

Testing the training of undergraduate students to rectify the proliferation of implicit lessons with unwanted views of the nature of science

ABSTRACT

This study is part of the teacher training line of research, with the aim of contributing to a proposal for teaching the subject "Evolution of Concepts and Theories in Physics", which is traditionally present in the curriculum of an undergraduate course in Physics, and by which are designated discussions on the evolution of scientific concepts that take place in the historical contexts of this science. The proposal is an essay and basically advocates the inclusion of two moments: 1) the insertion of justificationist and non-justificationist epistemological references about the development of scientific knowledge; 2) the insertion of excerpts from the history of science, selected for reading, in which the interpretative epistemological possibilities are established through these references by the students to the desired improvement through formative assessment. For the viability of the proposal, a selection of some epistemological references is presented by means of an analytical tool that can be used in discussions of the history of science, applying it, by way of example, to a historical excerpt now published in a newspaper, characterizing it as an instructional alternative to support the preparation of then undergraduates and future teachers. Some reflections are also made on the limits and possibilities of these analytical tools compared to the vast majority of educational resources in the history of science, which are textual in nature and usually prepared without philosophical intent. It is expected, therefore, to contribute to the training of future teachers, in order to overcome the common implicit teaching of an undesirable view of the nature of science when they come to teach in secondary/ high schools, a problem that has persisted in science education for some time.

KEY WORDS: Epistemological references. Pedagogical proposal. Formative assessment. History of science texts. Teacher training.

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Ensaio à formação de licenciandos para retificar a prosperação de lições implícitas com visões indesejadas da natureza da ciência

RESUMO

Este estudo insere-se na linha de pesquisa de formação de professores, com o objetivo de contribuir com uma proposta de instrução à disciplina intitulada “Evolução dos conceitos e teorias da física”, tradicionalmente presente na grade curricular de um curso de graduação em Física e pela qual se designam discussões das evoluções de conceitos científicos que se dão por contextos históricos desta Ciência. A proposta constitui-se num ensaio e defende basicamente a incorporação de dois momentos: 1) Inserção de referenciais epistemológicos justificacionistas e não justificacionistas acerca do desenvolvimento do conhecimento científico; 2) Inserção de trechos da história da ciência, selecionados para leitura, nos quais se estabelecem possibilidades epistemológicas interpretativas por meio desses referenciais pelos estudantes ao aprimoramento desejado via Avaliação Formativa. À viabilidade da proposta, apresenta-se uma seleção de alguns referenciais epistemológicos mediante um instrumento analítico exercitável em discussões da história da ciência, aplicando-a, a título de exemplo, num trecho histórico ora divulgado em jornal, caracterizando-se numa alternativa instrucional a fim de subsidiar a preparação dos então graduandos e futuros professores. São também estabelecidas algumas considerações dos limites e possibilidades desses instrumentos analíticos frente à grande maioria de recursos educacionais da história da ciência disponíveis do tipo textual, e que normalmente seguem elaborados sem intuítos filosóficos. Espera-se, portanto, contribuir à capacitação dos futuros professores para superarem comuns lições implícitas de uma visão indesejada da natureza da ciência, quando vierem a lecionar no Ensino Médio, preocupação esta que há tempos persiste na educação científica.

PALAVRAS-CHAVE: Referenciais epistemológicos. Proposta educacional. Avaliação Formativa. Textos de história da ciência. Capacitação de professores.

INTRODUCTION

One subject commonly found in the undergraduate Physics curriculum is “Evolution of Physics Concepts and Theories”. The course explores the historical context of scientific concepts and their evolution over time. According to Silva and Laburú (2010), every history of science presents an implicit lesson about the nature of science. Therefore, there can always be an epistemological¹ conception underlying any teaching situation (Silva & Laburú, 2016). However, it is not uncommon to find that those who teach the subject employ explicit conduct with little or no emphasis on a philosophical/epistemological nature in such contexts. Physics undergraduate courses are often taught by teachers from the local department, who usually have specific and further training in physics but little or no training in philosophy. While many of these teachers are competent in research, it is important to note that philosophy is an indispensable instructional tool for this subject.

The warning about the situation above is discussed in philosophical justification by Bunge (1973, p. 11), when he states that when one declares not being interested in philosophy, they are probably replacing an explicit philosophy for an implicit one, which he considers to be immature and uncontrolled. The main reason for persistent concern in science teaching is the need to overcome a vice arising from the empiricist position. This position is based on the belief that science starts from the sensible, from the observation of facts (Silva & Laburú, 2016, p. 37)², which considers scientific knowledge as something definitive and growing by accumulating eternal truths. (Lakatos, 2007, p. 18). Because positivism is seen as outdated on a philosophical level³ (Chalmers, 1994, p. 61; Koiré as cited in Lakatos, 1978, p. 18)⁴, it is also sought to be abolished from science teaching, where various educational studies highlight its undesirable survival (Costa et al., 2017, p. 8; Pereira & Amador, 2007, p. 213; Ponczek, 2009, p. 297; Silva et al., 2019, p. 111; Silveira; Ostermann, 2002, p. 7; Vásquez & Massareno, 1999, p. 378). For decades, research in science education has shown that outdated views on the nature of science and scientific work are one of the main obstacles to renewing science teaching (Chinelli et al., 2010, p. 18), and that there is lack of appropriate resources so that students and teachers may learn and teach not only science, but about science (Moura, 2014, p. 32). According to Moreira and Massoni (2016, p. 1), even after decades of discussion in the literature about the interfaces between epistemologies and science teaching, many of these interfaces are still ignored in practice today.

