, 2015, p. 716), instead of "an appreciation of science as a human enterprise that is epistemologically different from common-sense knowledge and other types of knowledge" (Martins, 2015, p. 716).

Matthews (2012) criticises some principles of this consensus view on the nature of science. Regarding the principle concerning the empirical nature of scientific knowledge, the author poses two main problems. The first one refers to the ontological status of theoretical entities in science. While Lederman (2004) states that there is a fairly broad agreement on the "existence of an objective reality, for example, as compared to phenomenal realities" (p.

303), Matthews (2012) argues that "the serious debate among philosophers is not the reality of the world, but the reality of explanatory entities proposed in scientific theories" (p. 12). All the ontological discussion disappears when it is affirmed that "science has an empirical basis". In this context, Matthews (2012) identifies that Lederman (2004) adopts a realistic, empiricist, and constructivist position on the theoretical entities of science. For the author, 'It is not the reality of the world that teachers need guidance about, it is the reality or otherwise of entities postulated in scientific theories.' (Matthews, 2012, pp. 13).

The second problem, signalled by Matthews (2012), is the distortion of the role of abstraction and idealisation in science when an empirical nature is emphasised. In relation to this, Matthews (2012) adds two new items from the list of characteristics of science: experimentation and idealisation. Regarding the subjectivity of scientific knowledge, Matthews (2012) raises questions about the psychological subjectivities associated with the scientist and philosophical subjectivities associated with knowledge, and the risk of them being confused by resulting in an understanding that scientific knowledge is personal and individual. With respect to the social and cultural incorporation of scientific knowledge, the author points to the fact that a dominant culture, a Western culture, influences and is influenced by, affects and is affected by scientific knowledge, which consists of the construction of knowledge in modern science. Other cultures, constructed from other world-views, do not seem to influence this dominant culture nor vice versa.

In short, criticism does not advocate denying the ideas present in the consensus view, but rather considering the frailties of this approach with care. For Martins (2015), the conclusion is not that the consensus view should be discarded or dismissed, because researchers who worked in this direction brought fundamental contributions to advancing knowledge in science education. The central point here is to highlight that the consensus view, due to its form and content, has faced criticisms. And that, even though the list of tenets may be reinterpreted, these criticisms are based on what is effectively published and what can work as a reference for instruction.

In this context, more recently, in science education, the development of renewed theoretical-methodological perspectives on the nature of science has been fostered, seeking to overcome the main criticisms of this consensus view, both epistemological and educational.

RENEWED PERSPECTIVES

There is a growing movement in the debate about the nature of science in science education to present emerging assumptions from renewed and potent milestones for science didactics. Each of these perspectives gives specific suggestions for addressing this subject in school and has a common criticism towards the consensus view on the nature of science. To understand the directions of the most current and renewed debate on the theme, we will systematise the main ideas of each of them.

Features of Science

Matthews (2012) proposes a shift in the research and terminology of the nature of science (acronym NOS) for a more flexible, contextual and heterogeneous approach to the subject. According to the author, this change of perspective aims to avoid philosophical, epistemological and educational traps that have been associated with much of the recent research about the nature of science from the perspective of Lederman, Abd-El-Khalick, Bell, and Schwartz (2002). Among the weaknesses of the proposed consensus view, Matthews (2012, p. 4) points out:

- The confused jumbling together of epistemological, sociological, psychological, ethical, commercial, and philosophical features into a single NOS list.
- The privileging of one side of what are contentious and much-debated arguments about the methodology or 'nature' of science.
- The assumption of particular solutions of the demarcation dispute between science and non-science.
- The assumption that NOS learning can be judged and assessed by students' capacity to identify some number of declarative statements about NOS.

The author emphasises that the list of affirmations and declarations of the consensus view can insert the theme in the classroom, suggesting some points to be discussed and providing instruments to measure learning about the nature of science. However, the list with declarative statements and sentences runs the risk of being interpreted dogmatically and may inhibit a more desirable critical reflection on the nature of science.

To avoid propagating misunderstandings about the nature of science, Matthews (2012) introduces eleven features of science – epistemological, historical, psychological, social, and technological – that can be used to describe the scientific enterprise, in addition to the list of classic aspects of the sciences proposed by Lederman, Abd-El-Khalick, Bell, and Schwartz (2002). The features of science proposed by Matthews (2012) are: 8. Experimentation; 9. Idealisation; 10. Models; 11. Values and socio-scientific issues; 12. Mathematisation; 13. Technology; 14. Explanation; 15. Worldviews and Religion; 16. Theory choice and rationality; 17. Feminism; 18. Realism and Constructivism.

