EDUR • Educação em Revista. 2025;41;e48737
DOI: http://dx.doi.org/10.1590/0102-469848737T
Preprint: https://doi.org/10.1590/SciELOPreprints.7290

ARTICLE

SCIENTIFIC LITERACY: A LOOK AT ITS DIFFERENT INTERPRETATIONS[1]

MARCELO COPPI[1]
ORCID: https://orcid.org/0000-0001-6734-7592
<mcoppi@uevora.pt>
ISABEL FIALHO[1]
ORCID: https://orcid.org/0000-0002-1749-9077
<ifialho@uevora.pt>
MARÍLIA CID[1]
ORCID: https://orcid.org/0000-0002-6009-0242
< mcid@uevora.pt >

[1] Centro de Investigação em Educação e Psicologia da Universidade de Évora, Évora, Portugal.

ABSTRACT: The study aimed to perform a critical and historical approach to the concept of scientific literacy, the definition of the words that compose the term, their translations and the existence of instruments developed to assess it, through a narrative literature review. It was observed that one of the reasons for the different conceptual perspectives is the meaning of the word literate, which, in the English language, can mean to hold knowledge and also to be able to read and write. Another reason is the translation of the word literacy, which can originate, in the Portuguese language, the words *alfabetização*, *literacia* or *letramento*, assuming different meanings according to their interpretation. Meanwhile, there are factors related to the theoretical approach adopted by the authors and to the field of language studies and language teaching. The concept of scientific literacy also reveals itself as one of the causes generating inaccuracies. The fact that there is a plurality of concepts means that scientific literacy is often confused and limited to the understanding of science. Finally, the assessment of scientific literacy is a source of debate among researchers in the area, since there are few instruments available in the literature, most of them assess isolated aspects and dimensions of scientific literacy, and a minority demonstrate the processes of validity in their elaboration. In summary, the study highlights the major controversies in the literature concerning scientific literacy, presents the main reasons for such controversies and demonstrates that, despite these aspects, scientific literacy is the subject of international research and is widely presented as the main objective of science education.

Keywords: concept of scientific literacy, definition of scientific literacy, assessment of scientific literacy.

LITERACIA CIENTÍFICA: UM OLHAR SOBRE AS SUAS DIFERENTES INTERPRETAÇÕES

RESUMO: O estudo teve por objetivo realizar uma abordagem crítica e histórica a respeito do conceito de literacia científica, da definição das palavras que compõem o termo, das suas traduções e da existência de instrumentos desenvolvidos para avaliá-la, mediante uma revisão narrativa da literatura. Observou-se

[1] Article published with funding from the *Conselho Nacional de Desenvolvimento Científico e Tecnológico* - CNPq/Brazil for editing, layout and XML conversion services. The translation of this article into English was funded by Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - CAPES/Brasil.

que um dos motivos para as diversas perspectivas conceituais é o significado da palavra *literate*, que, no idioma inglês, pode significar ser detentor do conhecimento e, também, ser capaz de ler e escrever. Outra razão é a tradução da palavra *literacy*, a qual pode originar, no idioma português, as palavras alfabetização, literacia ou letramento, assumindo diferentes significados de acordo com a sua interpretação. Em paralelo, há fatores relacionados com a adesão teórica adotada pelos autores e com o campo de estudos da linguagem e do ensino de línguas. O conceito de literacia científica também se revela como uma das causas geradoras de imprecisões. O fato de haver uma pluralidade de significados faz com que, muitas vezes, a literacia científica seja confundida e limitada à compreensão da ciência. Por fim, a avaliação da literacia científica configura-se como fonte de debate entre os pesquisadores da área, uma vez que existem poucos instrumentos disponíveis na literatura, a maioria deles avalia aspectos e dimensões isolados da literacia científica e uma minoria demonstra os processos de validade na sua elaboração. Em síntese, o estudo evidencia as grandes polémicas na literatura que concernem a literacia científica, apresenta as principais razões de tais controvérsias e demonstra que, a despeito destes aspectos, a literacia científica é objeto de pesquisas de âmbito internacional e apresenta-se, de uma forma ampla, como o principal objetivo do ensino de ciências.

Palavras-chave: conceito de literacia científica, definição de literacia científica, avaliação da literacia científica.

ALFABETIZACIÓN CIENTÍFICA: UNA VISIÓN DE SUS DIFERENTES INTERPRETACIONES

RESUMEN: El objetivo del estudio consistió en realizar una aproximación crítica e histórica al concepto de alfabetización científica, a la definición de las palabras que componen el término, a sus traducciones y a la existencia de instrumentos desarrollados para evaluarla, mediante una revisión narrativa de la literatura. Se observó que una de las razones de las diferentes perspectivas conceptuales es el significado de la palabra *literate*, que en inglés puede significar ser poseedor de conocimientos y también saber leer y escribir. Otra razón es la traducción de la palabra *literacy*, que en portugués puede dar lugar a las palabras *alfabetização*, *literacia* o *letramento*, adquiriendo significados diferentes según su interpretación. Paralelamente, existen fatores relacionados con el enfoque teórico adoptado por los autores y con el ámbito de los estudios lingüísticos y la enseñanza de idiomas. El concepto de alfabetización científica es también una de las causas de imprecisión. El hecho de que existan tantos conceptos hace que la alfabetización científica sea a menudo confusa y se limite a la comprensión de la ciencia. Por último, la evaluación de la alfabetización científica es una fuente de debate entre los investigadores del campo, ya que hay pocos instrumentos disponibles en la literatura, la mayoría de ellos evalúan aspectos y dimensiones aislados de la alfabetización científica y una minoría demuestra los procesos de validez en su desarrollo.

Palabras clave: concepto de alfabetización científica, definición de alfabetización científica, evaluación de la alfabetización científica.

INTRODUCTION

In 1999, the World Science Forum took place in Budapest, Hungary, held by the United Nations Organization for Education, Science and Culture (UNESCO), in cooperation with the International Council for Science (ICSU). Representatives of 155 Member States were present, including Ministers of Science and Technology, Research and Education or their equivalents, intergovernmental organizations, international non-governmental organizations and representatives of industry and two means of social communication, in order to define "a strategy that would ensure that science responds better to society's needs and aspirations in the twenty-first century" (UNESCO, 1999, p. 1).