The teacher's epistemological conception⁵ influences the science they teach in the classroom. Therefore, it is crucial to teach the subject “Evolution of concepts and theories in physics” with a reasonable philosophical orientation. This is especially important for the teacher training of undergraduates. In particular, it should bring the awareness to undergraduates of multiple methodological theories that make it possible to overcome historical interpretations with justificationist⁶ tendencies, which are more logically and epistemologically criticizable. In a sensibly crafted instructional guideline, the aim is to enhance students' preparation for their future roles as educators, steering away from implicitly conveying undesirable perspectives on the nature of science when they transition to teaching in secondary schools. This caution is echoed in the science education literature, which suggests that every historical account of science

implicitly imparts a certain understanding of the nature of science (Alchin, 2004; Lakatos, 2007; Matthews, 1994). These scholars argue that histories of science, in essence, construct philosophical viewpoints through their selection and interpretation of examples, thereby influencing the philosophical underpinnings subtly embedded in the teaching of science.

Therefore, the pedagogical proposal developed here, which constitutes a theoretical essay on the subject in question, detailed by historical discussions on the evolution of scientific concepts, aims to better enrich the preparation of undergraduate students in teacher training by basically advocating the incorporation of two moments (or stages):

1) The inclusion of justificationist and non-justificationist epistemological references on the development of scientific knowledge;

2) The inclusion of excerpts from the history of science selected for reading, in which epistemological possibilities are established for students to interpret such references for the desired improvement in this sense.

The literature surveyed here⁷ clarifies the first moment, while the second moment is proposed as the complementary instructional mode of training in Formative Assessment. In order to ensure the proposal's viability, the following sections present a selection of epistemological references for an analytical instrument that can be used in historical discussions of science and is expected to provide a useful instructional recommendation for preparing undergraduates. Finally, this text considers the limitations and capabilities of analytical instruments in comparison to the numerous educational resources on the history of science available in textual form. These resources are often created without philosophical intent, making it impossible to configure them to a specific epistemology.

EPISTEMOLOGICAL REFERENCES FOR STRUCTURING AN ANALYTICAL INSTRUMENT THAT CAN BE USED DIDACTICALLY

Firstly, it is important to address two contextual considerations:

1 - Within historiographies, purportedly “factual” propositions are imbued with methodological theories. Lakatos suggests that this phenomenon can be associated with the distinction between history₁ and history₂. History₁ pertains to actual historical events, while history₂ encompasses historical propositions. According to Lakatos, any history₂ is a theory – and a reconstruction of history₁ loaded with value. Furthermore, he contends that even the most professional historians, who ostensibly oppose the philosophy of science, inevitably produce philosophically motivated nonsense. Lakatos emphasizes that an inductive approach to historiography proves to be unattainable, stating that history without some theoretical inclination is impossible (Popper as cited in Lakatos, 2007, p. 157).

2 - The philosophy of science does not indicate that a philosophical standpoint is dismissed solely due to its characterization of historical discrepancies or the extent of intentional interpretative grafting in its historical reconstructions. Instead, it is when a superior epistemological alternative⁸ emerges under significant epistemological and logical scrutiny. This distinction underscores a separation between justificationist positions at a philosophical level and

subsequently, more enduring (non-justificationist) epistemologies, such as those proposed by Popper, Kuhn, and Lakatos, among others. Lakatos (2007, p. 20) situates the former within this division, stating that justificationism entails using proven knowledge to identify knowledge and has historically been the prevailing tradition in rational thought. He further notes that “neo-justificationism” (or probabilism) has also proven to be equally unsustainable. Lakatos emphasizes that all forms of justificationism⁹ rely on the provability of “factual” propositions, and thus far, they have all collapsed under the weight of epistemological and logical criticism (Lakatos, 2007, p. 158).

The instructional purpose is structured around an analytical instrument that selects aspects of the justificationist strand, logical positivism, and encompasses some of the main aspects of contemporary epistemologies. This selection is made because these references are widely highlighted in the philosophy of science. However, to maintain objectivity, it is possible to include another distinct selection of references for both sides, as long as the strongest and most unmistakable characteristic that serves as a separation is maintained in the comparison. The criterion for distinguishing these sides is that, while for any justificationist, knowledge is identified with proven knowledge (Lakatos, 2007, p. 20), this identification does not occur in any contemporary epistemological position.