For these items, instead of affirmative and definitive sentences about the characteristics of science, Matthews (2012) suggests a series of questions that can be used to raise the debate around each element. In this sense, teachers should seek a more complex understanding of knowledge and scientific work, without the need to artificially import philosophical subjects into science classes. In this sense, the author suggests philosophical questions such as: What is a scientific explanation? What is a controlled experiment? What is a crucial experiment, and are there any? How do models function in science? How much confirmation does a hypothesis require before it is established? Are there ways of evaluating the worth of competing research programmes? Did Newton's religious beliefs affect his science?

Nature of 'Whole' Science

Allchin (2011) systematises a methodological proposal that seeks to promote a discussion on how to effectively evaluate the practical and culturally functional knowledge of the nature of science, which he calls *Nature of Whole Science*. He justifies his concern with a belief in the importance of adequate training of citizens to participate in a society in which science and technology are increasingly important in public policies and social lives. The author considers that content knowledge is insufficient to act and make decisions in scientific debates, and that it is essential to know about the nature of science, suggesting that "Students should develop an understanding of how science works with the goal of interpreting the reliability of scientific claims in personal and public decision making" (Allchin, 2011, p. 521).

For the author, even if they do not master the whole set of concepts involved, an informed citizen can at least interact with experts on topics on which he can at least recognise relevant or false evidence, the limits and foundations of emerging scientific claims, negotiate scientific uncertainty, assuming the role of "a competent interpreter, or 'critic' of science, even if not a practitioner of science" (Allchin, 2011, p. 522). In this sense, interpreting the reliability of scientific claims requires a broad understanding of its practices: from experimentation to scientific dissemination.

Allchin (2011) argues that the lists of principles of the nature of science do not present a legitimate scientific context that can serve as a reference for "personal and social decision-making". For the author, the lists of consensual principles include items that are irrelevant to functional scientific literacy and omit other items that would be relevant, as regards the role of credibility and reliability over scientific claims. To do so, the author proposes using historical cases or contemporary scientific news, which are contextually rich, to promote a functional or interpretative analysis of the nature of science, replacing the approach around declarative affirmations.

Thus, Allchin (2011) suggests dimensions that seek to overcome some internal contradictions to the consensus view established by the declarative principles of the nature of science. They are: 1. Observations and reasoning; 2. Methods of investigation; 3. History and creativity; 4. The human context; 5. Culture; 6. Social interactions among scientists; 7. Cognitive processes; 8. Economics/funding; 9. Instrumentation and experimental practices. 10. Communication and transmission of knowledge.

These dimensions serve as tools for assessing historical cases or contemporary science news whose contexts are potentially fruitful to promote discussion of how science 'works' (or how it does not work and why). These groupings are possible because the purpose is to inform the students' interpretive abilities, not only to determine whether science is (absolutely) tentative or durable, conservative or creative, among other characteristics present in the principles of the consensual view of the nature of science.

Family Resemblance Approach

Irzik and Nola (2011) argue that the consensus view of the nature of science, while attractive, has shortcomings and weaknesses because it portrays a very restricted, monolithic, fixed, and timeless image of science. For the authors, this view presents only characteristics that are widely accepted in the standardised curricular documents of sciences in the field of epistemology, history, and sociology of science or in proposals of scientific literacy that do not contribute to overcoming the naïve images shared among young people. The main criticism on the consensus view is that it ignores the particularities of the different areas of science, the complexities regarding methodology and methodological rules, the objectives of science, and the lack of discussion about scientific research practices through which scientific knowledge is produced.

Irzik and Nola (2011) propose an alternative to assume the construction of a vision of what is the nature of science that is more comprehensive and systematic than the consensus view, in an attempt to cover general and structural aspects, living up to its complexity, but in a pedagogically useful way. The so-called *Family Resemblance Approach* originates from the following analogy: members of a family may resemble one another in some respects, but not in all or even more, and thus the network of characteristics may form a family based on similarities. In the case of science, there are common characteristics, but they cannot be defined in an absolute way as elements that demarcate science, as is the case of observation, data collection, inference, among others. In this argumentative line, the authors define as characteristics that contribute to the characterisation of the scientific disciplines: 1. Activities; 2. Aims and Values; 3. Methodologies e Methodological Rules; 4. Products.

