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Knowled of the Nature of Science as expressed by undergraduate students in teaching materials about the History of Physics [+*]

Evelim Lamaiara dos Passos Carvalho Santos[1]
Immaculate College the Heart of Mary
Objective College
São Lourenço – MG
João Ricardo Neves da Silva[1]
Evandro Fortes Rozentalski[1]
Federal University of Itajubá
Itajubá – MG

Abstract

This research aimed to evaluate how physics undergraduates express knowledge about the Nature of Science (NOS) during the formative process of developing teaching materials on the History of Physics (HP) for Basic Education. To carry out this investigation, teaching materials on historical episodes in physics, developed by students in a physics undergraduate program, were analyzed. In total, 12 (twelve) teaching materials constitute the documentary corpus. For data analysis, a priori categories on aspects of NOS were used based on theoretical frameworks in order to identify and characterize how these aspects are expressed or can be inferred from the materials. The main results revealed adequate and inadequate views on NOS in 13 different aspects, such as the scientific method and social and cultural roots. Furthermore, limitations and difficulties related to this study were identified, such as the limitation of the historical case in encompassing all previously defined aspects of NOS. The analyses highlight the potential of creating teaching materials on History and Philosophy of Science by undergraduate students as a teacher training practice for aspects of the Nature of Science, in addition to

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[1] E-mails: evelin.874@hotmail.com; jricardo.fisica@unifei.edu.br; e.rozentalski@unifei.edu.br

allowing reflection on training in History and Philosophy of Science in education and the formative practices proposed in the initial training of physics teachers.

Keywords: *Nature of Science; History of Science; History of Science; Didactic materials; Teacher Education.*

I. Introduction

The focus of this study concerns the initial training of physics teachers and their views on the Nature of Science (NOS). The objective is to understand how future physics teachers draw upon their knowledge of the NOS in the process of developing instructional materials on the History of Physics (HoP).

The NOS is a construct that has been studied more extensively since the mid-20th century, especially in the context of reflections on the relevance of science in political and social contexts (Martins, 2015). However, due to the plurality and heterogeneity of the sciences, it is not possible to find a single, exclusive definition for the term. This definition depends on the theoretical, philosophical, and epistemological frameworks adopted (Martins, 2015). Nevertheless, in general terms, it can be said that the NOS concerns the understanding of what science is, how it functions, and how it influences and is influenced by society (Vázquez-Alonso *et al*., 2007); that is, it is the quest to understand the characteristics of scientific knowledge as a whole.

There are several reasons for including a discussion of the NOS in basic science education; however, from a broader perspective, it is argued that it is an essential component of scientific literacy. In this sense, people with more accurate views of the scientific enterprise are more critical and engaged in making informed decisions about techno-scientific issues and problems (Praia; Gil-Pérez; Vilches, 2007), and they better understand the world and being aware of the benefits and impacts of science on society.

> *A deeply enriching way to understand science is precisely through an understanding of its justificatory practices: how scientists manage to transform data into patterns and models; how explanations come to be supported by evidence and how they in turn support new predictions; how representations manage to speak for scientists and travel through time and space, storing and unpacking various meanings, and so on.* (Mendonça, 2020, p. 11).

Furthermore, this can be a crucial element in helping students construct scientific concepts in a more organized and understandable way, since the NOS, as part of science education, plays a role in giving meaning to scientific content, while also contributing to the development of a scientific culture and the appreciation of science in society. Thus, discussing the Nature of Science helps avoid impoverished and stereotypical views of scientific activity, as Azevedo and Scarpa (2017, p. 581) state when they state that “we believe that science education must enable students to understand how scientific knowledge is produced, validated, and communicated, explicitly considering the epistemological particularities of science.”

However, it is not uncommon to find studies that point to distorted views of science, ranging from early research on this topic (Gil-Pérez *et al*., 2001; 2005) to more recent studies (Azevedo; Scarpa, 2017; Bagdonas, 2014), or even the propagation of myths related to the construction of scientific knowledge (McComas, 1998; Mendonça, 2020), at the elementary, technical, or higher education levels (Lederman, 2002).

While the importance of addressing the elements of NOS in science teacher education – and the importance of ensuring that these teachers are thoroughly familiar with these elements – has been established, there remains an emerging question that deserves to be addressed in academic research. What strategies can science teachers use to teach topics related to NOS? What types of knowledge about how to teach this content are necessary to ensure that the elements of NOS are taught effectively? How can science teachers be trained to teach based on the elements of NOS? It is within the scope of these questions that this study aims to analyze the results of a professional development program for physics teachers designed to foster future teachers’ knowledge of NOS.

In this regard, with respect to teacher training – in our specific case, the training of physics teachers – more appropriate professional training in the sciences is necessary to ensure that teachers are qualified for their professional activities, which include teaching aspects of NOS. Research studies such as those by Eichler and Del-Pinho (2020), Silva and Marcondes (2015), and Silva *et. al.* (2024), for example, demonstrate the potential of training practices involving the production of instructional materials in teacher education.

> *In this context, since we view the development of instructional materials as a strategy for the initial and continuing education of science teachers, in these courses, we encourage student teachers to develop their own instructional materials for implementing their curriculum proposals* (Eichler; Del-Pinho, 2020, p. 638).

In light of the problem presented, this study seeks to answer the following question: How is knowledge of the nature of science expressed in the training of physics teachers through the task of producing their own teaching materials on historical episodes in physics? Based on this, the specific objectives of this research are as follows:

- To characterize future physics teachers’ understanding of the Nature of Science (NOS) and its application in physics education, as expressed in teaching materials on the history of physics written by the teachers themselves;
- To analyze the contributions of the history of science to the promotion of aspects of the nature of science.

With these objectives in mind, it was possible to advance the study of the training process for physics teachers with a view to understanding the effects of developing teaching materials on historical cases in physics on the expression of knowledge regarding the NOS.

II. The Nature of Science in Physics Education: Contributions and Approaches

Since the main objective of this research is related to the study of the elements of knowledge regarding the Nature of Science (NOS), it is important to present the theoretical framework that underpins its conception and didactic use in physics education as discussed in this text.

Although the term "Nature of Science" (NOS) is widely used by researchers in the field of science education, numerous studies were required before a minimal consensus could be reached regarding the concept and its impacts on the teaching of scientific disciplines. This is justified by the fact that there is no single "Nature of Science" – or, at the very least, it is not possible to define one – "given the plurality of existing scientific disciplines, which, although they share similarities, exhibit divergences in scientific practice" (Silva; Martins, 2018, p. 73). Thus, we cannot assume a single way of conceiving the "Nature of Science," since there is no definitive conceptualization of what the NOS actually is.

However, we have found some attempts at a possible definition, but it should be noted that these are formulated with great care precisely so as not to limit the full scope of the term. According to McComas *et al*. (1998), NOS is a fertile and hybrid construct, in which the social studies of science (History, Philosophy, and Sociology of Science) are combined with research from the cognitive sciences (Psychology), which fosters a rich discussion about what science is, how it operates, how scientists work in social groups, and how society responds to scientific endeavors.

More recently, works such as those by Rodrigues, Oliveira, and Ferraz (2026) and Marcelino, Dalzotto, and Denadin (2026) discuss the possibilities and challenges of constructing appropriate views of NOS based on empirical classroom research, while Santos, Oliveira, and Siqueira (2025) present the results of a systematic review of studies that address Modern and Contemporary Physics through the Nature of Science. It is evident in these works that the view that:

> *The NOS in physics education also has the potential to demystify science as a body of absolute and linear truths, revealing it to be changeable, dynamic, and influenced by social and cultural contexts. Integrating the NOS into physics humanizes the discipline, deepens learning, and enables students to critically evaluate data and arguments* (Marcelino; Dalzotto; Denadin, 2026, p. 172).