Based on the framework outlined and suggested for reference selection, below are synopses of key aspects of the four epistemological threads proposed for identifying inclinations toward these aspects in historical texts. This serves as an exemplary analytical instrument tailored for the pedagogical objectives detailed in the subsequent section. Additionally, this instrument should be seen as an alternative model crafted for the context. Specifically, in the conventional curriculum of the course “Evolution of concepts and theories in physics”, it is advised to reserve discussions on each epistemological thread¹⁰ until after they have been introduced as a preparatory phase (the previously mentioned first phase, or stage 1). Only then, in stage 2, should the analytical instrument be employed with undergraduates to ensure its comprehensibility to them¹¹.

The model of the analytical instrument composed of the four epistemological strands is exemplified below:

1) Epistemological synthesis of logical positivism: it is suggested that science is characterized by rationality, with its path to truth rooted in empiricism-inductivism (Abbagnano, 2000). The focus on this scientific approach, recognizing a certain order and regularity in natural events, entails empirical generalizations articulated in observational terms and perceived through the senses, via verification. According to the perspective established by the members of the Vienna Circle, the core principle is that of verifiability: it is posited that the meaning of a proposition is reduced to the set of immediate empirical data, the occurrence of which confers truth on the proposition and the non-occurrence of which falsifies it; the meaning of a proposition is its empirical truth conditions (Schlick & Carnap, 1985, p. x). This principle, regarded by logical positivists as a demarcation criterion between science and metaphysics (Schlick & Carnap, 1985, p. xvii), is a fundamental tenet advocated by Schlick (1985), who states that verifiability means the possibility of verification (p. 90); it should be emphasized that when we speak of verifiability, we mean the logical possibility of verification, and only this (p. 92). Within this framework, it is asserted that all metaphysical statements are meaningless because they are not empirically verifiable (Abbagnano, 2000, p.

328), in contrast to laws and theories, which can be verified and are guided by logic and empirical observation.

Finally, Carnap (1985, p. 171) modifies the above principle by the principle of confirmability, admitting that general laws can never be completely verified, but can be gradually confirmed, as he explains that A scientific proposition's level of confirmation by experience would vary based on the quantity of empirical evidence supporting it, acknowledging the impossibility of consistently elevating the level of confirmation to absolute certainty (Schlick & Carnap, 1985, p. xvii). Carnap (1985, p. 172), states that in place of verification, the idea is gradually increase confirmation of the law, and the author also points out that inductive logic would make it possible to establish that the truth of certain logical consequences of a proposition determines for it a degree of confirmation (Schlick & Carnap, 1985, p. xvii). From this follows the notion of testability, in which a proposition is said to be testable if it is possible to carry out experiments capable of confirming it (Schlick & Carnap, 1985, p. xvii).

2) Popper's epistemological synthesis: in opposition to the empirical-inductivist method, which Popper (1975, p. 75) is unfavorable of, it emphasizes that theory permeates all our knowledge, even our observations. Contrary to the principles of verifiability and confirmability, Popper (1987, p. 20) advocates for the demarcation criterion based on falsifiability (or rejection), and affirms that, according to his criterion, a statement or theory is falsifiable only if there exists at least one potential falsifier. Consequently, pseudo-scientific theories (non-scientific or metaphysical) lack potential falsifiers. This perspective implies that a hypothesis is scientific only if it excludes some logically possible observation, leading to its confirmation upon passing an empirical test; otherwise, it is falsified.

It is important to note that, in the Popperian perspective, both theoretical and observational propositions are influenced by theories and expectations. Furthermore, statements regarding the "empirical basis" are not determined by universally agreed-upon standards but by singular spatio-temporal contexts, leading Popperian falsificationism to align with conventionalism. This alignment distinguishes between the understanding of a rejected (falsified) theory and a refuted theory, thereby embracing fallibilism. According to Popper (as cited in Lakatos, 2007, p. 27), it is impossible to conclusively refute a theory, and those who await an infallible refutation will indefinitely delay their learning from experience. In the pursuit of bold and "risky" falsifiable theories and crucial negative experiments, genuine falsifications will always remain conjectures, fallible and open to critique. This process follows the rationale that it is important to substitute a falsified hypothesis with a superior alternative. Typically, before falsifying one hypothesis, another is already in consideration, as the falsifying experiment often serves as a crucial test to choose between the two (Popper, 1972a, p. 92).

Since there is no way of proving the veracity of scientific knowledge, the progress of science occurs, therefore, through the accumulation of falsified theories, replaced by others that may come closer to the truth according to the concept of likelihood, represented by the calculation of the measure of the content of truth subtracted from the measure of the content of falsity of a theory, and whose result is also thus compared to that of another theory or theories (Popper, 1972b, p. 259).

3) Kuhnian epistemological synthesis: The idea of a paradigm is introduced by Kuhn, defined in periods of normal science, such as astronomy during the Middle Ages (Ptolemaic paradigm), mechanics in the 18th century (Newtonian paradigm),

and the Theory of Relativity in the 20th century (relativistic paradigm) (Kuhn, 1987). In these periods, the author establishes a metaphor with the resolution of puzzles, inserted in a category of problems deliberated by the prevailing paradigm and whose resolution tests the ingenuity or skill of scientists. When there is a significant accumulation of failures in these puzzle resolutions, the puzzles are considered anomalies, which generates a state of crisis in the research area and contextualizes a period called extraordinary science. And in the quest to invent theories that explain observed phenomena, he states that he disagrees, along with Popper, with any efforts to produce observational language that is neutral (Kuhn, 1979, p. 6).