The authors argue each of these characteristics in a very descriptive way. Concerning (1) Activities, for example, they list a set of them, such as observational practices (such as sky observations using instruments and observations for recognition or identification of fossils), material practices (such as experimental practices), and classificatory practices (such as the formulation, proposition and solution of issues or problems). Each of these practices may characterise some sciences, but not others, thus forming a set of family similarities. The point is that all sciences share some subset of activities (Irzik & Nola, 2011).

Regarding (2) Aims and Values, they basically depend on the philosophical understandings and positions adopted or incorporated into scientific theories and practices, including: consistency, simplicity, fecundity, and broad scope (Kuhn, 1977); high confirmation, as emphasised by the logical empiricists (Hempel, 1965); falsehood, truth, or verisimilitude (Popper, 1963, 1975); empirical adequacy (Van Fraassen 1980); viability (Von Glasersfeld, 1989); heterogeneity and ontological complexity, as emphasised by empiricist feminists (Longino, 1997). Sometimes, values in science can serve as criteria for theoretical choice and can be expressed as methodological rules among competing theories, for example.

Regarding (3) Methodologies, "Science does not achieve its various aims in a haphazard way, but employs a number of methods and methodological rules" (Irzik & Nola 2011, p. 598). Science is full of them, some controversial, but others generally accepted. Some examples of the types of rules considered necessary in the methodological process in science are: to construct highly testable hypotheses/theories/models; to avoid making ad hoc reviews for theories; among theories that have similarities in other aspects, choose the theory that is more explanatory; choose the theory that makes new true predictions over the theory that only predicts what is already known; reject inconsistent theories; accept simple theories and reject more complex ones; accept a theory only if it can explain all the successes of its predecessors; use controlled experiments when testing random hypotheses and when conducting experiments on humans, always use blind procedures.

In relation to (4) Products, it may include hypotheses, laws, theories, and models, as well as collections of observational reports or collections of experimental data. Without seeking to explore disputes between products in each of the scientific subject matters, Irzik and Nola (2011) state that: "The ultimate propositional end product of scientific activities is knowledge or rational belief" (Irzik & Nola, 2011, p. 600). Therefore, they again argue that these characteristics they call scientific products may form a set of family similarities, with each science sharing some of them, and perhaps not others.

In summary, for the Family Resemblance Approach, each individual science will be formed by some subset of elements belonging to the four categories of activities, aims and values, methodologies and methodological rules and products, which may be different from another subset that characterises another science individual. As well, a couple of disciplines consisting of structured knowledge can share that "there are sufficient similarities, overlaps and criss-crosses that make them both 'sciences'" (Irzik & Nola, 2011, p. 601).

Finally, regarding the application of this approach to teaching students about the nature of science, Irzik and Nola (2011) point out the flexibility of the proposal to allow the teacher to focus on any of the categories – activities, aims and values, methodology and methodological rules and products – as long as they intend to discuss some aspect of science in more detail. In addition, they argue that this proposal allows historically oriented teachers to give students an idea about the historical development of science from a philosophically neutral approach.

The Structuring Theoretical Fields

Adúriz-Bravo (2007) considers it necessary to identify epistemological bases of the study of the nature of science that is characterised as a relevant and valuable curricular component to reach the objectives of authentic scientific literacy and that represent an efficient and valuable tool in the professional development of science teachers. For this, the author proposes a differentiation of perspectives and objectives for the teaching of the nature of science in the training of science teachers. The first consists of a perspective that he calls a curricular perspective. In this perspective, the nature of science has an intrinsic value for citizens' education, especially regarding the formation of opinions and decision-making process on socio-scientific issues, in which teachers need to know about the nature of the sciences to teach it. The second perspective, adopted by Adúriz-Bravo (2005, 2007) in his proposal, is identified as the meta-theoretical perspective. In this perspective, the "NOS is then assumed to represent a second-order reflection on the content and methods of science that positively contributes to teachers' autonomy in the task of didactical transposition" (Adúriz-Bravo, 2007, p. 45).