Adúriz-Bravo (2005) points out that, due to its relationship with these other fields of knowledge, NOS enables studies on how scientific knowledge changes over time, the scientific values employed in the formulation of a theory, and the relationship between science and society, among other topics. According to Lederman (2007), NOS refers to "the epistemology of science, science as a mode of knowing, or the values and beliefs inherent in scientific knowledge and its development" (p. 833). Meanwhile, for Vázquez-Alonso *et al*. (2007), NOS:

> *[...] It encompasses a wide range of aspects regarding the nature of science, its internal and external workings, how it constructs and develops the knowledge it produces, the methods it uses to validate this knowledge, the values involved in scientific activities, the nature of the scientific community, its links to technology, the relationship between society and the techno-scientific system and vice versa, and the contributions of the techno-scientific system to culture and the progress of society* (Vázquez; Alonso *et. al.*, 2007, p. 34).

Regarding the understanding of what NOS is, according to Moura (2014), it "involves a framework of knowledge about the epistemological, philosophical, historical, and cultural foundations of science. Understanding the Nature of Science means knowing what it is made of, how to construct it, and what and why it influences and is influenced" (p. 33).

It can be observed that there are distinct definitions of the NOS construct in the literature. For example, in the statement described by Lederman (2007), the researcher offers a more restricted definition of NOS, which appears to pertain solely to the field of the philosophy of science; on the other hand, there are broader definitions, as found in Vázquez-Alonzo *et al.* (2007) and Guerra (2014), which include numerous aspects drawn from the sociology of science. According to the latter, "it is necessary to consider teachers' perspectives, their beliefs about teaching, and what they consider to be the primary objectives of science education" (p. 228).

Another equally important study regarding perspectives on scientific activity is that of Gil-Pérez *et al.* (2001; 2005). Based on a literature review of leading international journals in science education, the authors identified seven distorted views regarding the construction of scientific knowledge and the work of scientists, which recur in the transmission of knowledge, whether actively or passively. According to them, the "Decontextualized and socially neutral view," the "Elitist and individualistic view," the "Empiricist and atheoretical view," the "Rigid view (algorithmic, exact, infallible…)," the "unproblematic and ahistorical view," the "exclusively analytical view," and the "cumulative, linear-growth view" can be constructed by teachers with their students when they teach scientific content.

Similarly, Acevedo *et al.* (2005) argue that science curricula often emphasize conceptual rather than procedural aspects of science, that is, they promote teaching centered on the products of science (theories, laws, models, concepts), without discussing how they were produced and accepted, relying solely on empirical results and overlooking the fact that these are insufficient for understanding what science is, how it is constructed, how it functions, and its relationship with society. "The 'insertion of content about the sciences in scientific education fosters a dialogue between knowledge areas and can contribute to the development of the competencies necessary for the 21st-century citizen' (Forato; Pietrocola; Martins, 2011, p. 29)."

In this context, following the academic publication of studies about this idea, what became known during the 1990s was the so-called consensual view of NOS. Since then, supporters of this approach have argued that a consensus regarding aspects of NOS can be established in scientific education. Thus, the consensual view of NOS is understood as:

> *[...] a set of aspects, of a general nature, about which there would be a broad consensus regarding what is expected to be present in the science curriculum. As a reference for instruction, the VC (consensual vision) seeks a pragmatic consensus around certain aspects that would be valid for considering the inclusion of NOS (*Martins, 2015, p. 706).

Therefore, the lists are indicative of common aspects of the scientific enterprise; they do not offer a snapshot of what science is, but rather an attempt to identify common aspects of science. McComas et al. (1998) and Lederman (2002) recognize a consensus regarding the aspects of NOS that are most important to include in science curricula. These authors present the main topics about NOS for an adequate understanding of scientific activity in science curricula.

Other proposals to address NOS in teaching have been developed to avoid transmitting a single, decontextualized, and simplified view of science. For example, Martins (2015) presents a proposal centered on themes and questions about NOS that seeks to overcome criticisms of the consensual view. The author argues that "it is better to offer some teaching about the nature of science, even if limited, than to refrain from acting and allow the continued propagation of distorted and mistaken views of science" (Martins, 2015, p. 717). For this author, the "most appropriate consideration of the NOS theme in Science curricula should start from a more open, plural, and heterogeneous perspective," and, in this sense, he argues that "no list will be exhaustive and will always present problems," as "it is not about asserting that some aspects would be consensual and others not".

It can be observed through this context that understandings of the Nature of Science can be many and multifaceted, where sociological, historical, and epistemological factors imply certain specific knowledge about scientific activity. In this way, each element of NOS varies in relation to lesson planning and objectives.

Therefore, regarding the discussion about NOS in physics teaching, it is necessary to emphasize that we do not intend to cover here the entire plurality of works on this topic, whether they are favorable or contrary to the consensual view of NOS. Thus, based on the above, it is clear that no single list can define what science is, nor can any encompass its heterogeneity and complexity.

III. Research Methodological Procedures: The Context and the Data Analysis Process

This research is characterized as an exploratory field study with a documentary nature, in which a specific situation was analyzed, with the peculiar characteristics of the context in which it is inserted. In our case, the conception of the field for the research takes place in the context of the course called “Evolution of Physics Concepts” and the formative task of producing teaching material in the course by students in a Physics Teaching degree.

The teaching degree students created the materials produced and analyzed in this research as a formative task for a course that was related to the contents of the History of Physics[2]. The course is offered once a year, in even semesters, and has a workload of 96 (ninety-six) class hours, of which 64 (sixty-four) hours are in-person classes at the university and 32 (thirty-two) hours are dedicated to online activities using distance education (EaD) platforms. The course had mandatory participation from students in the Bachelor of Physics program from the 6th (sixth) semester onward and from the Teaching Physics program from the 8th (eighth) semester. Additionally, it is possible for students from other programs to enroll in the course as long as they meet the necessary prerequisites, meaning they must have passed General Physics I, II, III, and have partially met the prerequisite for General Physics IV.

The course syllabus, which outlines the content worked on with the research participants, covered the following topics: i.) Historical and epistemological analysis of the development of physical concepts; ii.) Historical construction of fundamental concepts in mechanics, electromagnetism, optics, and astronomy; iii.) Theories and models in physics; iv.) Different philosophical, epistemological, and methodological views on the production and evolution of knowledge in physics. In this sense, the course promotes a historical approach to the construction of physical concepts (mass, field, charge, temperature, heat, etc.), without explicitly aiming to discuss aspects of the NOS. This feature justifies the purpose of this research, which sought to analyze the NOS elements that emerge in the construction of the history of physics teaching materials by student teachers.

It is important to point out that the course syllabus did not undergo any changes or influence related to the particular interests of the research, continuing to be characterized as a course purely related to the historical construction of the main concepts in physics. The class had 18 (eighteen) students from the Physics Teaching degree program, and the data were collected in 2019, meaning that these works were created by education students before the advent of Generative Artificial Intelligence, and are original productions by the participants. Intending to analyze the understandings about NOS (Nature of Science) for spontaneously teaching metascientific content, the research data consist of the teaching materials prepared by the students and are intended to present the historical construction of a Physics concept.