One of the conference products was the *Declaration on Science and the Use of Scientific Knowledge*, popularly known as the Budapest Declaration, a document that claims to be necessary to develop and expand scientific literacy[2] "in all cultures and sectors of society as well as reasoning ability and skills and an appreciation of ethical values, so as to improve public participation in decision-making related to the application of new knowledge" (UNESCO, 1999, p. 5).

In 2015, the World Economic Forum published a list of the most critical competencies for the 21st century (World Economic Forum, 2015), including scientific literacy in the group called foundational literacies. According to this organization, this literacies group, composed of reading literacy, numeracy, scientific literacy, ICT literacy, financial literacy and cultural and civic literacy, is the basis necessary for students to build competencies – critical thinking and problem solving, creativity, communication and collaboration – and character qualities – curiosity, initiative, persistence, capacity of adaptation, leadership and social and cultural awareness – more advanced and equally important (World Economic Forum, 2015).

After more than two decades of the Budapest Declaration and the recent crisis caused by the COVID-19 pandemic, which evidenced inequalities, gaps and vulnerabilities in education, UNESCO published the document *Education in a post-COVID world: nine ideas for public action* (UNESCO, 2020), which presents new ideas to build the foundations of post-pandemic education. Among them, to ensure scientific literacy in the curriculum, once a deep reflection on the curriculum becomes necessary, "particularly as we struggle against the denial of scientific knowledge and actively fight misinformation" (UNESCO, 2020, p. 6).

For Rudolph (2023), "scientific literacy has been perhaps the single most touted goal of science teaching over the last 40 years, and it continues to be examined and debated in academic journals and policy circles to this day" (p. 520). Currently, it is considered as one of two emerging research areas in science education and is intended as one of the goals of learning and the objective of science education, as an attempt to expand knowledge about science and technology, linked to training for citizenship (Lorenzetti, 2017, 2023).

Introduced in this scientific field in the 1940s (Rudolph, 2023), the term scientific literacy has been widely used as a slogan by educators, researchers and politicians, as it is employed in various contexts, in a broad and vague way, to discover a set of competencies related to science (DeBoer, 2000). According to Laugksch (2000), in the 1980s, scientific literacy was presented as an uncertain and indefinite term. Since then, it has become the focus of various studies (Chassot, 2003; Laugksch, 2000; Laugksch & Spargo, 1996a; Miller, 1983; Roberts, 2007, 2011; Sasseron & Carvalho, 2011; Valladares, 2021), more objective and concrete mainly to define its concept.

Currently, despite the literature using many equivalent definitions, it is still difficult to give an unequivocal meaning to the term (DeBoer, 2000; Laugksch, 2000; Rudolph, 2023). Miller (1983), at that time, announced that scientific literacy is "one of those terms that is often used but seldom defined" (p. 29). Shamos (1995) also referred to the problem of the lack of clear and broad conceptualization in the scientific community.

From a review of the history of scientific education, DeBoer (2000) states that there are, at the very least, nine different objectives of scientific education that are related to the broad purposes of scientific literacy. Likewise, Laugksch (2000) discusses five factors, which will be addressed throughout the text, which intervene in the conceptualization of the term, giving rise to multiple definitions of scientific literacy, often imprecise. This inconsistency in its definition produces a plurality of intervention, teaching and assessment strategies, making scientific literacy confusing and limited, at times, only to scientific education.

In this framework, the study presented in this article aims to carry out a critical and historical approach about the concept of scientific literacy, the definition of the words that comprise the term, their translations – mainly for the Portuguese language, a reason that fuels the debate around do concept of scientific literacy, especially in Brazil since it is a country in which these words can assume more than a translation –, theoretical support for its use and the existence of instruments developed for its assessment.

---

[2] It was decided to use the original terms in certain situations to avoid problems of interpretation. Their translation and discussion will be presented throughout the article.

It is also proposed to present a definition of scientific literacy as a result of the synthesis of the analyzed literature.

Through a narrative literature review, defined as a comprehensive bibliographic review appropriate for “describing and discussing the development or ‘state of the art’ of a given subject” (Rother, 2007, p. V), the study sought to take stock of these debates surrounding scientific literacy. Once this methodological premise was established, the research was carried out in the following databases: Scientific Electronic Library Online (SciELO), *Biblioteca do Conhecimento Online* (B-on) and Google Scholar, considering studies and research published in English, Portuguese and Spanish. It was decided not to establish a time frame to analyze the evolution of the debate on the subject over time.

In this sense, the following terms were combined as descriptors: “scientific literacy”, “*literacia científica*”, “*alfabetização científica*”, “*letramento científico*”, “definition”, “concept”, “*conceito*”, “*definição*”, “literacy”, “*literacia*”, “*alfabetização*”, “*letramento*”, “assessment” and “*avaliação*”. In addition, studies and research that did not address the four aspects in the review were excluded: the concept of scientific literacy, the definition and translations of the words that make up the term and the assessment instruments.

A GLIMPSE OFHISTORY

Recognition of the importance of scientific literacy emerged essentially in the 1950s, after the Second World War and the beginning of the space race, a period in which scientists and governments witnessed the great scientific and military achievements used, such as the atomic bomb (Laugksch, 2000). Also from this decade onwards and, especially, in the following one, humanity experienced “an abrupt decline in the quality of life caused by rapid environmental degradation”, increasing concern with environmental and social issues (Dias, 1991, p. 3).

Alongside these events, Hurd (1958) adds that a major factor in recognising the importance of scientific literacy was the advance of research in the fields of biology, physics and chemistry. The author argues, for example, that half of the chemicals in common use at that time were unknown in the previous decade and that “plastics and pesticides, biotics and detergents, silicones and symthetic elements have introduced the modern world of chemistry” (Hurd, 1958, p. 13). He also states that due to advances in the study of medicines, molecules, cells, vaccines and viruses, biophysics and biochemistry were getting closer to understanding the nature of life.

According to Hurd (1958), from the 1950s onwards, science, linked to its technological applications, began to be recognized as the most characteristic feature of modern society, whose knowledge became essential for citizenship. In this sense, science teaching could no longer be regarded as “an intellectual luxury for the select few” (Hurd, 1958, p. 13), and its expansion to the whole of society was required.

Given this reality, many countries recognized that the best way to avoid catastrophes and promote the advancement of science would be to raise awareness among the general public about the potential use of science, for good and for ill (Shamos, 1995). According to the author, teaching science to the public was not a new idea at that time, but after scientists became aware of the military use of science, the focus shifted to the social and political dimensions of the use of science and technology (Shamos, 1995). Thus, “a loosely structured but highly visible movement toward what came to be called ‘scientific literacy’ for the general public” was born (Shamos, 1995, p. 76, emphasis added).