The author proposes to approach the nature of science from "structuring theoretical fields", from a meta-theoretical perspective, "since they refer to general reflections on the deep nature of the disciplines that can be established in the classroom in different educational levels" (Rodríguez & Adúriz-Bravo, 2017, p. 3503). This structure is proposed in two senses: in stages constituted by an academic epistemological periodisation and in strands of the nature of science defined on the basis of philosophical concerns of science.

The epistemological stages proposed by Adúriz-Bravo (2007) are:

1 Logical positivism and received view (1920-1965) – this stage sustains a strict rationalist and realist reconstruction of science both as a product and as a process.

2 Critical rationalism and the new philosophy of science (1935-1980) – this second stage represents a serious undermining of philosophical orthodoxy.

3 Postmodernism and contemporary accounts (1970-actual) – this stage combines 'emerging' philosophical constructions with elements from other meta-sciences (sociology of science, cognitive science, science studies).

On the other hand, the epistemological currents to which Adúriz-Bravo (2007) refers are 1. Correspondence and Rationality; 2. Representation and Languages; 3. Intervention and Methodologies; 4. Contexts and Values; 5. Evolution and Judgement; 6. Demarcation and Structure; 7. Normativity and Recursion.

In the matrix of the "structuring theoretical fields" with its stages and currents, it is possible to map different theoretical models about science, as well as to evaluate their pertinence in the training of science teachers, in the sense of allowing clearer options when selecting elements to be taught about the nature of science. These elements can be combined into a diachronic representation of the philosophy of science, organising ideas, schools, and authors, locating them at a time (stages) and in thematic spaces (currents) and that "goes through the whole history of epistemology giving it identity as a discipline" (Adúriz-Bravo, 2005b, p. 8). These structuring theoretical fields of epistemology involve classical meta-theoretical questions that refer to generic reflections on the deep nature of the natural sciences (Adúriz-Bravo, 2007)

As a didactic proposal to teach the nature of science, Adúriz-Bravo (2007) exemplifies some didactic situations constructed to familiarise future teachers with relevant aspects of the nature of science, such as the nature of the scientist's image, the nature of the scientific method, and the nature of scientific values. Finally, he points out that other studies are necessary to verify the extent to which science teachers benefit from this approach based on learning key ideas about the nature of science, as proposed by this model.

Subjects and Questions (nature of science through questions)

Martins (2015) presents a very relevant discussion for the area of science teaching in relation to what to teach about meta-scientific contents, that is, knowledge about science. The author argues that "even with limitations, any teaching on the nature of science is better than to stop acting and allow the continuity of propagation of misrepresented and misguided views of science" (Martins, 2015, p. 717).

In this sense, he presents a proposal based on "subjects and questions", which seeks to overcome frequent criticisms about the consensus view of the nature of science insofar as: a) they do not consist of declarative knowledge or short statements and general domain about science; b) they suggest an approximation to an investigative character for the treatment of the subject of the nature of science; c) they assume a more open, plural and heterogeneous character, both from the historical and social point of view as well as epistemological; d) they dialogue more fruitfully with other more recent proposals (Martins, 2015).

For this, the author suggests a change in form and content by proposing questions and subjects, respectively, to approach the subject of the nature of the sciences in the curriculum, from two main axes: historical and sociological axis and epistemological axis. According to the author, the first axis would bring subjects such as (a) the role of the individual and the scientific community; (b) intersubjectivity; (c) moral, ethical, and political issues; (d) historical and social influences; (e) science as part of culture; and (f) communication of knowledge. The second, broader axis would bring subjects such as (a) the origin of knowledge; (b) methods, practices, procedures, and processes of science; (c) content/nature of the knowledge produced.

Martins (2015) suggests an interrelation between these two axes – sociological and historical axis with the epistemological axis –, whose division is partly artificial, because "the epistemic aspects that characterise the 'nature' of the knowledge produced come from a construction that is collective (intersubjective), historical and social" (Martins, 2015, p. 718).

In relation to inserting subjects of the nature of science in the curriculum to guide the choices of teachers in the classroom, Martins (2015) suggests some useful dimensions that can be considered, such as a) History of Science versus current/contemporary Science; b) Nature of Contextual Science versus Nature of General Science (exploring the important elements of this false dichotomy); and, c) Epistemological versus Sociological. In order to illustrate this proposal, for each of the subjects within each of the axes, Martins (2015) lists a number of issues that can be explored.