For the analysis, we carried out the categorization of the data collected about NOS. For that, the data were separated into analysis categories, considering that “categories need to be anchored in the theoretical framework used, but they also need to be in harmony with the data collected during the research” (Carvalho, 2012, p. 1). Categories can be chosen before data collection, a priori, or formulated afterward. When defined beforehand, they rely solely on the

[2] The study was documentary in nature, involving the analysis of materials produced by pre-service teachers; therefore, the research objects were documents rather than human subjects. Nevertheless, all participants agreed to take part in the study by signing an Informed Consent Form (ICF). Only materials produced by participants who had provided informed consent were included in the analysis.

adopted theoretical framework; when chosen afterward, categories conceived from practice emerge in the context of the research, based on the data collection.

In the present work, the chosen categories were developed a priori, based on the NOS frameworks outlined in the theoretical foundation. The categories theoretically built regarding NOS are shown in Table 1. These categories allowed us to understand key issues about how the process of expressing NOS elements occurred throughout the course. Although it was not our goal to align with a specific approach, it is important to point out that the selected categories reflect the consensual view of NOS, considering that the studies consulted to map appropriate and inappropriate views of NOS were from this perspective. As mentioned earlier, criticisms of the consensual view have emerged in recent years, and we acknowledge them. Nevertheless, in this research, the consensual aspects proved fruitful for interpreting and giving meaning to the results found in the teaching materials produced.

Table 1 – Categories of NOS elements built a priori from the references.

NOS Categories	Definitions from the references
The provisional nature of scientific knowledge	Scientific knowledge is not static and convergent, but changeable and limited. Scientific knowledge, while lasting, has a provisional nature; although it lasts in the form of facts, laws, and theories, science is provisional and subject to change.
Difference between observation and inference	Observations are descriptive statements that are directly accessible to the senses; on the other hand, inferences go beyond the senses and use theoretical entities.
The scientific method	There is not a single method that guarantees the production of flawless scientific knowledge, nor a sequence of steps that will reliably lead scientists to answers or solutions; scientists need careful records, peer review, and reproducibility.
The role of experimentation in science	Scientific knowledge relies heavily, but not entirely, on observation, experimental evidence, rational arguments, and skepticism.
Difference between scientific Laws and Theories	Laws and theories are different types of scientific knowledge – laws are descriptions or statements of relationships between observable phenomena; theories are inferred explanations for observable phenomena; therefore, students should understand that theories do not become laws, even with additional evidence.
The role of the scientific community	Shared training is an essential part of the agreement between scientists.
Profile of a scientist	People from all cultures contribute to science.
Communication of scientific knowledge	New knowledge should be reported clearly and openly.
Relationship between Observations and Theories	Observations are loaded with theory: theoretical commitments, beliefs, prior knowledge, training, experiences, and expectations influence what scientists' research and how they research it.
The role of creativity and imagination in scientific activity	Scientific theories are not just inductions, but hypotheses that are imaginative and necessarily go beyond observations, so scientists are creative, even though based

	on observations of the natural world, or derived from them, at least partially; scientific knowledge also involves human imagination and creativity.
Scientific Progress or the Development of Science	The history of science shows both an evolutionary and a revolutionary character.
Social and cultural roots of scientific endeavor	Science, as a human endeavor, is practiced in a broader context, and its practitioners are products of that culture.
Relationship between Science and Technology	Science and technology influence each other. The understanding that the development of science and technological devices is an integral part and is mutually related to each other.
Complexity of scientific knowledge	Nature does not produce evidence simple enough to allow an unambiguous interpretation.
Uncertainty in human interpretation of nature	Scientific theories cannot be proven; science is an attempt to explain natural phenomena.

Source: Elaborated by the authors based on the theoretical references of the research.

It was decided to use the abbreviations T1, T2, Tn… to refer to the analyzed works. In addition to these elements, it is also important to mention that not all fragments representing the participants' NOS views were shown in this work, in order to avoid being redundant and repetitive with similar excerpts. The categorization process followed the principles outlined in Content Analysis (Bardin, 2016), so that the excerpts found in the teaching materials were separated, unitized, and counted as belonging to one of the categories in Table 1. This analytical procedure is better illustrated in Figure 1 below.

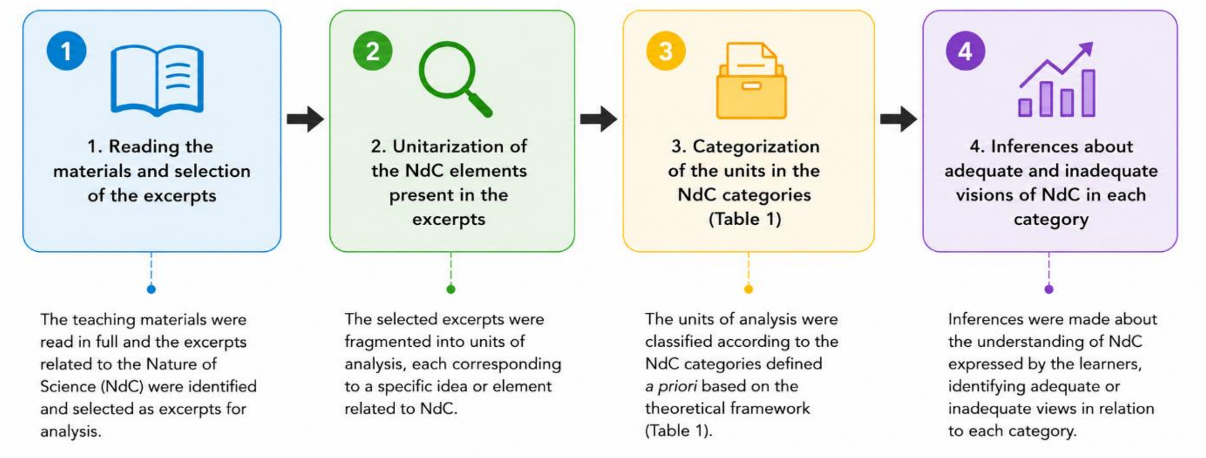

Figure 1 – Script and data analysis based on the adopted methodology.
Source: Prepared by the authors with the support of Artificial Intelligence.

In addition, Table 2 lists the works created by the teaching students and their respective physics content.

Table 2 – Physics concepts covered in each of the analyzed teaching materials.

Graduates	Content
T1	Relativity
T2	Gravity
T3	Gravity
T4	Force
T5	Heat
T6	Force
T7	Celestial Bodies
T8	Time
T9	Mass
T10	Electric Charge
T11	Electricity
T12	Light

Source: Prepared by the authors.

Based on these references and the methodological process of data collection and analysis described so far, we begin the presentation and discussion of the NOS elements found in the papers written by the undergraduates on the History of Physics. From the objectives and methodological procedures described, the analysis of the data obtained from the 12 teaching materials prepared by the future physics teachers was carried out.

IV. Results and Discussion: The NOS elements shown by student teachers in educational materials about the history of physics

Based on this analysis methodology and aiming to examine the views of NOS expressed by physics undergraduates in teaching materials about HP that they produced themselves, we carried out the categorizations of the elements listed in Table 1 and expressed in the teaching materials created by the subjects. It is worth noting that the understandings identified in the participants' teaching materials are spontaneous, since the real context of the course was investigated, and the research interests did not influence it. For example, students were not explicitly asked to have the teaching material address aspects of NOS. The main goal of the activity was to teach a Physics concept using a case from the History of Physics.

Initially, it was identified which elements of NOS appeared explicitly in the materials produced by the participants. This way, it was possible to map the participants' conceptions of NOS involved in this research. The categories found are presented as appropriate and inappropriate views of NOS, with this division based on the NOS references highlighted in this study. The categories most present in the students' materials are expressed below and summarized in Table 1.

Table 1 – Scheme regarding the frequency of NOS aspects in teaching materials.