However, Kuhn (1987, p. 108) warns about the abandonment of a paradigm, stating that once a scientific theory has attained the status of a paradigm, it is deemed invalid only if a viable alternative is present to supplant it. Examples of scientific revolutions include: the case of the Ptolemaic paradigm (geocentric model), abandoned with the emergence of the Copernican paradigm (heliocentric model), and the replacement of the phlogistic paradigm (Phlogiston Theory) by Lavoisier's paradigm (Theory on the combustion of oxygen) (Kuhn, 1987). Kuhn (2006, p. 24) observes that such scientific revolutions are far from cumulative processes, due to articulations of predecessor paradigms, leading to incommensurability. Thus, proponents of competing paradigms practice their professions in different worlds, illustrating shifts in conceptual frameworks perceived by scientists, as in the case of Newtonian mass being conserved while Einsteinian mass is convertible with energy. Kuhn came to be classified as a relativist for advocating faith in the chosen paradigm candidate, which does not necessarily need to be rational: "If there is a criterion of demarcation (I understand that we should not seek a clear or decisive criterion)" (Kuhn, 1979, p. 11). Among the most useful criteria, Kuhn lists (1987, p. 252): accuracy in predictions, balance between everyday and esoteric subjects, number of different problems solved, simplicity, scope, and compatibility. When it comes to two scientific theories, for example, it is always possible to violate some semantic rules by which the world is described through some "universal and timeless" criterion because the individual who gave a certain name to a determined science, while another individual did not, was just exercising his preference (Kuhn, 2006, p. 262). Regarding this, the author concludes (2006, p. 264) that, even though he will not attempt to give any answer to that question, he would like to have one. Finally, Chalmers (2000, p. 124) summarizes Kuhn's framework of how science progresses with the following open scheme: pre-science - normal science - crisis/revolution - new normal science - new crisis.

4) Lakatosian epistemological synthesis: Lakatos acknowledges "rational research programs" where Kuhn identifies "paradigms" (Lakatos 2007, p. 119). A significant distinction lies in how scientific revolutions are approached, not as religious conversions, but as rational advancements within what he terms the methodology of research programs (Lakatos, 2007, p. 19). A research program consists of a "firm core" (a set of postulates or theories)¹² with negative heuristics preventing its refutation by scientists, and a "protective belt" (a collection of auxiliary hypotheses and observational methods) with positive heuristics guiding scientists to adjust this belt based on experimental outcomes, directing falsifications towards the auxiliary hypotheses and amidst an "ocean of anomalies" that also suggest paths for potential transformation into predictions with confirmations. A research program is deemed "progressive" when it forecasts new

facts supported by corroborated predictions (both theoretical and empirical growth), which may include “improbable facts, or even forbidden” by another competing program (Lakatos, 2007, p. 46). Without such predictions, the program is considered “degenerative,” even if its predictions lack corroboration. Unlike Kuhnian incommensurability, simultaneous work on two rival programs is feasible, as illustrated when the Cartesian theory of vortices was elaborated by Newton, in order to demonstrate that it was inconsistent with Kepler’s laws (Lakatos, 2007, p. 147).

The history of science thus represents stories of competing research programs, where so-called “scientific revolutions” are viewed as instances of rational processes of surpassing one program (theory) with another. Lakatos (2007, p. 46) determines that the rule of acceptance (or “demarcation criterion”) for a theory to be deemed “acceptable” or “scientific”, is that it must possess a surplus of empirically supported content in comparison to its predecessor (or rival). In other words, it must contribute to the discovery of new facts. The author then questions of how scientific revolutions happen, and explains that if there are two rival research programs and one progresses while the other degenerates, scientists tend to adhere to the progressive program. However, the falsification of one research program against another does not occur instantly through crucial experiments, which would take decades later to be deemed as crucial (Lakatos, 2007, p. 97), in hindsight. Moreover, in some cases, research program which are composed of talented and imaginative scientists can hardly be defeated (Lakatos, 2007, p. 96), since they may even turn a crucial experiment into a victory for the program. This is sometimes viewed by the same scientists as degenerative or defeated, thereby making it progressive once again (Lakatos, 2007, p. 115).

As it stands, the analytical instrument is a synthesis of epistemologies previously discussed in classes and selected with the guidelines set out here: it comprises justificationist and non-justificationist views. In this teaching approach, taking into account the conventional classes on the mentioned references alongside readings suggested from primary and/or secondary sources, it is advisable for the subject teacher to mandate that each student create this specific analytical instrument. This will enable them to utilize it during the strategic review of content in the Formative Assessment, as detailed in the subsequent section. Despite this method, it is prudent to assist students by supplementing their individual efforts, which may occasionally lack clarity or accuracy, with the provision of an analytical instrument akin to the one developed here and now by the teacher.