In addition to the proposal developed by Martins (2015) for the use of Subjects and Questions in the insertion of the theme of the nature of science in the school curriculum, it is worth mentioning that Clough (2006, 2007) also criticises the establishment of declarative statements about science and, following the same line, presents a defence to deal with aspects of the nature of science as issues rather than principles.

CONTRASTS AND APPROXIMATIONS BETWEEN CONSENSUS AND RENEWED TENDENCIES

The theoretical-methodological perspectives – classical and renewed perspectives – of the debate on the nature of science in science education have important contrasts and approximations that we will summarise now. This systematisation occurs in two senses that have been criticised more recently, both in terms of the presentation of contents about the nature of science and the contents that are generally attributed to the subject of the nature of science. It is worth mentioning that the systematisation and analysis proposed here are only based on the referenced works (the most used and cited by these authors) and do not consider possible new contributions in later articles and works.

Firstly, in relation to the presentation of the main points and elements of the nature of the science of each of the proposals, they were listed: the presentation of the items on the theme of the nature of science in the form of a list, questions or matrix; the explicit presentation of a specific item on the subject of scientific methodology; consideration of nuances and differences between scientific disciplines; the presentation of pedagogical considerations for the application of the proposal in the classroom; and, finally, the explicit presentation of a discussion of historical, sociological, philosophical and epistemological aspects.

Regarding the presentation of the items, the first criticism refers to the nature of science contents organisation as lists. More specifically, this critique is related to the fact that the lists often consist of a set of short, direct and general assertions about science, and even the proponent does not have that intention, they become understood and appropriated as truths about science, that must be memorised and applied by students and teachers. Consensus View of the Nature of Science, Features of Science, proposed by Matthews (2012), and Family Resemblance Approach, proposed by Irzik and Nola (2011), present the contents about the nature of science as lists, while Structuring Theoretical Fields, proposed by Adúriz-Bravo (2007), and Subjects and Questions, proposed by Martins (2015), present the contents as questions and matrices. On the other hand, Nature of 'Whole' Science, proposed by Allchin (2011), presents a series of elements, more dynamic than the traditional lists, to be applied in analyses of case studies on science and scientific practice that is contextually rich.

Regarding the specificities and the concern to consider the epistemological aspects to each area, the criticisms are about the discussion about scientific methodology and nuances between the different scientific disciplines. Regarding the proposition of a specific discussion on scientific methodology, only the proposals Nature of 'Whole' Science, Family Resemblance, Structuring Theoretical Fields and Subjects and Questions bring and deepen the theme. In this sense, regarding the nuances between different scientific disciplines, only the proposals Family Resemblance Approach and Subjects and Questions consider this, while Consensual Vision of the Nature of Science and Features of Science, Nature of 'Whole' Science, and Structuring Theoretical Fields make no specific mention of this item.

Regarding the pedagogical considerations for the teaching about the nature of science, all proposals present some satisfactory description in favour of applying activities that contemplate an approach of the nature of science in the classroom. Concerning the discussion of historical, sociological, philosophical and epistemological aspects for studying the nature of science, all proposals mention it, however, in different sophistication levels, some more refined, such as Structuring Theoretical Fields and Subjects and Questions.

Secondly, regarding the content generally attributed to the subject of the nature of science, we listed some of the main criticisms made on the consensus view by the authors of each of the proposals and if they can overcome these criticisms.

The main criticisms made by Matthews (2012) concern (a) the non-distinction between epistemological, ethical, financial and philosophical characteristics of the nature of science, (b) the privilege given to philosophical positions or positions in scientific controversies, (c) the presupposition of a specific solution for the demarcation dispute between science and non-science, and (d) the judgment and evaluation of learning about the nature of science by the ability of students to identify declarative statements. These criticisms arise in Features of Science approach, inasmuch as Matthews (2012) suggests changing the focus of the nature of science, i.e., changing the point of view on how to approach the elements that can characterise science — remembering that Matthews (2012) also suggests complementing the seven principles of the consensus view, represented by the proposal of Lederman, Abd-El-Khalick, Bell, and Schwartz (2002), maintaining the first seven and adding eleven other features. This change of view advances in the sense of questioning the 'consensus' and of indicating the necessity of a historical, philosophical and epistemological refinement in each one of the debates to which they propose; to then become useful for science education. Regarding the criticisms pointed out by Matthews (2012), the analysis that we performed shows that Features of Science, Nature of 'Whole' Science, Family Resemblance Approach, Structuring Theoretical Fields and Subjects and Questions, contemplate all the criticisms and demands made by Matthews (2012).