NOS Category	% that cover	% that does not cover	% Appropriate view*	% Inadequate view*
Provisional nature of scientific knowledge	70%	30%	68%	32%
Difference between observation and inference	0%	0%	0%	0%
The scientific method	50%	50%	67%	33%
The role of experimentation in science	87%	13%	40%	60%
Difference between scientific Laws and Theories	0%	0%	0%	0%
The role of the scientific community	67%	33%	75%	25%
Scientist profile	58%	42%	0%	100%
Communication of scientific knowledge	0%	0%	0%	0%
Relationship between Observations and Theories	10%	90%	100%	0%
The role of creativity and imagination in scientific activity	20%	80%	50%	50%
Scientific Progress or Development of Science	58%	42%	57%	43%
Social and cultural grounding of the scientific endeavor	60%	40%	100%	0%
	0%	0%	0%	0%
Relationship between Science and Technology	25%	75%	100%	0%
Complexity of scientific knowledge	20%	80%	50%	50%

Source: Prepared by the authors.

The categories that appeared most frequently in the teaching materials were "The role of experimentation in science," "The role of the scientific community," "Development of science," "Social and cultural grounding," "Scientific Method," and "Scientist profile."

It can be more clearly observed that the aspects related to "the role of experimentation in science" and "the role of the scientific community" were the ones most mentioned in the works. Meanwhile, the inadequate view appeared more frequently in the teaching materials that addressed the aspect "role of experimentation in science".

It is also possible to see that, although the elements "Social and cultural rooting of science," "scientific method," and "scientist's profile" appear with similar frequencies, there are differences in how they are handled. For "social and cultural rooting of science," all the works show the right view on this aspect, whereas in the scientist's profile, we see an opposite scenario – that is, 100% of the works present inadequate or less informed views on this element of NOS.

Looking back at Table 1, the elements “the role of experimentation in science” and “scientists’ profile” are the aspects that most showed inadequate views. On the other hand, the elements “the role of the scientific community” and “social and cultural rooting of science” are the aspects where appropriate views were most commonly found.

Moreover, we see that the subcategories: “Relationship between Science and Technology,” “Difference between observation and inference,” “Difference between scientific Laws and Theories,” and “Communication of scientific knowledge,” were not covered in the participants' work.

In this sense, the NOS categories most reflected in the work, in general, are related to aspects of the scientists' own activity in the original construction of physics concepts, and not necessarily to aspects of the science-society relationship, as can be inferred from the results. When the teacher chooses to present the historical development of physics concepts by highlighting the research methods used by various scientists over the centuries and the way concepts were built from experiments and publications, these features stand out more in the students’ work.

Having made these initial considerations about the general analysis of this category, the analyses of each fragment of the prepared materials regarding the manifestation of these elements of NOS will be presented below. Through this analysis, it is possible to understand the future teachers' views concerning each of the aspects of NOS presented in the prepared educational materials, making it possible to identify their more accurate conceptions and inadequate views about the scientific endeavor.

In analyzing the materials, it was possible to notice a range of elements that represent views on the role experimentation played in the development of physical theories. When having to address, in a didactic way, the events that led to the development of physical concepts and ideas, the pre-service teachers strongly emphasized the performance of historically relevant experiments. However, we observed the expression of both appropriate and inappropriate views on the subject, based on what the research's theoretical frameworks help us understand about experimentation in the development of physics. The excerpts that illustrate these views are transcribed below.

- Appropriate view:

> *With this in mind,* ***a series of experiments followed that made it possible to establish a new worldview as we entered the modern period*** *(T1, our emphasis). Benjamin Franklin, in 1746,* ***conducted a series of experiments. In one of them, he discovered*** *that the wire coming out of the Leyden jar carries electricity opposite to that of the glass of the jar.* ***Thus, he developed his own theory*** *of electricity, which* ***contradicted the then-accepted*** *two-fluid theory of electricity by Du Fay (T10, our emphasis).*

- Inadequate view:

> *After* ***countless experiments****, his* ***hypothesis was proven****, and Galileo was able to* ***establish the law of falling bodies*** *(T2, our emphasis).*
>
> ***Starting his research on statics****, Benjamin Franklin* ***began several scientific experiments to prove his theories on electricity*** *(T11, our emphasis).*
>
> *It can be noticed that a characteristic inherent to the development of Electromagnetism is the presence of* ***experiments prior to the theorization*** *of phenomena; this paradigm shift is what makes the rapid development of this scientific field possible (T1, our emphasis).*

Regarding the category **'The Role of Experimentation in Science**,' when analyzing the views of T1 and T10, which represent perspectives found in most of the materials analyzed, it is noticeable that there is an emphasis on the importance of experiments that come before theoretical formulation. This is clear in the statements taken from T1, which highlight the relevance of experiments prior to theorizing about phenomena in Electromagnetism, with this feature being a milestone for the rapid progress in this scientific field. T10 adds to this view by mentioning the experiments done by Benjamin Franklin in 1746, when he developed his theory of electricity based on experimental observations that contradicted Charles Du Fay's ideas about electric fluids.

However, excerpts taken from T2 and T11 offer a more complex view of scientific experimentation. In them, there is the consideration that experiments are conducted to prove previously formulated hypotheses. Still, this view is not without problems. By using the word 'proof,' participants may convey an infallible image of science, which goes against its nature, which, according to McComas *et al.* (1998), is a continuous attempt to explain natural phenomena rather than the discovery of absolute truths. Regarding this aspect, it is worth noting, as pointed out by Gil-Pérez *et al.* (2001; 2005) and Oliveira *et al*. (2020), this view reflects an empirical-inductivist or atheoretical perspective, in which experimentation is seen as a neutral process independent of guiding hypotheses. This approach does not take into account the fundamental role of existing theories and the hypotheses that direct scientific investigation. By treating experiments as something casual, the participants suggest that isolated experimentation can generate new worldviews or discover new concepts, ignoring the importance of the theories that shape the research process.

Therefore, we can infer that, based on the appropriate and inappropriate views, the student teachers express how they understand the role that experimentation plays in building physical theories, considering two main aspects: experimentation precedes and is part of the process of creating a scientific theory; and experimentation has been part of the verification of historically constructed theories. Teixeira *et al.* (2009) already reflect on the importance of overcoming the inductivist-empiricist view of the role of experiments in the construction of science and of having greater "diversity in views on scientific methods and the role of experiments in science.” (p. 32)

One of the categories that was frequently expressed by the undergraduates in their materials deals with the influence of various thinkers in the construction of the same physical concept. The participants express in their work how a certain scientific content was historically built due of the work done by many people. This is a relevant element to be noted, as it is typically something that can be constructed in the study of the History of Physics. However, there were still both adequate and inadequate views concerning this element of NOS.