EXEMPLIFYNG AN APPLICATION OF THE VIABILITY OF THE PROPOSAL WITHIN A FORMATIVE EVALUTION

A proposta considera que, antes de uma Avaliação Somativa acerca dos Assessment of the epistemological references in the midst of the historical approaches discussed in class, a Formative Assessment can be useful, consisting of the use of the analytical instrument in certain history of science texts found in textbooks, various magazines, newspapers, among any other reading materials in this regard. Formative Assessment then refers to any continuous practice aimed at enhancing ongoing learning, regardless of the framework or the specific degree of teaching differentiation (Costa et al., 2017, p. 46). Regarding the instruments that

the teachers may use, Pedrochi (2017) presents a survey of the characteristics of Formative Assessment detailed by Bloom et al. (as cited in Pedrochi, 2017, p. 3), which states that, if used well, they can provide the teacher and the students with adequate information about how well each unit is being learned. The author then observes that the nature of each unit can be different, depending on its purpose, and that it can also be a single lesson. Therefore, the pedagogical purpose in the classroom is to establish this stage of Formative Assessment which, according to Fernandes (2006, p. 23), can happen as reviews of the subject matter or in the form of a formative test, before the Summative Assessment. In this way, it is strategically proposed to present the students with a text containing historical discussions of science so that they can carry out interpretative readings using the epistemological references of the analytical instrument they have been given.

Figure 1 displays a chosen text accompanied by an exemplary analysis meant for the teacher to conduct with the class, facilitating comparisons with individual student analyses. This approach, as previously mentioned, ensures that both the teacher and students are adequately informed about the level of understanding of each unit in this Formative Assessment. The instrument provided to analyze Figure 1 encourages interpretative readings of the propositions within the text, which is dissected into 11 paragraphs and scrutinized individually. Following this process, a synthesis is presented, highlighting the implicit lesson in epistemological terms and the educational implications of the text. It is recommended to conclude this Formative Assessment by discussing this synthesis with the class.

Figure 1 shows the original text in Portuguese, as it was published by the newspaper Folha de S. Paulo, and is followed by its translation into English.

Figure 1

Text published in a newspaper, alluding to periods in the history of science



Source: Folha de S. Paulo, 17/05/1998, p. 16.

The Ether Theory or the Phoenix of Cosmology (by Marcelo Gleiser¹³)

Certain ideas in science, abandoned for reasons that are perfectly justifiable at one time, tend to reappear in times of crisis as possible explanations for apparent mysteries. More often than not, these ideas enjoy a brief period of glory, only to be abandoned and replaced by simpler and more effective explanations.

One idea that appeared and reappeared throughout the history of physics was the existence of a material medium that permeated all of space, the "ether", whose function changed according to the needs of a particular theory.

For Aristotle, celestial objects were composed of ether, or the fifth essence, which had completely different properties from the four elements that described matter at the time: water, air, earth, and fire.

Much later, the French philosopher René Descartes postulated the existence of a material medium responsible for transporting celestial objects through the heavens. Isaac Newton, in his magnificent work on the laws of motion and gravitation, showed that this medium was unnecessary.

In the 19th century, another type of ether was accepted as the medium in which electromagnetic waves propagate through the air like sound waves. In 1905, Einstein showed that this ether was unnecessary and that electromagnetic waves could propagate in empty space.

But Einstein himself introduced one of these ideas, which I call phoenix ideas because, like the mythical bird, they rise from their own ashes.

In 1917, when Einstein used the equations of his new theory of general relativity to describe the universe as a whole, there was no definitive evidence that the universe was expanding. Like most scientists at the time, Einstein believed that the universe

was static and as symmetrical as possible. But his attempts to solve his equations describing a static universe failed.

To avoid disaster, Einstein introduced a constant that we now call the “cosmological constant” whose function was to create a repulsive force to balance the collapse of matter. In other words, the cosmological constant acted as a kind of anti-gravity: in a universe with no matter and only the cosmological constant, the distance between two points would increase exponentially.

When astronomer Edwin Hubble showed in 1929 that the universe was not static but expanding, Einstein abandoned his cosmological constant. As the Russian Alexander Friedmann had proved in 1922, Einstein’s equations were perfectly compatible with an expanding universe.

But problems began early. Hubble also showed that his observations predicted the age of the universe to be about 2 billion years, younger than the Earth itself! Several models have tried to solve this dilemma. One of them, first proposed by Georges Lemaitre, who was a priest as well as a cosmologist, used the cosmological constant to slow down the expansion rate of the universe, making it “older”. In 1952, new measurements showed that the Universe was comfortably older than the Earth. The cosmological constant was again abandoned.

So it was with a mixture of “disbelief and horror” that scientists received the news that very distant objects were being accelerated to greater and greater distances, as if some force were pushing them away. Again, the simplest explanation for such a phenomenon is the cosmological constant, although we have no idea why such a constant should exist in nature. Although much caution is needed, as these recent observations are very difficult and prone to misinterpretation, I wonder how many lives the cosmological constant will have, or if it is truly immortal.