Until recently, several studies (Bybee, 2016; Laugksch, 2000; Silva & Sasseron, 2021; Valladares, 2021) attributed to Paul Hurd (1958) the first publication in which the term scientific literacy was used, in an article entitled *Science Literacy: its meaning for American Schools*, published in the journal *Educational Leadership*, in October 1958 (Rudolph, 2023). DeBoer (2000) was one of the few authors to identify the use of the term in other studies published in the same year: the article *The pursuit of excellence: Education and the future of America*, published in the book *Prospect for America: Report Number V of the Rockefeller Panel Reports*, in June 1958, by the Rockefeller Brothers Fund; and the article *Toward a population literate in science*, by Richard McCurdy, published in the journal *The Science Teacher*, in November 1958.

However, due to the extensive digitization process of printed materials over the last few decades, it has been possible to identify numerous occurrences of the use of the term scientific literacy before 1958 (Rudolph, 2023). In his study, Rudolph (2023) located publications dated from the 1940s and 1950s, the first being attributed to Gaylord Harnwell, in the article *A new foundation*, published in October 1945 in the journal *Review of Scientific Instruments*. Among other examples found by the author are the following: a 1946 speech by Caltech president Lee DuBridge, in which he states that it would be shameful if a large part of the United States population were scientifically illiterate; the appointment of the new director of *Science Teacher*, Dwight Sollberger, who stood out for his interest in ensuring scientific literacy for all individuals; the development of a scientific literacy criterion to measure schools' performance in this area, in 1948; and the creation of an introductory course that would convey a basic scientific literacy necessary for the modern era, by Oliver Loud, professor of science at Antioch College, in 1950. It is therefore clear that it is inaccurate to legitimize Paul Hurd as the introducer of the term scientific literacy in the literature and that the term was by no means a new expression in the late 1950s (Rudolph, 2023).

Although, at first, this discussion of the first author to use the term scientific literacy may seem of little importance, Rudolph (2023) highlights the merit of accurately stating the facts, especially when it comes to fundamental and historical ideas within a field of study, which allow us to understand how the term scientific literacy was used in public and political discourse during these years and how this idea came to define the objective of science teaching in schools, revealing a lot about its central functional value (Rudolph, 2023).

It is interesting to note that the debate on scientific literacy grew, strengthened and, over the following decades, became linked to the movements on the relationship between Science, Technology and Society (STS) and between Science, Technology, Society and Environment (STSE). Nevertheless, as Oliveira and Linsingen (2019) state, there are three main traditions for the STS movement: the European, organized in a more academic lines, with the purpose of highlighting how scientific and technological knowledge is produced and the different interests involved in this process; the North American, pragmatic and concerned with the social and environmental consequences of technological products and related to the social movements that were being established in the 1960s and 1970s; and the Latin American, which arose from the need to combat the hegemonic model of science and technology imposed on these societies and seeks the development of scientific and technological knowledge to meet regional needs.

Regardless of the approach adopted, the link between scientific literacy and the STS and STSE approaches has promoted the growth of studies in these perspectives, resulting in works that increasingly highlight the need for science teaching to enable society's participation and engagement in promoting scientific literacy (Valladares, 2021). Furthermore, since the term was established, there has been a period in which public knowledge of science has gained momentum and scientific literacy has become the main goal of science education (Coppi et al., 2023a; DeBoer, 2000; Shamos, 1995; Yacoubian, 2018; Rudolph, 2023; Valladares, 2021).

For Rudolph (2023), however, although the emergence of scientific literacy drew society's attention to the importance of science education, it did little to provide guidelines for the development of the science education needed at the time, in 1945, "or that it desperately needs today in our current era when the cultural authority and value of science is under threat" (p. 521). Possibly, one of the main reasons lies in the definition of the term, which has raised many questions since its first appearance. Shamos (1995) points out that, in the post-Sputnik period, the concept of scientific literacy, in addition to being vague and imprecise, came to be associated basically with the understanding of science. A bibliographic study carried out by Laugksch (2000) identified that, mainly in the 1980s, there was a massive increase in research involving scientific literacy, which presents different interpretations and definitions.

In English-speaking countries, one of the factors responsible for this plurality of perspectives is the meaning of the words literacy and literate. In non-English-speaking countries, especially Portuguese-speaking countries, the translation of the English words literacy (scientific literacy) and literate (to be scientific literate) contributes to the multiplicity of understanding. Besides these two factors, there is a topic of discussion about the theoretical affiliation of the authors and the field of language studies. These aspects, as well as some other elements that support this debate, will be analyzed in the following section.

MEANINGS AND TRANSLATIONS

As previously stated, in English-speaking countries, one of the impasses is the meaning of the words literacy and literate. Miller (1983) explains that referring to an individual as literate can have two different meanings: to be learned and to be able to read and write. The author also claims that most debates related to scientific literacy fail to distinguish the meaning of both words, generating inaccuracies (Miller, 1983).

Laugksch (2000) reinforces the inconsistency and imprecision in the meaning of the word literate. The author argues that, in the English language, an individual can be considered literate as learned, literate as competent and literate as able to function minimally in society, considered not only competent but able to perform specific activities in society (Laugksch, 2000).

In non-English-speaking countries, specifically Portuguese-speaking countries, the problem lies in the translation of the English word literacy. This can give rise to the Portuguese words *literacia*, *letramento* (Martins, 2010) or *alfabetização* (Teixeira, 2013). According to Silva and Sasseron (2021), in the Portuguese language, it is common to find the adoption of the expressions *alfabetização científica* and *letramento científico* in Brazil and the use of *literacia científica* in Portugal.

Regarding the words *letramento* and *literacia*, Soares (2002) and Dionísio (2007), experts in the field of linguistics, argue that both have the same meaning, with *literacia* being used in Portugal and *letramento* in Brazil. As Soares (2002) states, in Portugal, the discussion is about "the phenomenon of *literacia*, a word recently introduced into Portuguese from Portugal, preferred there to the Brazilian word *letramento* (p. 17).