- Appropriate view:

> *[...] That is, there is* ***a constant revisiting of older works and shaping of classical thoughts*** *to fit the paradigms in which the researcher finds themselves (T1, emphasis ours).*
>
> *If I have come this far, it is because* ***I stood on the shoulders of giants*** *(T9, emphasis ours).*
>
> *Science is* ***not built individually, but rather as a collaborative effort that is constantly evolving*** *(T3, emphasis ours).*
>
> *However, since his work was carried out based* ***on medical observations, and not in a physics laboratory, it was initially largely ignored by the scientific community, who did not recognize its credibility****, even though it was published in a reputable journal (the “Annalen der Chemie”) in 1842. Only much later did Mayer’s theories gain recognition, thanks to Rudolf Clausius (T5, emphasis ours).*

- Inadequate view:

> *Newton spent almost* ***18 months alone at home, and during this time, he made revolutionary advances in mathematics and optics, and began working on what would become his great work, gravity*** *(T2, our emphasis).*
>
> *As the story goes,* ***Newton*** *was sitting under an apple tree reading a book when suddenly an apple fell beside him. He looked up to see where the apple could have come from and, in the background,* ***noticed*** *the pale Moon in the daylight, and* ***he wondered, 'If apples fall, does the Moon fall too?'*** *(T2, our emphasis).*
>
> *After countless experiments, his hypothesis was proven,* ***and Galileo was able to establish the law of falling bodies*** *(T2, our emphasis).*

In the category **The Role of the Scientific Community**, excerpts from T1, T9, and T3 highlight science as a collective construction, in which the work of scientists across different eras contributes to the continuous development of ideas. Newton's famous phrase, 'if I have seen further it is by standing on the shoulders of giants,' reflects the understanding that science is not the result of individual efforts, but of a collaborative process that spans generations. According to Kuhn (2009), the scientific community is responsible for evaluating new hypotheses and for accepting or rejecting them, thus determining the progress of scientific knowledge.

We understand that this category being filled by a considerable number of excerpts is an important indication that both the HP class and the task of building the material have potential for developing knowledge of this aspect of NOS, since it is a privileged environment for dealing with the process of constructing physical concepts and theories. Moura (2014) and Peduzzi and Raicik (2020), for example, highlight the importance of teacher training on HP as a way to build elements of NOS. For instance, Moura (2014, p. 40) states that "There is, therefore, a large number of articles in both the international and national literature that discuss NOS and how to incorporate it into teaching from the perspective of the History and Philosophy of Science".

As already discussed in the theoretical framework, understanding the development of science by future teachers is a constant part of their work in teaching physics, since the way topics are handled in school should reflect an understanding of their development. This is, then, a very important element of the Nature of Science (NOS) that student teachers should demonstrate. In the didactic materials on HP that were prepared, we found elements of proper understanding as well as some inadequate views, as shown in the following example excerpts.

- Appropriate view:

> *The idea* ***was not very well received when it was first published****, as it went completely* ***against the paradigm of the time****. However, it has been gaining more and more experimental support* ***and is now widely accepted by the scientific community*** *(T1, our emphasis).*

> ***The construction of these concepts does not happen linearly*** *[...], meaning there is a constant revisiting of old work and* ***shaping of classical ideas to fit the paradigms the researcher is working within*** *(T1, our emphasis).*

> *Galileo begins to undertake one of the first processes for* ***breaking the Paradigm*** *(T2, our emphasis*).

> ***Newton's mechanics was a total success****, as he managed to solve an* ***absurd number of problems, in a qualitative way*** *(T9, our emphasis).*

> *Obviously, the development of the concept of* ***force did not stagnate*** *in history;* ***other formulations or approaches*** *regarding this concept* ***were developed*** *[...] (T4, our emphasis*).

- Inadequate view:

> *Therefore, in order to solve this problem through his calculations, Kepler formulated his first law,* ***denying all the centuries of tradition*** *that existed regarding the view of orbits and the solar system (T2, our emphasis*).

About the category **Scientific Progress or Development of Science**, when analyzing the excerpts related to this category, we notice that the passages from T1, T2, and T9 convey the idea that the construction of scientific knowledge does not happen in a linear and cumulative way. T1, for example, highlights that the scientific community, facing resistance due to the prevailing paradigms, does not always immediately accept new knowledge. This idea is part of the understanding of important philosophers of science, like Kuhn (2009), who argues that scientific development is marked by crises and paradigm shifts, where new knowledge challenges and eventually replaces established ideas.

In short, the development of science depends as much on experimentation as it does on collective validation and questioning of paradigms. However, empiricist-inductivist and individualist views are still common, as shown in excerpt T2, which can lead to inadequate ideas about the role of experimentation and the scientific community.

As Gil-Pérez *et al.* (2005) point out, it's crucial to understand science as a dynamic process, marked by crises and breaks, rather than as a body of accumulated and infallible knowledge. This broader and more critical view of science is key to promoting more effective and contextualized teaching of the history and philosophy of science.

However, it is worth noting that all of the participants' works in the research show a linear view of science. In the twelve works analyzed, all participants chose a perspective of presenting science in a linear and progressive way, addressing questions about the concept from the Greeks to the most accepted formulations today, rather than opting to write about a specific episode. This linear view is also seen in works that include, besides the text, a timeline with the main characters and events related to the historical development of the concept over the centuries. Figure 2 shows an example of these timelines.

This feature runs through all the materials, revealing an aspect that should also be considered by the teachers who train future physics teachers, especially those who deal with HP content. Very likely, the linear and progressive view of scientific development is one of the most deeply ingrained characteristics in students' thinking about HP and, therefore, one of the things that should be most addressed in the training process.

In addition, it is important to note that building a narrative that spans a long period of study across diverse socio-historical contexts around a scientific concept can be a dangerous trap (Martins, 2001). Telling a linear story can lead to an interpretation of science as evolutionary, without breaks, unproblematic, and generalist. In this case, focusing on historical episodes, as recommended by Forato, Bagdonas, and Testoni (2017), is a more relevant training strategy, since “studying different historical episodes can contextualize discussions on various aspects of NOS, challenge essentialist views, and promote better-informed perspectives in teacher education” (p. 3511).

Figure 2 – Timeline in the T11 teaching material.

Science is a complex and tricky endeavor, which is not neutral and is influenced by human interests. Given that, it's questionable whether it's possible to cover, in a single narrative, over 2000 years of understandings about science, addressing issues related to the development of a scientific concept and the particularities of each social, historical, cultural, and scientific context.

The understanding of the scientific method is one of the most important features of knowledge about NOS and is fundamentally relevant in the process of training physics teachers. Various studies on teacher training in HPC emphasize the importance of this training in developing in future teachers an appropriate view of the scientific method and how it is part of the construction of physical knowledge. For Massoni, Moreira, and Silva (2018), for example,

> *For Larry Laudan (2000), HPC has a common concern and a specific interest in the history of the scientific method, and the historian should be concerned with this issue since it is not possible to ignore scientists' opinions on methodological questions when explaining their theories and scientific procedures* (p. 903).

That said, this is relevant information about how the students express their views on the scientific method in materials written by themselves, as we can see below.

- Appropriate view:

> *The "science" practiced by Aristotle **differs** in many ways from **what we understand today as the scientific method**. Ideas arose through **the observation of everyday** phenomena, and their **acceptance was determined by the philosopher's power of argument** (T1, our emphasis).*

> *This was another interesting achievement of Galileo; he was the first to systematize and give a mathematical form to one of the most intriguing phenomena of the time.*

*Not only that, but he also demonstrated **a different way of doing science through measurements and comparisons of models** (T2, our emphasis).*

***The scientific method at the time was based on argument and counter-argument**. However, in the 17th century, with the advancement of science, which started with Copernicus, Kepler, and Galileo, humans began to see the universe as the result of evolution, no longer by the direct action of a Creator, **but through the existence of universal laws of nature that can be expressed mathematically** (T6, our emphasis*).

- Inadequate vision:

*After **countless experiments, his hypothesis was proven**, and Galileo was able **to establish the law of falling bodies** (T2, our emphasis).*

*Around 1760, Joseph Black moved away from his work in chemistry and devoted himself to studying heat, a topic that fascinated him. **Always using his method of rigorous measurements**, he conducted experiments studying the transition between liquid and solid states, which led him to define latent heat (1761) (T5, our emphasis).*

About the category, **the scientific method** expressed by the student teachers, the contributions from T1, T2, and T6 give us an interesting perspective on how they understand this concept. The science practiced by Aristotle, for example, differs significantly from what we currently understand as the scientific method. The philosopher based his ideas on everyday observation, where the acceptance of his theories depended on the strength of his argument (T1). With the transition to a more quantitative approach, Galileo stood out by systematizing phenomena through measurements and comparisons, establishing a new scientific paradigm (T2).