Paragraph 1 - Kuhnian propensity: abandonment of a theory occurs for reasons (criteria) justifiable at the time, which characterizes a relativist position because it does not emphasize any single universal and timeless criterion. An idea (ether theory) resurfaces at times of crisis during the monopoly of a paradigm. Ideas (theories) enjoy a short period of glory (normal science), being replaced by “simpler and more effective explanations”, criteria which are compatible with those on Kuhn’s list in periods of scientific revolution;

Paragraph 2 - Lakatosian propensity: talented and imaginative scientists can convert a research program (ether theory) from degenerative to progressive by modifying hypotheses of the protective belt, as in the case of changing the function of the ether according to the needs of the theory (research program);

Paragraph 3 - Kuhnian or Lakatosian propensity: basic description of the identification of the Aristotelian “paradigm” or core of the Aristotelian “research program”;

Paragraph 4 - Kuhnian or Lakatosian reading: at a time when a “paradigm” (or “research program”) assumed the existence of the ether, in another it was unnecessary;

Paragraph 5 - Kuhnian bias: while in one “paradigm” the existence of a new conception of the ether was assumed in the 19th century, in another later “paradigm” such a conception proved unnecessary at the beginning of the 20th century;

Paragraph 6 - Lakatosian propensity: introduction of ideas (theories) into the protective belt.

Paragraph 7 - Lakatosian propensity: prediction of a new fact (expanding Universe) by the relativistic research program, when there was no evidence to this effect and no credit was given to the belief in the expansion of the Universe;

Paragraph 8 - Lakatosian propensity: insertion of an auxiliary hypothesis into the protective belt of the relativistic program (cosmological constant), in order to produce a repulsive force to balance the collapse of matter;

Paragraph 9 - Lakatosian bias: the cosmological constant served as an auxiliary hypothesis within the framework of another, namely the notion of a static Universe. Both hypotheses ultimately faced exclusion by the midpoint of the third decade of the previous century. The former was invalidated due to the widespread adoption of Hubble's evidence, which demonstrated the dynamic nature of the Universe as expanding rather than static. Meanwhile, the latter hypothesis was rendered untenable by the predictions inherent within the relativistic paradigm itself, which foresaw and accommodated this expansion, making the efforts of a static Universe unfeasible at the time (as was the case with the auxiliary hypothesis of the cosmological constant);

Paragraph 10: the emergence of theoretical incongruence stemming from Hubble's theoretical "observations" predicting a Universe younger than Earth engendered a degenerative trajectory within the research program. In response, efforts ensued to seek a supplementary hypothesis, employing the cosmological constant to retard the Universe's expansion, thus reconciling its perceived age with that of Earth. Later observations confirmed that the Universe is older than Earth, even though scientists initially considered the cosmological constant as a secondary factor. However, according to the ideas proposed by Kuhn, scientists temporarily solved the problem of the Universe appearing older than Earth by adding the cosmological constant to artificially increase its age. But, in line with the viewpoint of Lakatos, further experimental evaluations upheld the idea that the Universe is older than Earth. Eventually, scientists disregarded the cosmological constant as a crucial element in understanding this puzzle.

Paragraph 11 - Lakatosian propensity: finally, the progress of the research program found itself once again embracing the auxiliary hypothesis of the cosmological constant to act in the explanation of the observed phenomenon, in which very distant objects are "accelerated to greater and greater distances, as if a force were pushing them away". Kuhnian propensity: Finally, within the "paradigm", it was possible to evade the enigma, in which very distant objects are "accelerated to greater and greater distances, as if a force were pushing them away", by readjusting the "piece", the cosmological constant, of the puzzle in question.

SUMMARY OF THE PROPENSELY IMPLICIT LESSONS OF AN EPISTEMOLOGICAL NATURE THAT THE TEXT CARRIES

From an analytical view, the discourse presented in Figure 1 suggests a potential alignment with both Lakatosian and Kuhnian post-positivist perspectives, with a subtle preference towards the former in terms of epistemological interpretation. Notably absent within the text are indications that might favor the Popperian approach or logical positivism over other epistemological references. This absence can be attributed to the historical narrative surrounding two theoretical constructs – the cosmological constant and the ether – which have

undergone cycles of acceptance, rejection, and modification, resulting in divergent trajectories of reassessment. Thus, the discernible trajectory of the narrative in Figure 1 does not lend itself to a conclusive inclination towards implicitly critiquing specific paradigms regarding the nature of scientific inquiry, as delineated by Silveira (1996, p. 225), when the author asserts four principles: firstly, observation serves as the wellspring and purpose of knowledge; secondly, scientific knowledge derives from phenomena; thirdly, speculation, imagination, intuition, and creativity ought not to contribute to knowledge acquisition; and fourthly, scientific theories are not products of creation, invention, or construction but rather discoveries aligned with empirical data.

Moreover, it is worth mentioning that there are no rewards for thinking that knowledge builds up step by step or that it is gained through unbiased observations leading to general conclusions. Similarly, the idea that knowledge is always correct and solid is not encouraged either. These ideas, along with others in the justificationist way of thinking, like those supported by logical positivism, are not directly supported.