Concerning the word *alfabetização* widely used in Brazil, in Portugal, it is used in particular circumstances, such as in adult education (Dionísio, 2007). As the author mentions, in Portugal,

> We do not use the term *alfabetização*. We have used it and even reserved it for very specific contexts and even, often, in adult education, in adult literacy. It is rarely discussed at the initial levels, for the initial moments of learning to read and write. It was a concept that occurred and occurs in certain situations. For example, when we are referring to the education of adults who do not know how to read or write, and therefore, this process of teaching them to read and write has been designated as *alfabetização*. (Dionísio, 2007, p. 210).

Martins (2010) analyzed the definition of these words in Portuguese dictionaries and found that, in many of them, the concepts of *alfabetização* and *literacia/letramento* are considered synonymous. However, as Teixeira (2013) explains, linguists attribute different meanings to them. For Benavente et al. (1996), "the concept of *alfabetização* translates the act of teaching and learning (reading, writing and calculation)" (p. 4), while *letramento* translates "the ability to use the skills (taught and learned) of reading, writing and calculation" (p. 4).

Soares (2004a) reinforces this idea, arguing that, while *alfabetização* is related to the acquisition of the conventional writing system, *literacia/letramento* refers to the competent use of reading and writing in social practices. According to the author, *alfabetização* and *literacia/letramento* are distinguished "both in the objects of knowledge and in the cognitive and linguistic processes of learning and, therefore, also of teaching these different objects" (Soares, 2004a, p. 97).

Martins (2010), in turn, argues that *alfabetização* is a component of *literacia/letramento*. According to the author, "the big difference between *alfabetização and literacia* lies in the fact that the latter concept refers more to the use of skills than to their acquisition" (p. 16). Lima Santos and Gomes (2004) corroborate the idea, arguing that *alfabetização* skills, such as learning to read, write and calculate, are "basic for us to become literate, but they are not exclusive, since *literacia* finds its foundations in *alfabetização*, but is not confined only to educational objectives, referring us to the appropriate use that the individual gives to written language" (p. 170).

Although they agree with the distinction between *alfabetização and literacia/letramento*, Krasilchik and Marandino (2004) justify the use of the term scientific literacy by claiming that, despite the semantic difference between *alfabetização* and *literacia/letramento*, the first term is consolidated in Brazilian social practices. Therefore, the authors consider that *alfabetização científica* "encompasses the idea of literacy, understood as the ability to read, understand and express opinions about science and technology, but also to participate in scientific culture in the way that each citizen, individually and collectively, considers appropriate" (Krasilchik & Marandino, 2004, p. 18).

Researchers Sasseron and Carvalho (2011) also choose to use the term *alfabetização científica*. The choice is based on the concept of *alfabetização* idealized by Paulo Freire, which, as the authors explain, is understood as "a process that allows the establishment of connections between the world in which the person lives and the written word; and from such connections arise the meanings and constructions of knowledge" (Sasseron & Carvalho, 2011, p. 61), as well as "developing in any person the ability to organize their thoughts in a logical manner, in addition to helping to build a more critical awareness in relation to the world around them" (Sasseron & Carvalho, 2011, p. 61).

Thus, in Portuguese, scientific literacy can acquire three possible translations: *literacia científica, letramento científico* and *alfabetização científica*. Sasseron and Carvalho (2011) and Silva and Sasseron (2021) add that, in Brazilian literature, although it is not the result of its translation, some researchers use the expression *enculturação científica*. Those who do so justify the use of this term by arguing that science teaching should provide conditions for students to integrate a scientific culture, in which scientific notions, ideas, and concepts are part of their intellect, allowing them to participate in discussions of this culture (Sasseron & Carvalho, 2011; Silva & Sasseron, 2021). The same interpretation also occurs in France, a country where some researchers adopt the expression *culture scientifique* (Laugksch, 2000), in addition to *alphabétisation scientifique* (Silva & Sasseron, 2021).

In Brazil, some researchers also opt to use the term scientific and technological literacy (*alfabetização científica e tecnológica*) (Kauano & Marandino, 2022; Lorenzetti, 2023; Silva & Sasseron, 2021). This choice seems to be related both to the translation of the French term *alphabétisation scientifique et technique*, used in the article *Alphabétisation scientifique et technique: Essai sur les finalités de l'enseignement des sciences*, published by Fourez in 1994 (Silva & Sasseron, 2021), and also to the theoretical preference for the STS approach, from a critical perspective pertinent to social dynamics (Lorenzetti, 2023; Richetti & Milaré, 2021). Even so there is a predominance of the use of the terms *letramento científico* and *alfabetização científica* (Silva & Sasseron, 2021).

In view of the above, it is clear that both the meaning and the translation into Portuguese of the words literacy and literate are a matter of debate among researchers in the field. In the English language, the pluralism of meanings is more closely related to the word literate and is understood when it is said that an individual is scientifically literate. In the Portuguese language, the existence of at least three possible translations for the word literacy – *literacia, letramento* and *alfabetização* – is associated with the definition of these three words in the language and also with the country in which the term is used, *alfabetização* and *letramento* in Brazil and *literacia* in Portugal. However, there are authors in Brazil who, even recognizing the semantic difference between the words *alfabetização* and *literacia/letramento*, choose to use the former, justifying the use based on the consolidation of the term in the country, such as Krasilchik and Marandino (2004), or because they understand that the word *alfabetização* can take on a broader meaning, such as Sasseron and Carvalho (2011).

It is important to emphasize, however, that, at least in Brazil, the debate over the use of one term or another transcends the issue of translation, reflecting a discussion more linked to theoretical adherence and the field of language studies and language teaching (Cunha, 2017; Silva & Sasseron, 2021). For Paulo Freire, for example, *alfabetização* should not be reduced to the teaching of letters, syllables, and words (Freire, 2018), but understood as the mastery of writing and reading in conscious terms, in which an individual understands what he or she reads and writes what he or she understands (Freire, 1989).

For Freire (2018), being literate means being able to establish connections between the written word and the world in which one lives. In this sense, *alfabetização* is structured "along with the process of becoming critically aware based on problematizations of reality that are capable of, based on the vocabulary universe of the learners, attributing deep, diverse and connected meanings between words and the world" (Kauano & Marandino, 2022, p. 8), a concept that encompasses aspects foreseen in the ideas of *literacia/letramento* and *enculturação* (Silva & Sasseron, 2021). Marandino et al. (2022) reinforce that Freirean *alfabetização* is an "integral, problematizing, contextualizing, dialogic process, which aims to raise critical awareness of theoretical and practical elements towards transformative praxis" (p. 98) and that this conception began to guide some fundamental axes of studies on scientific literacy in the area of science education.