However, this narrative raises questions about the views of NOS held by future teachers. Do they consider other elements that make up the scientific method, like creativity, argumentation, and the complexities involved in knowledge construction? While some passages indicate an understanding of the need for rigor and systematic approaches, there is concern that scientific activity might be seen in a simplistic and linear way.

The contrast in views about the scientific method among the participants reveals a plurality of understandings. One of them suggests that Galileo managed to establish laws from experiments, showing an inductivist perspective (T2). However, this is not exactly new, since the construction of the concept of the scientific method linearly and technically is ingrained in physics teaching itself, as Bagdonas et al. (2010) state, when they understand that:

The inadequate views on NOS found in these studies are mainly linked to the empiricist-inductivist and atheoretical perspective, as well as to the rigid and algorithmic view of scientific practice, which would be characterized by the universal scientific method (Bagdonas *et. al.*, 2010, p. 19).

Another participant, however, emphasizes the need for rigorous measurements, presenting a perspective that might seem limiting by suggesting that the scientific method is the only way to understand phenomena (T5).

The provisional nature of scientific knowledge or the idea that physics concepts have been modified throughout their historical development was addressed in a significant part of the materials prepared. This is also one of the NOS views that are most potentially developed in the context of teaching HPC, as it is a feature of scientific content closely linked to its historical development. Thus, the views expressed by the undergraduates went in this direction.

- Appropriate view:

> *[...] Note that these definitions are so basic* ***that changes in their definitions and structures would cause changes in all of contemporary physics****. In my view, this is the main characteristic of a concept; I see them as* ***the backbone of scientific knowledge*** *(T2, our emphasis).*

> *Science is not built individually, but is a collaborative work that is* ***constantly evolving*** *(T3, our emphasis).*

> *Caloric was thus the most ephemeral of the concepts discussed here. It was* ***influential for much of the 18th century, but by the late 1790s, it was already clear that it had become very controversial,*** *and by the mid-19th century, it* ***had passed into History*** *(T5, our emphasis).*

> *Just like the previous experiments, this experiment made it possible,* ***through its negative result, to change the paradigm in which physics was situated*** *(T6, our emphasis*).

- Inadequate view:

> *After* ***countless experiments, his hypothesis was proven, and Galileo was able to establish the law of falling bodies*** *(T2, our emphasis).*

> ***This would be the first step toward a complete understanding of the phenomenon of combustion*** *– a process that actually involves the combination of oxygen from the air with the substance that is burning (T5, our emphasis*).

Regarding the category of **Provisional Nature of Scientific Knowledge**, although the excerpts presented are illustrative examples of the total excerpts found in each category, it is noteworthy that this characteristic was present in the materials, reporting that the student teachers generally took care to address in the didactic material on HP the provisional nature of scientific knowledge. The participants acknowledge that this is a constantly changing process. T2 mentions that changes in definitions can alter the whole structure of contemporary physics, emphasizing that science is not a static construction, but rather an evolving field (T3 and T5).

This understanding aligns with the ideas of Popper (1975) and Kuhn (2009), who highlight the dynamics of science and the need for constant questioning. Besides being epistemologically aligned, they are also relevant for the training of physics teachers, since it is a view on the construction of physics knowledge that, according to Sobiecziak (2017), should be part of a physics teacher's knowledge base.

An important view, which is also part of the consensual perspective of NOS in the theoretical references, is the understanding that scientific knowledge is complex, meaning that its construction is not done solely through the application of a method or with fully controllable variables. According to the interpretation of Peduzzi and Raicik (2020):

> *There cannot be science; at least in the way it has been produced since its beginnings, without the (metaphysical) assumption that nature is understandable. In every era, science develops in light of a context: philosophical, economic, political, and religious. Even though it has its own drive, which pushes scientists to look for answers to the problems they pose and encounter, it is neither immune to nor independent from the dilemmas and the multiple interests and values present in the environment (society) in which it exists. There are historical, cultural, and social influences and forces acting on science (McComas, 2004). As a result, for example, some research is supported while others are discouraged, censored, or even banned depending on the context in which it takes place* (p. 30).

In this way, few expressions of knowledge on this matter were found, and all of them were considered adequate, as can be seen in the example excerpts below.

- Adequate view:

> ***Human thought is built in a complex way****, and the paths followed by* ***the paradigms of each specific era are closely related to various political, geographical, environmental, social, economic****, and other characteristics.* ***Scientific thought is no different*** *(T1, emphasis ours).*

> *This pursuit, besides being stimulating, can* ***support*** *individuals in* ***understanding the world*** *through a more* ***critical analysis of reality****, unlike common sense (T2, emphasis ours).*

> ***It is difficult to present this evolution in a clear way, because the concept of mass is very subjective and complex****; that is, it is hard (T9, emphasis ours*).

In this way, in the category of **Complexity of scientific knowledge**, the excerpts from T1, T2, and T9 show again how complex scientific knowledge is, which is naturally connected to many social and cultural factors. This understanding makes us see science not as an absolute truth, but as a product of the interaction between human knowledge and the natural world, shaped by different and changing contexts.

Although it is a very important view in the constitution of the elements of NOS, the fact that there are uncertainties in scientific work and the importance of these uncertainties in the construction of physical theories was shown in a few excerpts from the undergraduates' papers, as expressed below.

- Appropriate View:

> *Above all, the* ***most important thing we want to take from here is that time is a perception****.* ***In addition, this perception will vary depending on the cycle we are living through, our minds, and where we are situated****. If we lived for 28 days, we would not experience the cycles, we would not be able to know the seasons of the year, and we would only know a lunar cycle, so we would not have all knowledge that we have (T8, our emphasis*).

- Inadequate view:

> ***There was no doubt, since it was mathematically proven*** *(T6, our emphasis).*

> ***This would be the first step toward a complete understanding of the phenomenon of combustion*** *– a process that actually involves the combination of the oxygen in the air with the substance that is burning (T5, our emphasis*).

About this category of **Uncertainty in human understanding of nature**, some participants show inadequate views of NOS when they suggest in their excerpts that hypotheses can be "proven" absolutely (T5 and T6). However, participant T8 brings an appropriate perspective to the discussion of this concept. She points out that time is a perception and that this perception can vary depending on the frame of reference. This represents an adequate view of scientific activity because science is not an exact copy of reality, nor an absolute description of nature, but rather an attempt to explain natural phenomena.

This dichotomy reveals the need for a critical approach that recognizes the complexity and subjectivity in scientific interpretation. A necessary reflection on this involves two aspects, the first being to what extent this aspect was emphasized with the student teachers during the HP classes themselves. The limited expression of this view on uncertainties, although highly relevant in physics, may have been little explored during the training process of the student teachers who created the written materials.

Moreover, there's the fact that this feature of scientific practice, that is, the view that science is uncertain at certain times, generally isn't part of common sense about science and physics, and it can be a perception that's harder to develop, even in HP classes.

Regarding the category, **the role of creativity and imagination in scientific activity**, there were more expressions of inadequate views, especially those that link creativity to the genius of scientists. You can notice the authors' intention to convey that scientists are creative.