SOME CONSIDERATIONS ON THE POSSIBILITIES AND LIMITS OF APPLYING NA ANALYTICAL INSTRUMENT

In line with the proposal, it should be noted that analytical instruments based on specific epistemologies are often used in texts that deal with the history of science. However, it is difficult to develop detailed characteristics of science that are specific to a single epistemology of the instrument. This is due to the historiographical nature of the available materials, which are elaborated in different manners. In regards to the awareness of undergraduates in the discipline, these materials can be divided¹⁴ into two main groups: rational reconstructions¹⁵ and quasi-histories (Whitaker, 1979).

The case with the greatest possibility of identification with a particular epistemological stance occurs when the text has undergone a rational reconstruction, which is why every historian of science who advocates for the advancement of science as the advancement of objective knowledge implicitly employs a rational reconstruction, whether they acknowledge it or not. (Lakatos, 2007, p. 246). It is worth agreeing with Popper (as cited in Lakatos, 2007, p. 157) when he states that it is inconceivable to have history devoid of any theoretical inclination. Lakatos (2007, p. 154) points out that, for the most influential of the methodologies of science, which has proved to be inductivism, an inductivist historian acknowledges only two categories of authentic scientific discoveries: pure factual statements and inductive generalizations. When writing history, the inductivist historian looks for these types of scientific discoveries; finding them is a completely different matter. By another view of progress, a Popperian historian would bring to light great and “risky” falsifiable theories and important negative crucial experiments. Lakatos’s methodology of scientific research programs, on the other hand, would show research programs evaluated in terms of progressive and degenerative changes in problems, in which scientific revolutions consist of one research program succeeding another (surpassing it in progress). Lakatos (2007, p. 154) affirms that, as a consequence, the characteristic model of the rational development of scientific knowledge is revealed by each rational reconstruction. Also, one can always demonstrate the way a methodology influences the selection

of certain facts over others and how the interpretation of these facts does not occur without some theoretical bias.

In the making of history, therefore, the details that are influenced by the historian's social, national, psychological and religious views are, to an even greater degree, influenced by the Theory of Science or Philosophy of Science that the historian believes in, determining a normative methodology that the historian relies on in the making of internal history.

Considering that scientific progress¹⁶ in historical terms is practically unquestionable, one can also exemplify the work of a historian with the Kuhnian vision who, according to Lakatos (2007, p. 243), will not be able to escape the temptation to “cook” a history of the monopoly of a theory or paradigm and prepare a state of “crisis” followed by a “moment of conversion”.

While the philosophy of science is primary, and sociology and psychology are secondary when writing the history of science, Lakatos (2007, p. 246) assures us that histories of science, without exception, are philosophies that fabricate examples¹⁷. Therefore, it is easier to apply an analytical instrument to a reading as long as it coincides with the epistemological strand through which historiography took place in the rational reconstruction of a text to be identified analytically. However, there is still a difficulty when the epistemological references of an analytical instrument¹⁸ do not coincide directly with those found in the rational reconstruction of a historical text. In the interest of getting around this difficulty, it is sensible to study a wide range of philosophical references during the course, a recommendation that not only helps to develop, but also to train in dealing with an analytical instrument.

Additionally, while implicit rational reconstructions may become apparent, it is not uncommon to encounter a limited or mixed interpretative understanding of the epistemological aspects within an analytical framework, particularly in cases where rational reconstruction has not been employed in historiography. This scenario echoes what Whitaker (1979) termed as quasi-history, observed notably in many natural science textbooks. In quasi-history, contextualization often unfolds in logical rather than chronological order, eschewing the posture of rational reconstruction. Whitaker (1979, p. 239) further posits that while he refrains from assuming any philosophical intent on the part of quasi-history writers, he perceives quasi-history as primarily driven by a misplaced desire for order and logic, serving as a pedagogical convenience.

According to the author, a prevalent example of quasi-history found in textbooks involves the assertion that the Rayleigh-Jeans law was known prior to Planck's discovery of his own law. This narrative suggests that the failure of this classical physics law was pivotal in accurately predicting the law of black body radiation, ultimately leading to Planck's formulation of the quantum hypothesis. In this example, while there is uncertainty as to whether it should be assumed that Planck had seen Rayleigh's work, it is clear that the latter did not influence him in any way from the dates on which the different works were published (Whitaker, 1979, p. 108). Thus, according to Whitaker (1979, p. 109), quasi-history arises from numerous books wherein authors sought to enhance their explanations of an episode by incorporating historical elements, yet ultimately reshaped history to align closely with physics.

Quasi-history, as identified by Whitaker (1979), glosses over the social dimension and distorts the portrayal of scientific progress through the propagation of propaganda and myth. This phenomenon is evident in numerous instances

within books detailing the evolution of modern physics. Consequently, when confronted with quasi-history, interpretative analyses of paragraphs and sentences within a text, concerning the configuration of aspects within an analytical framework, may yield contradictory epistemological implications. Such contradictions are unsurprising, given that while writers of quasi-history may lack a philosophical stance, they nonetheless inadvertently adhere to what Bunge (1973, p. 11) describes as an “immature and uncontrolled” philosophy in their historical narratives. This serves as a cautionary note against implicit lessons that are less susceptible to logical and epistemological scrutiny regarding the nature of science, as highlighted in the literature.