From this perspective, the use of the term *alfabetização científica* is based on the acquisition of skills that allow an individual to establish connections and correspondences between their reality and scientific knowledge, aiming at understanding scientific activity and its use for analyzing situations and making decisions (Silva & Sasseron, 2021). This concept is used by several authors in the field of science teaching (Kauano & Marandino, 2022), who assume *alfabetização científica* as a language to be appropriated in a reflective way (Chassot, 2003), enabling participation and engagement for social transformation (Valladares, 2021) and the construction of scientific knowledge to apply it in everyday situations (Sasseron & Carvalho, 2011).

The choice of the term *letramento científico*, used in numerous Brazilian publications, is closely associated with the STS approach, whose themes aim to expose students to critical analyses of everyday situations that contrast aspects related to science, technology, and society (Silva & Sasseron, 2021). This relationship is supported by several studies in the area of language (Kleiman, 1995; Soares, 2004b), considering that, in *letramento*, learning comes from social practices and not from the mechanical appropriation of a code (Silva & Sasseron, 2021). It is also worth noting the fact that Soares (2004b) states that, in Brazil, the emergence of the term *letramento* was related to the failure of methods and strategies for teaching students to read and write, emerging as an alternative to strategies that aspire to the formation of readers and text producers.

In turn, the use of the term *enculturação científica*, although low in incidence, is related to the opportunity to experience different aspects of scientific culture (Silva & Sasseron, 2021). Nevertheless, according to the authors, it is possible to find marks of the scientific enculturation process in the definitions of *letramento científico* and *alfabetização científica* "when these reveal the intention that science teaching allows students to come into contact with different aspects of scientific research and not just with concepts, laws and theories" (Silva & Sasseron, 2021, p. 4).

It is worth noting that many studies use one of these words without justifying the reason for their choice. This may be associated with the fact that these words are classified as synonyms in Portuguese language dictionaries (Martins, 2010), meaning that, in the authors' view, there is no need to justify it.

Given that this study is part of a larger project carried out by researchers from a research center in Portugal, a country where the most commonly used term is *literacia* (Dionísio, 2007), and based on the semantic differences between *alfabetização e literacia/letramento* previously discussed, mainly the fact that *literacia/letramento* is more related to the use of skills than to their acquisition (Martins, 2010), this study opted to use the term scientific literacy (*literacia científica*) instead of other analogous terms, which will be used from now on to refer to any of these similar terms.

In this sense, another factor that generates vigorous controversy and is open to debate will be discussed below: the concept of scientific literacy.

THE CONCEPT OF SCIENTIFIC LITERACY

Since the emergence of the term scientific literacy, one of the issues that has guided debates in the scientific community has been the definition of its concept (Laugksch, 2000). According to DeBoer (2000), not even Hurd and the authors of the Rockefeller Report paid attention to this issue and simply described scientific literacy, in a broad sense, as "knowledge of science and the scientific enterprise, especially in the context of science's newly acquired strategic importance in society" (DeBoer, 2000, p. 587).

Furthermore, the author states that, although there have been many attempts to define the concept of scientific literacy, none of them have been universally accepted. There are several reasons for this scenario, the most important is in DeBoer's (2000) perspective, "the fact that scientific literacy is a broad concept encompassing many historically significant educational themes that have shifted over time" (p. 582).

Laugksch (2000) presented five main factors capable of influencing the interpretation of the term scientific literacy, resulting in an ill-defined, diffuse and controversial concept: "the number of different interest groups that are concerned with scientific literacy, different conceptual definitions of the term, the relative or absolute nature of scientific literacy as a concept, different purposes for advocating scientific literacy, and different ways of measuring it" (Laugksch, 2000, p. 74).

Within the first factor – interest groups –, the author distinguishes four different groups. The first is represented by the science education community, whose main interest is the relationship between formal education and scientific literacy. The second, composed of social scientists and public opinion researchers, is concerned with public support for science, as well as with public participation in scientific and technological activities. The third group includes sociologists and science educators interested in the sociological approach to scientific literacy and the way this knowledge is used in everyday life. Finally, the fourth interest group, formed by the informal science education community, including science museums, zoos, botanical gardens, journalists and science writers, whose interest is in promoting opportunities for the general public to become familiar with science (Laugksch, 2000).

Regarding the second factor – different conceptual definitions of the term –, Laugksch (2000) states that, over the decades that followed the introduction of the term scientific literacy, it was developed as a concept. Since then, a large number of definitions and interpretations have been proposed, many of them based on research and others based on perceptions (Laugksch, 2000). The author refers to some authors who began the work of defining the term scientific literacy, among them Pella et al. (1966), Showalter (1974), Shen (1975) and Branscomb's (1981). However, John Miller, in 1983, proposed a multidimensional definition for scientific literacy in his publication *Scientific Literacy: A Conceptual and Empirical Review* in *Daedalus - Journal of the American Academy of Arts and Sciences* (Laugksch, 2000).

For Miller (1983), the concept of scientific literacy must present three dimensions to become truly relevant to the contemporary condition: understanding of scientific terms, knowledge of how science is structured, and understanding the impact of science and technology on society. According to the author, until then only the first two were traditionally used to define scientific literacy.

Regarding the third factor – the relative or absolute nature of scientific literacy as a concept –, Laugksch (2000) argues about the lack of precision in the definition of the word literate, as presented in the previous section. According to the author, the term can be understood as "literate as learned; literate as competent; and literate as able to function minimally in society" (Laugksch, 2000, p. 82).

The fourth factor highlighted by the author – purpose and benefits of scientific literacy – takes into account the fact that, although the idea of scientific literacy is seen as something positive, the reasons for defending it have still not been fully explained. For this reason, Laugksch (2000) grouped the arguments in favor of scientific literacy into two perspectives: macro and micro. From a macro perspective, the arguments address the connection between scientific literacy and the economic well-being of a nation, public support for science, and the relationship between science and culture. According to Laugksch (2000), "the macro view of the arguments in favor of promoting scientific literacy thus includes benefits to national economies, science itself, science policymaking, and democratic practices, as well as to society as a whole" (pp. 85-86). From a micro perspective, the author states that a scientifically literate population will result in citizens who are more confident and competent in dealing with issues related to science and technology that emerge throughout their daily lives.