- Inadequate View:

> *The beautiful thing about the science of that time was, in fact, not just explaining observable phenomena, but going beyond, explaining those that weren't observed and creating* ***the most delicate and precise concepts we have today*** *because of* ***the great ability of abstraction they could achieve*** *through the mind and the* ***great creativity*** *based on logic (T2, our emphasis).*

> ***Newton's mechanics was a total success, as he solved an absurd number of problems, in a qualitative way*** *(T9, our emphasis).*

In the excerpt from T2, we can see a hyperbolic interpretation, shown by the use of adjectives like "great," "more delicate," and "more precise" in relation to these activities. This choice of words highlights traits in the image of the scientist, giving them qualities of genius that allow them to explain knowledge considered infallible. After all, as T2 wrote, "the science of that time created the most delicate and precise concepts we have today." According to Gil-Pérez and colleagues (2005), these views are distorted when it comes to science.

Moreover, it is problematic to claim that the concepts formulated at that time are the most accurate we have today. According to Martins (2006, p. 22), "gradually, ideas are refined through debates and criticisms that often completely transform the initial concepts." Therefore, it cannot be stated that the work developed at that time is, even today, the most precise, as it has been refined and modified through other contributions. Its creator can also find this triumphalist and anachronistic characteristic in the excerpt from T9 when referring to the brilliant construction of the theory.

The category **Social and Cultural Rooting of scientific enterprise** refers to an understanding that should be part of the process of building scientific knowledge by future teachers, but which, according to Peduzzi and Raicik (2020), is a characteristic of science that is not usually included in common-sense views about the process of science construction. It is about understanding that scientific content, as well as its consolidation, also happens through the social and cultural influences of scientists or groups. Examples of appropriate views were found.

- Appropriate View:

> ***Time, as we know*** *it with hours, minutes, seconds, months, and years,* ***is a social construct that came about to meet the needs of our progress, our society, and the world in general*** *(T8, our emphasis).*

> *Aristotelian ideas were very strong during this period since they had the* ***support of the church*** *[...] (T1, our emphasis).*

> *And of course, as* ***the church was growing at this time and had a great influence on the ethical and moral issues of society****, Ptolemy's model was well defended and* ***accepted by the Catholic Church****, since it was also believed that man and creation (animals, birds, and planet Earth) should be at the center of all creation, based on biblical texts (T2, our emphasis).*

> ***The Medieval Inquisition** happened during the 12th century and was one of the darkest periods in human history. The Inquisition's premise was to punish any kind of heresy committed **against the Church**. **Numerous figures in science suffered because of the Inquisition.** Giordano Bruno and Galileo Galilei were examples of this. The first was burned alive, and the second was sentenced to house arrest for the rest of his life. **During this period in history, science took** severe hits and stagnated considerably (T12, our emphasis).*

> *Science is a path that can be followed and, in Brazil, has **suffered a series of budget cuts and attacks driven by political interests** (T3, our emphasis).*

> ***After selling assets and businesses, he had more time and resources for his research**, which earned him an international reputation (T11, our emphasis).*

Observing the statements of the undergraduates in this category, the excerpts reveal a concern with highlighting the intersections between the construction of scientific knowledge and the social, cultural, political, and economic conditions that surround it. Besides seeking to understand natural phenomena, science plays a fundamental role in solving problems that affect our daily lives. Therefore, social influences have a direct impact on scientific endeavors. We live in society and, as such, the issues around us shape us. Thus, science is not only influenced by society but also influences it.

The importance of religious factors in the scientific journey is equally evident. The passages highlighted by the participants point out that those Aristotelian ideas, supported by the Church, shaped the scientific thinking of a time when morality and ethics were under strong religious influence (T1 and T2). The Medieval Inquisition illustrates how social and religious pressures can affect science, resulting in tragic consequences for figures like Giordano Bruno and Galileo Galilei (T12). These accounts show that, at certain times, the power of the Church had a decisive impact on research and scientific development.

Moreover, the sections that address political and economic factors reinforce the understanding that science does not operate in a vacuum. Financial and political support is essential for scientific activity. One participant points out that in Brazil, science has suffered budget cuts and attacks driven by political interests, which undermine the necessary investments (T3). Likewise, another participant's account reveals that access to financial resources is crucial for the success of their research (T11). This intersection between science and politics is not an isolated issue, but reflects a broader reality that transcends time and space.

The conceptions addressed by the research participants, as noted by Lederman (2002), include the view that science is a human endeavor deeply intertwined with cultural context. Science, therefore, is not an isolated entity, but a reflection of the various social and cultural elements surrounding it.

When we look at the category **Scientist Profile**, the excerpts presented highlight the individuality and genius of scientists, portraying them as solitary figures in search of discoveries. This view, which emphasizes objectivity and genius, overlooks the complexity of scientific work, which is often collaborative and multifaceted. In this case, for example, the materials written by the preservice teachers predominantly reflected inadequate views regarding the profile of the scientist, with the exception of a single excerpt from T2, which describes the earlier development of the knowledge now known as Kepler's Laws.

- Appropriate View:

> *Although Kepler proposed the first model for orbits to be ellipses,* ***we cannot credit him as the "discoverer"*** *of the idea.* ***There were already documents long before him about a woman, a Greek Neoplatonist*** *from Roman Egypt.* ***She was the first documented woman to be the head of the Platonic school of Alexandria, where she also taught philosophy and astronomy. Even though there is no data showing that Kepler had access to her works and ideas***, ***he deduced the same ideas as*** *Hypatia simply through mathematics and observation of Brahe's data (T2, our emphasis*).

- Inadequate view:

> *He was a rather* ***shy young man, did not have many friends, and hardly socialized****, so he focused on investing in his knowledge (T2, our emphasis).*
>
> *Newton spent practically 18 months* ***alone*** *at home, and during this time,* ***he made revolutionary advances in mathematics and optics,*** *and started working on what would become his* ***great work****, gravity (T2, our emphasis).*
>
> *[...] after a few years, the teachers realized that the young Johannes* ***was a brilliant boy,*** *and he was sent to the University of Tübingen with excellent school grades (T2, our emphasis).*
>
> *The* ***genius*** *Sadi CARNOT himself (T5, our emphasis*).
>
> *Then emerges* ***the one who would become the greatest experimental physicist in electricity and magnetism of all time****, Michael Faraday (T10, oral information, and our emphasis).*
>
> *In 1794, he* ***decided to set up a device*** *where two different metals were placed, without contact with any kind of fabric.* ***As a result of his work****, he discovered that an electric current was flowing between the two metals (T11, our emphasis*).

In the same vein, there are no fragments in the passages that suggest what problems motivated the work of these characters. In this sense, scientific activity appears in a caricatured, masculine, impoverished, unproblematic, and ahistorical way. The contribution of a female figure such as Hypatia, although representing an alternative and therefore appropriate approach in contrast to the preceding ones, is still presented in a superficial manner within a predominantly male context, without a proper critical examination of the exclusion of women from intellectual and philosophical inquiry characteristic of that period.

The discussion of the scientist as a citizen prone to social relationships, power, and money, for example, although present in historical cases, is still not present in the image of the scientist that college students chose to highlight in their teaching selections. Bejarano, Audúriz-Bravo and Bonfim (2019, p. 979) reflect on this idealized view of the scientist that still permeates science communication.

> *Actors like tense personal relationships, competition for obtaining research funds using personal power and influence, and the exchange of favors that are not always commendable, are legitimate other aspects of NOS that can be highlighted from this text. These aspects also help give scientists a degree of 'humanity' that is rarely considered.*

That being said, there is still a need to improve how physics content is developed with future teachers, even in HP training processes, aiming to build an image of scientists and physicists that better matches the reality they experienced in their respective times.