Allchin (2011) point out as essential the development of an alternative instrument to the consensus view to identify students' conceptions about the nature of science. Allchin (2011), in Nature of 'Whole' Science approach, uses historical cases and analysis of contemporary science news using the Reliability Dimensions in Science instrument. Irzik and Nola (2011), in Family Resemblance Approach, indicate questions for the teacher to use in the classroom by prioritising any of the four sets of characteristics of their proposal. Adúriz-Bravo (2011), in the Structuring Theoretical Fields approach, presents examples of didactic situations to familiarise teachers with relevant aspects of the nature of science about the scientist's image, the nature of the scientific method, and the nature of scientific values. Martins (2015), in the Subjects and Questions approach, presents a series of questions about each of the subjects of the nature of science classified in the sociological, historical, and epistemological axes. However, Matthews (2012), in the Feature of Science approach, does not present or develop an alternative instrument to the consensus view to identify conceptions about the nature of science.

Irzik and Nola (2011) point out as essential to any approach on the nature of science to evidence and distinguish the particularities of the different areas of sciences with respect to the methodological complexities, objectives, and research practices by which scientific knowledge is produced. In their Family Resemblance Approach, they propose four elements that hold scientific variety, dynamics, and richness to encompass complex general and structural aspects of science. Allchin (2011), in Nature of 'Whole' Science approach, presents the analysis of various historical and contemporary scientific cases, considering specific elements of each. The Subjects and Questions approach by Martins (2015) brings three axes: sociological and historical and epistemological axis, in which they recognise the problem of the origin of scientific knowledge; the methods, procedures, and processes of science; and the content/nature of the scientific knowledge produced. The Features of Science approach, by Matthews (2012), and the Structuring Theoretic Fields approach, by Adúriz-Bravo (2007), do not explicitly recognise these particularities.

The main criticisms made by Adúriz-Bravo (2007) are (a) presentation of up-to-date content on the nature of science, (b) concern about the compatibility of ideas from different philosophical movements, and (c) reflection on the specific role of the nature of science in the training of science teachers. In his Structuring Theoretical Fields approach, he proposes three epistemological stages that encompass logical positivism, critical reasoning, and a new philosophy of science and postmodernism and contemporary views, composed by axes and approaches that enable the discussion of different and renewed contents about the subject, and the analysis of ideas from different philosophical stances. Regarding the demand for up-to-date content on the nature of science, the proposals Features of Science, by Matthews (2012), Nature of 'Whole' Science, by Allchin (2011), Family Resemblance Approach, by Irzik and Nola (2011), Structuring Theoretical Field (2011), by Adúriz-Bravo (2007), and Subjects and Questions, by Martins (2015), to a greater or lesser extent, bring this concern. Despite presenting up-to-date content about the subject of the nature of science expressed in characteristics such as ‘values and social-scientific issues’, ‘technology’ and ‘feminism’, the proposal Features of Science, by Matthews (2012), does not make explicit a concern in exploring the compatibility of ideas from different philosophical movements. Nature of ‘Whole’ Science, by Allchin (2011) and Family Resemblance approach, by Irzik and Nola (2011), also do not.

About the reflection on the specific role of the nature of science in the training of science teachers, Adúriz-Bravo (2007) points out that the approach of Structuring Theoretical Fields starts from a meta-theoretical perspective that enables generic reflections about the in-depth nature of scientific disciplines, contributing positively to the autonomy of teachers. To some extent, all approaches present this type of reflection on teacher education.

The last criticism mentioned here was made by Martins (2015) regarding the use of declarative knowledge or short statements and common sense about science in the consensus view. In our analysis, it seems, the proposals Nature of ‘Whole’ Science, by Allchin (2011), Family Resemblance Approach, by Irzik and Nola (2011), Structuring Theoretical Fields, by Adúriz-Bravo (2007), and Subjects and Questions, by Martins (2015), seek to value an approximation to a more investigative approach for the treatment of the subject of the nature of science, more open, plural and heterogeneous, both from a historical and social and from an epistemological point of view. Again, the approach Features of Science, like the Consensus View of the Nature of Science, valued declarative knowledge and common-sense statements about science, as criticised by Martins (2015).