Finally, regarding the fifth factor – scientific literacy assessment –, Laugksch (2000) points out that the scientific literacy assessment can be carried out using observation techniques in case studies and interviews and through questionnaires and tests. The choice of the instrument to be used is made according to the interest group and the objective of the study. This aspect will be addressed later in the section on the scientific literacy assessment.

It is observed that relevant factors involve the complexity in defining the concept of scientific literacy. Thus, below are presented some of the definitions that seem to be most relevant in the context of science education.

Miller (1998) argues that, to be considered scientifically literate, the individual must know scientific concepts, understand the methodology used by science and understand how science and technology can interfere in society. According to the author, scientific literacy should be seen as the level of understanding of science and technology necessary for an individual to act minimally as a citizen and consumer in society and, in this sense, the definition of scientific literacy does not imply an ideal, or even acceptable, level of understanding, but rather a minimum level (Miller, 1998).

In previous studies (Miller, 1983a, 1987, 1989, 1992, cited by Miller, 1998), the author argues that, in addition to the aspects mentioned above, it is necessary to master a basic vocabulary of scientific terms and concepts. This idea is in line with that presented by Chassot (2003), in which science is understood as a language and, therefore, being scientifically literate means being able to read and interpret natural phenomena. The author defines scientific literacy as "the set of knowledge that would facilitate men and women to make an interpretation of the world in which they live" (Chassot, 2000, p. 19) and compares the difficulty of this process with the difficulty of reading a text in an unknown language. This perspective is shared by Viechneski et al. (2012), who argue that the knowledge acquired by the individual through mastery of the language of science is "fundamental for their action in society, helping them make decisions that involve scientific knowledge" (p. 858).

For the Organization for Economic Co-operation and Development (OECD), "knowledge of science and science-based technology contributes significantly to the personal, social and professional lives of individuals, and its understanding is fundamental to preparing a young person for life" (INEP, 2015, p. 3). In this sense, the OECD defines scientific literacy as "the ability to engage with science-related issues, and with the ideas od science, as a reflective citzen" (OECD, 2017a, p. 22), stating that "a scientific literate person is willing to engage in reasoned discourse about science and technology, which requires the competencies to explain phenomena scientifically, evaluate and design scientific enquiry, and interpret data and evidence scientifically" (p. 22).

In turn, the Council of the European Union (CEU), referring to scientific literacy as competence in science (Siarova et al., 2019), conceives it as a key competence, related to "the ability and willingness to explain the natural world by making use of the body of knowledge and methodology employed, including observation and experimentation, in order to identify questions and to draw evidence-based conclusions" (Council of the European Union, 2018, p. 9). The CEU associates competence in science with competences in technology and engineering, because these are related to the applications of knowledge and methodologies of competence in science, due to human aspirations or needs (Council of the European Union, 2018). In this sense, "competence in science, technology and engineering involves an understanding of the changes caused by human activity and responsibility as an individual citizen" (Council of the European Union, 2018, p. 9).

Siarova et al. (2019) argue that, although the OECD and the CEU apply different concepts, the essence of the concept of scientific literacy and scientific competence is similar, highlighting the importance of understanding the impact of science, technology and human activity on society and the responsibility of citizens.

The National Research Council (NRC), through the *National Science Education Standards*, a document that establishes what American students need to know, understand, and be able to do to be considered scientifically literate in each grade/year, defines scientific literacy as "the knowledge and understanding of scientific concepts and processes required for personal decision making, participation in civic and cultural affairs, and economic productivity" (NRC, 1996, p. 22). According to the document, being scientifically literate means that

> a person can ask, find, or determine answers to questions derived from curiosity about everyday experiences. It means that a person has the ability to describe, explain, and predict natural phenomena. Scientific literacy entails being able to read with understanding articles about science in the popular press and to engage in social conversation about the validity of the conclusions. Scientific literacy implies that a person can identify scientific issues underlying national and local decisions and express positions that are scientifically and technologically informed. A literate citizen should be able to evaluate the quality of scientific information on the basis of its source and the methods used to generate it. Scientific literacy also implies the capacity to pose and evaluate arguments based on evidence and to apply conclusions from such arguments appropriately. (NRC, 1996, p. 22).

The director of Project 2061, developed by the American Association for the Advancement of Science (AAAS), George Nelson, in his article *Science Literacy for All in the 21st Century* (Nelson, 1999), points out that, according to the institutions AAAS, National Academy of Sciences and National Science

Teachers Association (NSTA), scientific literacy consists of "a knowledge of certain important scientific facts, concepts, and theories; the exercise of scientific habits of mind; and an understanding of the nature of science, its connections to mathematics and technology, its impact on individuals, and its role in society" (Nelson, 1999, p. 15).

Bybee (2012) refers to scientific literacy as the central objective of science education, which is "scientific knowledge and use of that knowledge to identify questions, to acquire new knowledge, to explain scientific phenomenon, and to draw evidence-based conclusions about science-related issues" (p. 65).

Howell and Brossard (2021) criticize previous definitions and argue that, due to the contemporary complexity of science, social issues, and information networks, a definition of scientific literacy should consider "the entire 'science information lifecycle'" (p. 1). Although they do not propose a definition for scientific literacy, the authors argue that, today, a scientifically literate individual needs skills and competencies that allow him/her to

> 1) understanding how science is produced, and what that means for how science relates to broader society, or "civic science literacy"; 2) understanding how science information appears and moves through media systems, or "digital media science literacy"; and 3) understanding how people interpret science information when they come across it, or "cognitive science literacy". (Howell & Brossard, 2021, p. 2).

DeBoer (2000), from a unique perspective, suggests that we should accept "the fact that scientific literacy is simply synonymous with the public's understanding of science and that this is necessarily a broad concept" (p. 594). According to the author, some researchers have admitted that scientific literacy is just a useful slogan for educators and researchers in the field of education to support the improvement of science teaching and, thus, "to speak of scientific literacy is simply to speak of science education itself" (DeBoer, 2000, p. 582).

In a more recent study, Rudolph (2023) states that scientific literacy "is simply the understanding of science we would ideally expect of a non-specialist, that is, someone not on a career path that would entail the technical use of science concepts, theories, vocabulary, techniques, and the like" (p. 521). In his research, the author states that there are several meanings for the term scientific literacy and presents four that, for him, are the most prominent, which are described below.