FINAL CONSIDERATIONS

This study started from a concern that has been present in science education for some time, signaled by the difficulty of overcoming inappropriate views of the nature of science and scientific work. In particular, in undergraduate physics courses, a subject that can help train students in this regard is called “Evolution of concepts and theories in physics”, which allows discussions on the development of scientific concepts that take place in the historical contexts of this science. Attention has been drawn to the not uncommon occurrence of teachers teaching this subject without any training in (and/or interest in) philosophy, which is undoubtedly one of the negative factors implicit in the worrying picture highlighted by the literature. This is true even though the inclusion of epistemological references to the development of knowledge in the curriculum is in principle pedagogically justified, recommended, and often seriously followed by teachers, so that the previous sentence cannot be generalized. And for the teachers who make such insertion in the subject, this proposal indicates that they are carrying out a preparatory stage of the educational process, through classroom discussions, which has been called the first moment (or stage 1).

Before the traditional continuation of the Summative Assessment that would take place at the end of Stage 1, it was proposed here to insert a Formative Assessment in order to subsidize the training of students in the study context defined in Stage 2. The feasibility of an exemplary analytical instrument¹⁹ applied to a text from the history of science was discussed, and the analytical reflections extended to some of the limits and possibilities of the proposal. It is important to mention that the application of the analytical instrument is a way of revisiting the content and an interesting way of exercising the knowledge acquired from the epistemological references, even if it is uncertain whether this reference fits the selected historical text or parts of it. This moment stimulates the creativity of interpretative readings and class discussions, allowing the teacher to better monitor the learning performance of the references studied in the formative assessment, a stage that precedes the intended summative assessment. Finally, with this proposal for an increase, we hope to contribute to better qualification of undergraduate students – in teacher training courses – on what concerns epistemological terms, implying that it will subsidize greater changes in this context at the secondary school level when they get to work there.

NOTES

1. Although "immature and uncontrolled" (Bunge, 1973, p. 11).
2. From a pedagogical perspective, it is imperative to dismiss the empiricist notion linked to the conviction that scientific knowledge is absolute and beyond doubt. There is concern regarding the persistent prevalence of the belief that scientific knowledge is derived directly from experimental outcomes, particularly within science education among both teachers and students. (Lôbo, 2012, p. 431).
3. Chalmers (1994) suggests that the positivists sought to demonstrate that genuine science is validated and deemed true or likely true based on "protocol sentences" – facts perceived by diligent observers through their senses.
4. Koyré showed (defended) that positivism provides a bad orientation for the historian of science (Lakatos 1978, p. 9).
5. Allchin, 2004, p. 188; Chinelli et al., 2010, p. 18; Matthews, 1994, p. 83; Whitaker, 1979, p. 108.
6. Explained further below.
7. This is an unmistakable attempt to emphasize what could be covered in this subject by a teacher better committed to explicitly involving the philosophy of science.
8. An example of this is inductivism, which can be rejected as a methodological theory for interpreting episodes in the history of science (Duhem as cited in Lakatos, 2007, p. 167), but only definitively because of its logical and epistemological unfeasibility independent of history.
9. Of inclinations towards dogmatic empiricism – whether they are inductivists, probabilists, dogmatic falsificationists, or even conservative conventionalists (Lakatos, 2007, p. 158).
10. With a certain degree of historical episodes in an evolutionary context.
11. Stage 2 then takes the form of Formative Assessment, discussed in the next section.
12. E.g.: the Three laws of dynamics and Newton's law of gravitation (Lakatos, 1979, p. 163).
13. Marcelo Gleiser (at the time of the publishing) was a professor of theoretical physics at the Dartmouth College in Hanover, (USA), and is the author of the book "A Dança do Universo" (The dance of the universe).
14. On purpose for this educational interest.
15. Strong arguments for the debate against historiographical theses contrary to a rational reconstruction are widely presented by Lakatos (2007), with some educational implications for the use of the history of science defended in Silva and Laburú (2010).
16. A term that is synonymous with "evolution", present in the title of the subject "Evolution of the concepts and theories of physics".
17. Allchin (2004) presents criticisms about the persuasiveness of scientists that are often ignored in reconstructions such as Lawson's (2000). Allchin argues that interpreting history through an ideological 'lens' can be misleading because it oversimplifies the scientific method. In response, Lawson (2004) thoroughly analyzes Allchin's (2004) version of his rational reconstruction of William Harvey's research. Lawson (2004) argues that Allchin (2004) characterizes an inductivist version of Harvey's research in

several passages, contradicting Lawson's defense of the hypothetico-deductive method. Allchin also points out the need to beware of the powerful rhetorical effects of ideology that a rational reconstruction carries, which Lawson agrees with. Therefore, Allchin's arguments are not exempt from his own criticism.

18. That could even affect the analytical instrument presented here in the last section, which is now being used as an example for reflection in this sense. According to the guideline established here of its constitution with justificationist and contemporary (non-justificationist) references.

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