Generally, the approaches Features of Science, Nature of ‘Whole’ Science, Family Resemblance, Structuring Theoretical Fields, and Subjects and Questions present elements that help build an understanding of the nature of science by teachers and students in science classes. The recommendations are to build a more open, plural, and heterogeneous image, one that is fruitful and flexible, allowing the compatibility of ideas with different schools of thought, without privileging certain historical, philosophical, epistemological, and sociological stances.

The Structuring Theoretical Fields and the Subjects and Questions approaches present the elements of the nature of science as a matrix, allowing the debate to be developed according to the epistemological period or philosophical approach being explored. These approaches enable historical episodes or contemporary controversies, for example, to be analysed according to their period of philosophical discussion. We should also note that these approaches present a careful reflection about the specific role of the nature of science in the science teachers' education and are concerned with teaching these elements in basic education as well.

FINAL REMARKS

Considering the importance and implications of the debate on the nature of science for science education, we acknowledge the advances and importance of specific discussions about students' conceptions on the development, implementation, and testing of proposals aimed at improving these concepts, and studies that consider the conceptions of science teachers on the subject. We present the theoretical-methodological perspectives of the classical consensus view and renewed perspectives on the nature of science, analysing contrasts and approximations between several proposals and authors.

In this debate, we show that different theoretical and methodological perspectives, which have been called renewed perspectives, may not be overcoming the criticism of the classic view of the debate on the nature of science in science education. Regarding the presentation of contents about the nature of science, it was not possible to identify considerations about the nuances of the different scientific disciplines in the proposals *Consensus View of the Nature of Science*, *Features of Science* (Matthews, 2012), *Nature of 'Whole' Science* (Allchin, 2011) and *Structural Theoretical Fields* (Adúriz-Bravo, 2007).

Regarding the contents that are generally attributed to the nature of science, we identified that a few important criticisms made by authors of the renewed tendencies of the nature of science were not overcome. The proposal *Features of Science* (Matthews, 2012) does not present or develop an alternative instrument to the consensus view for identifying students' conceptions, as Allchin (2011) pointed out. Also does not clearly allow compatibility of ideas of philosophical movements, a criticism made by Adúriz-Bravo (2007) on the consensus view. In addition, the proposals *Features of Science* (Matthews, 2012) and *Structuring Theoretical Fields* (Adúriz-Bravo, 2007) do not mention the particularities of the different areas of science that include complexities referring to methodology and methodological rules, the objectives of science, and the practices for scientific investigation through which scientific knowledge is produced, something pointed out by Irzik and Nola (2001).

On the other hand, in our analysis, we can verify that all proposals bring considerations about historical, sociological, philosophical, and epistemological aspects of the nature of science, some of them with greater depth than others. All the proposals also present pedagogical considerations for the application in the classroom aiming at teaching the nature of science to the students, some of them more structured than others. We point to the need and importance of studies and research that propose to improve these pedagogical considerations, especially for teaching the nature of science in basic education, especially in the development of didactic materials that incorporate the theoretical and methodological references of the nature of science for a richer understanding of science in science education.

In this sense, it is worth emphasising that we do not defend the idea of a new proposal capable of overcoming all criticisms of the classical view of the nature of science. However, we propose that reflection on the limits and potentialities of each perspective on the nature of science, which was discussed in this paper, may contribute to the production of effective actions that improve teachers' and students' understanding of the content of science, about the process of construction of scientific knowledge and of the historical-social context that is inserted.

As already mentioned, the systematisation and analysis proposed here were carried out only based on the most used and cited works by these authors and did not consider possible new contributions in articles and later works. We understand that future studies should update this reference list, contrasting other works and other authors, researchers, and specialists of the area of the nature of science in science education, who can contribute to advance the discussion. Another possibility for continuing this work is to develop a more in-depth reflection about the specific role of the nature of science in science teachers' education, to comprehend the part and influence teacher educators for the teaching, comprehension, and sharing of views about the form and content of the nature of science.

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All authors actively participated in the writing, review, and approved the final version of the work.

DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article because no new data was created or analysed in this study.

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