In the first, established between the 1950s and 1960s in order to maintain the scientific elite in a democratic political system, scientific literacy was defined as the knowledge necessary for "the average citizen to learn enough about scientists and how they worked to appreciate and support the scientific enterprise" (Rudolph, 2023, p. 526). In this sense, science education was designed to foster public appreciation and respect for science to ensure continued public funding (Rudolph, 2023).

In the second meaning, which began in the early 1970s and was more focused on a critical understanding of science and society, the understanding of scientific literacy was more associated with the understanding of the relationships between science, technology, and society. This change was necessary due to a growing segment of the public that began to associate science with weapons of war, environmental pollution, and dangers to health and well-being. Thus, the definition of scientific literacy began to include the recognition of the harmful effects and limitations of the scientific enterprise, in an attempt to rehabilitate the image of science and "steer the public back to the golden age of generous federal support of scientists and scientific research", referring to the previous two decades (Rudolph, 2023, p. 527).

The third meaning, which emerged in the late 1970s and gained strength in the following two decades, related it more to economic development. During this period, the idea of scientific literacy became more associated with the development of "workplace skills and technical competencies for both those on-track to enter science-related careers as well as the general, non-science-bound public, thus blurring the boundaries between the two" (Rudolph, 2023, p. 527).

Finally, the fourth meaning, one of the most recent, associates scientific literacy with basic knowledge of science content. Rudolph (2023) claims that this view originated from the growing focus on standardized assessments, which gained strength in the 1970s, mainly in the United States. He also states that the appearance of scientific literacy tests and, in the late 20th and early 21st centuries, of the international assessments called *Trends in International Mathematics and Science Study* (TIMSS) and the *Program for International Student Assessment* (PISA), caused the concept of scientific literacy to be reduced to something that can be tested, typically associated with the recall of basic facts (Rudolph, 2023).

Among the many efforts made to describe the concept and systematize the elements of scientific literacy, the study by Roberts (2011), which expanded the discussion of his 2007 study (Roberts, 2007), and by Valladares (2021) are highly relevant, especially in the school context. Roberts (2011), with the aim of discussing and analyzing the competition on the concept of scientific literacy and not getting lost in the details associated with the dozens of definitions for the term, compiled several meanings present in the literature of the field of science education research and organized them into two major visions that are recurrent in science education curricula, visions I and II. For the author, "a vision provides professional educators, researchers, policy makers, and the public with an answer to the big-picture question 'What should a scientifically literate person know and be able to do?' (Thus we 'envision' the scientifically literate person.)" (Roberts, 2011, p. 12).

View I, considered internalist (Silva & Sasseron, 2021), is more related to the products, processes and characteristics of the scientific enterprise, as well as to the development of conceptual understanding, that is, to the subject of science (Roberts, 2011). According to Roberts (2011), from the perspective of view I, school science is oriented towards developing a set of potential scientists.

View II, considered externalist (Silva & Sasseron, 2021), refers to the aspects and situations in which science demonstrably plays a role in human affairs, that is, in which science expresses, imposes and receives from society, including, but not limited to, scientific thought and activity (Roberts, 2011). From the perspective of vision II, more aligned with the STS approach and, more recently, with the Education for Sustainable Development (ESD) movement, school science is oriented towards students understanding and facing science-related situations that, as adults, they will face as citizens (Roberts, 2011).

According to the author, the main difference between vision I and II is not in the definition of scientific literacy, but in the formative purposes (Roberts, 2011). Such purposes, according to Silva and Sasseron (2021), guide the choice of content, objectives and didactic approaches adopted in the classroom, recognizing that vision I involves traditional elements and activities, while vision II considers the actions and relationships of science teaching in students' daily lives. Valladares (2021) corroborates this idea, stating that both views result from the advancement of research within the scope of the STS approach, but while view I reflects a positivist image of science, isolated from society, "whose teaching practices were focused on achieving the canonical concepts of science" (p. 564), view II reflects a post-positivist science, linked to society, "whose teaching practices changed focuses on the technological and social context in which science is developed" (p. 565).

In her study, Valladares (2021) analyzed the main views of scientific literacy developed in the last 20 years and characterized the historical context associated with the two views proposed by Roberts (2011), presenting a third view. According to Valladares (2021), this new vision comes from the advancement of studies in STS, which allowed demonstrating how society and culture are co-constructed by science, requiring a new vision of scientific literacy.

Vision III, in addition to expanding the conceptual scope of scientific literacy developed in Vision II, takes science teaching beyond its social contextualization and adds issues related to social engagement and citizen impact (Valladares, 2021). This vision comprises three innovative aspects: the fusion of the fundamental and derived meanings of scientific literacy; the introduction of the notions of engagement and participation in science; and the inclusion of a political and emancipatory agenda aligned with the values of equity and social justice (Valladares, 2021).

For the author, these three aspects align Vision III with the challenges of the 21st century, as it is more prone to volatility, uncertainty, complexity, ambiguity and is increasingly difficult to foresee and manage. She further claims that,

> in order to transform human relationships and consequently the different systems of injustice, economic, cultural, and social gaps, and to change the growing expressions of hate and violence towards certain social groups as well as to stop the exacerbation of environmental crisis, it is not enough to contextualize science and reflect on its multiple risks and impacts, but rather a

> different orientation of science education and a set of skills that promote greater social activism and individual and collective agency are required. (Valladares, 2021, p. 565)

Silva and Sasseron (2021) corroborate this idea, stating that Valladares' (2021) vision III integrates and transcends the theoretical constructions present in Roberts' (2011) visions I and II, updating the idea of scientific literacy necessary for the 21st century.

In summary, from the origin of the term to the present day, several studies have sought to identify, clarify, categorize and discriminate the idea of scientific literacy and its real meaning for science education and for the public (Rudolph, 2023). However, the fact is that "scientific literacy, in other words, has never really been a specific thing at all" (Rudolph, 2023, p. 528) and there is no single identity or meaning for the term.

The existence of multiple definitions reflects the complex task of giving meaning to scientific literacy, as it is a concept that is constantly changing and subject to social, cultural, and political contexts (Queiruga-Dios et al., 2020, Rudolph, 2023). This situation is related to the fact that, since the middle of the last century, studies in the area of science education have discussed and incorporated new perspectives into the idea of scientific literacy, which, today, must be broader and more explicitly focused on social transformation (Silva & Sasseron, 2021). Furthermore, it is necessary to recognize that, as stated by Kauano and Marandino (2022), the concept of scientific literacy, as well as that of the STS movement, has developed over time and based on different conceptions of science and its relationship with education and society.