In the category **Relationships between observations and theory**, the highlights regarding the relationships between observations and theories allow us to infer that participant T1 considers that the foundations of a scientific concept, that is, of theories, can lie in the observation of phenomena, in experimentation, or in other works, reflecting an inadequate view of the scientific endeavor, since they do not consider that the role of theories in developing scientific concepts precedes observations.

- Inadequate view:

> ***Scientific concepts*** *can* ***be defined as constructions based on the observation of phenomena, experiments****, and mainly,* ***structured on a multitude of works*** *developed throughout history (T1, our emphasis).*

Although it was the least mentioned category in the materials, it is important to highlight the relevance of this information, since the construction process necessarily involves the relationship between observations and theories. As Pumfrey (1991) argues, "meaningful observation is not possible without a pre-existing expectation" (p. 69). Therefore, this passage shows an empiricist-inductivist and atheoretical view, which supports the role of 'neutral' observation and experimentation, while overlooking the essential role of hypotheses in guiding research and the coherent bodies of knowledge (theories) available, which direct the whole process (Gil-Perez *et al.*, 2005, p. 45).

Moreover, it is essential to understand that the relationship between observation and theory involves recognizing that experiments in physics have historically been developed based on previously established theoretical frameworks. In this sense, it is expected that undergraduate students understand that many historical experiments were not originally designed to formulate new theories, but rather were created and conducted in light of existing theoretical structures that guided their design, execution, and interpretation.

Melado (1997) helps us understand this contradiction. The author reports that through his work, in which he investigated the conceptions of pre-service science teachers who had contact with views of NOS, although they had multifaceted conceptions of scientific activity, there were moments when they were insecure and contradictory in their statements. Moreover, they admitted that they had never reflected on these issues before.

With the analyses and discussions of the results presented, it is up to us to understand the meaning of this information for the initial research question, which aimed to understand the possibilities of the formative strategy of having teaching material written by pre-service teachers in HP classes in revealing conceptions about NOS. The analysis shows that the initial training of physics teachers still faces challenges regarding the understanding of NOS. The presence of inadequate viewpoints points to the need for more in-depth work in teacher education, ensuring that future teachers convey a more accurate and well-founded understanding of how science works to their students. Even so, given the fact that there were many expressions of views on NOS in the written materials, this is a relevant strategy for training physics teachers on these topics, as recommended by Moura (2014):

> *According to the authors, introducing the nature of Science in teaching is important, for instance, to challenge students and teachers' inadequate views on the construction of scientific knowledge and to improve the learning of concepts and interest in Science. Finally, the authors highlighted the importance of NOS in teacher education, discussing studies that showed changes in teachers' conceptions when they took specific courses on the subject (*Moura, 2014, p. 38).

The analysis of the excerpts taken from the teaching materials created by the undergraduates reveals a variety of views on the NOS among physics students. The inadequate views illustrate simplified and sometimes distorted conceptions of the scientific process, while the adequate views reflect an understanding more in line with the epistemological principles of theoretical frameworks, such as the consensual view of NOS. Finally, this discussion is not disconnected from the formative potential of this type of practice regarding the training of physics teachers.

Since the focus of the research is also the initial training of physics teachers, it is relevant to contribute to overcoming the inadequate views of NOS expressed in the materials. The History of Physics course, which is the subject of this practice, should explicitly problematize and discuss the NOS aspects that underlie the historical constructions of concepts, as argued, for example, by Forato and Pietrocolla (2011):

> *In this way, when one chooses to use the history of science (HS) in science education, it's important to be clear that any historical narrative holds a particular view of science and the processes of its construction (ALLCHIN, 2004; MARTINS, 2006a). By building, using, or sharing a certain version of HS, one is spreading an idea of how science was constructed* (p. 30).

Giving the proper details to this issue, we notice that the recurrence of interpretations that give experiments the role of "proving" theories suggests that the empirical-inductivist view is still present in the training of future teachers who created these materials. This result reinforces the need for training practices that explicitly question the role of experimentation in the construction of scientific knowledge, discussing its relation to hypotheses, theoretical models, creativity, and scientific argumentation. In this sense, using historical episodes, like those already covered in the course, that highlight controversies and different interpretations of the same set of evidence could help achieve a more sophisticated understanding of scientific activity and overcome empiricist conceptions of science.

This result points to the need for educational practices that promote a critical analysis of the historical narratives traditionally used in physics teaching, questioning heroic, individualistic, and masculinized discourses of scientific activity. One strategy for reinterpreting these moments could be, for example, the use of interrupted stories (Schiffer; Guerra, 2019; Rozentalzki; Cavalari, 2025) as a way to challenge these narratives.

V. Final Considerations

This work was developed with the goal of analyzing how students in initial teacher training for the physics course spontaneously express their knowledge about the Nature of Science (NOS) while creating teaching materials, using the History of Science as a teaching strategy to explain a scientific concept. After analyzing the data, we understand that the main contribution of the research is to show that producing teaching materials on the history of physics by pre-service teachers can spontaneously reveal their ideas about the Nature of Science, making it a relevant strategy both for investigating these ideas and for the initial training of physics teachers.

From the analysis of the materials produced by the pre-service teachers, we found that they explore 11 (eleven) of the 15 (fifteen) NOS categories used as a reference in this work. More specifically, it was possible to find in the pre-service teachers' work the manifestation of the following NOS categories: The role of experimentation in science; The role of the scientific community; Development of science; Social and cultural embedding of science; Scientific method; Scientist profile; Provisional nature of scientific knowledge; Uncertainty in human interpretation of nature; Complexity of scientific knowledge; The role of creativity and imagination in scientific activity; and Relationships between observations and theories. The data analysis allowed us to recognize both adequate and inadequate views on these elements, based on the educational materials produced.

However, it is noted that the activity was limited to identifying these mobilizations of the student teachers in a spontaneous and explicit way in the materials. Thus, during the training of the student teachers, the characteristics that make up the elements of NOS were not discussed within the chosen approach. Furthermore, it is highlighted that the results have limitations, as not every historical episode allows for exploring various aspects of NOS. Nonetheless, given the possibility of identifying in the materials produced by the student teachers their adequate and inadequate views of NOS, we believe that this teacher training practice in physics carries significant potential as a tool for expressing NOS knowledge.

It is also possible to identify moments when pre-service teachers reveal both adequate and inadequate views about the same aspect of NOS. This happens because they are still in the process of training and reflecting on scientific endeavors. Additionally, the frameworks of knowledge about scientific processes are heterogeneous, multifaceted, and plural, which requires training that enables reflection and confrontation of inadequate or poorly informed views about science that are already ingrained. After all, these views are also formed through everyday experiences, whether through formal science education or through media and science communication.

In this way, the results obtained from this research indicate possibilities for continuing this study. It is pointed out that, after having identified the main forms of spontaneous and explicit expressions of the pre-service teachers regarding aspects of NOS, it would be important to follow the teachers investigated in their professional practices using the teaching material produced by them.

The data suggest that creating teaching materials is a promising strategy to make future teachers' knowledge about the Nature of Science more visible. However, the results also indicate that simply doing this task is not enough to overcome less informed ideas about scientific activity. This highlights the importance of explicit and reflective training processes, where aspects of the Nature of Science are intentionally discussed, questioned, and evaluated during the initial training of physics teachers.

Finally, it’s worth highlighting the need for a deeper analysis of the relationships between the knowledge found and not found in this research and the teacher training process, since the data presented indicate that these relationships are a result of experiences that education students have during their initial training. Exploring them, therefore, can bring contributions both to the ways content is taught and to the fields of teacher education.

Refererences

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