Nevertheless, the analysis carried out concisely describes how scientific literacy is no longer limited to reading and writing scientific texts, but includes the social sphere, replacing a transmissive vision with a transformative vision. It is possible to state that, within this conglomerate of definitions, scientific literacy currently includes cognitive, affective, communicative and technological skills, as well as the skills and scientific-technological knowledge necessary to: understand science, explain natural phenomena, solve problems, actively participate in issues related to scientific matters and to understand its various applications in society, such as in medical sciences, engineering, telecommunications, among other areas, which allow for greater participation and involvement of science in a social context (Valladares, 2021).

Having presented the basic conceptual issues surrounding the debates on scientific literacy, the following section will analyze how it has been assessed over time. Although this analysis does not address the debate about the concept of scientific literacy, it illustrates how it has been assessed and presents some of the main instruments used to assess it.

SCIENTIFIC LITERACY ASSESSMENT

Despite the vigorous debate surrounding the term and the concept of scientific literacy, until the 1980s, little research was conducted with the aim of assessing it (Miller, 1983; Rudolph, 2023). According to Miller (1983), before the 1960s, tests were conducted at school level and, for the most part, applied to selected populations of some schools, which, for a national assessment, was insufficient.

In 1979, an American survey conducted by the National Science Foundation of the United States applied a test to adults to assess their attitudes towards science and technology. The test used a considerable sample of the American population, with a sufficient number of items to measure each of the three dimensions of scientific literacy and, for the individual to be considered scientifically literate, a minimum number of correct answers was required in each of the three areas (Miller, 1983). The results of the research indicated that only 7% of those evaluated were qualified as scientifically literate, with most men, over the age of 35 and university graduates. Miller (1983) points out that even among those with degrees, only a quarter were considered scientifically literate.

In the 1980s, especially after the publication of Miller's article (1983), many studies began to be conducted with the aim of assessing students' knowledge in the three dimensions of scientific literacy (Laugksch & Spargo, 1996a). In another article (Laugksch & Spargo, 1996b), the authors state that the dimensions proposed by Miller (1983) – the nature of science, knowledge of science and the impact of science and technology on society – guided most national and international research on scientific literacy, which has been carried out in the United States, Great Britain, the European Community, China, Japan, Sweden, Canada, Australia and South Korea.

Nevertheless, Laugksch and Spargo (1996b) claim that in most studies that developed instruments for assessing scientific literacy, researchers proposed separate tests for each of these dimensions. The authors present the most recognized tests to date, developed to assess one of the three dimensions of scientific literacy proposed by Miller (1983): the *Test on Understanding Science* (TOUS), developed by Cooley and Klopfer in 1961; the *Nature of Scientific Knowledge Scale* (NSKS), proposed by Rubba and Anderson in 1978; the *Nature of Science Scale* (NOSS) created by Kimball in 1968; and the *Views of Science-Technology-Society* (VOSTS), developed by Aikenhead and Ryan in 1992.

Gormally et al. (2012) corroborate this idea, stating that several instruments have been developed to assess individual aspects of competencies related to scientific literacy, but none are capable of measuring all competencies. In their study, the authors present only 11 instruments, which include items on competencies related to non-laboratory scientific processes, such as the definition of science, on the vocabulary and content of science, on critical thinking and reasoning, and on the quality, credibility, and interpretation of scientific research.

Fives et al. (2014) argue that current instruments are based on some degree of complex knowledge of one or more specific scientific disciplines and that most do not include the assessment of students' attitudes toward science. Coppi et al. (2023c), when conducting a systematic review of the literature on the assessment of scientific literacy from the 1990s onwards, identified only 13 instruments, used in 43 studies. The authors found that most instruments assess different scientific literacy skills and were developed for high school students.

Laugksch and Spargo (1996b) also showed that most of the instruments developed had considerable methodological limitations. With the exception of those that assess the extent of the impact of science and technology on society, the instruments have been based on a relatively small number of items, with unspecified content validity (Laugksch & Spargo, 1996b). The authors also reveal that many of the studies used interviews and questionnaires in person or by telephone, which made the study expensive and time-consuming, restricting its use to research with high funding and few participants.

The studies by Gormally et al. (2012) and Coppi et al. (2023c) reinforce such methodological limitations, especially about the presentation of the instrument validation processes. Gormally et al. (2012), considering the studies analyzed, state that the psychometric properties of the instruments used in these studies that assessed scientific literacy were unknown, being a limiting factor for the generalization of the results.

Coppi et al. (2023c) identified that only six of the 13 instruments present and describe the processes for collecting validity evidence based on content and on internal structure. Of the other seven, four indicate them, but do not describe them, and three partially portray the processes, specifying only the collection of validity evidence based on the internal structure of the instruments, leaving the validity evidence based on content only with the information that the instrument underwent evaluation by a panel of experts (Coppi et al., 2023c).

Considering the diversity of instruments developed since the 1980s to assess specific content and skills in different areas of science, the following five instruments will be addressed in publications indexed in the B-On, SciELO, Google Scholar and RCAAP databases: the *Test of Basic Scientific Literacy* (TBSL), the *Test of Scientific Literacy Skills* (TOSLS), the *Scientific Literacy Assessment* (SLA), the *Global Scientific Literacy Questionnaire* (GSLQ) and the *Scientific Inquiry Literacy* (ScInqLiT) (Coppi et al., 2023c). In addition to these, there is the *Avaliação da Literacia Científica Essencial* (ALCE) instrument, developed by Coppi et al. (2023b), a qualitative analysis instrument, developed by Sasseron and Carvalho (2008), and two international assessment instruments, PISA and TIMSS.

The instruments

Although it is not an instrument in itself, Sasseron and Carvalho (2008) suggest a qualitative analysis of the presence of indicators of scientific literacy in arguments made by students after a didactic sequence of investigation proposed by the authors. They state that the skills associated with the work of the scientist, such as the serialization, organization and classification of information, logical and proportional reasoning, hypothesis raising and testing, justification, prediction and explanation, are worked on and developed by students in the classroom and can act as indicators of scientific literacy.

These indicators represent competencies in science and scientific practice "developed and used for the resolution, discussion and dissemination of problems in any of the Sciences when there is a search for relationships between what is seen of the problem investigated and the mental constructions that lead to understanding it" (Sasseron & Carvalho, 2008, p. 338).

Regarding assessment instruments, researchers Laugksch and Spargo (1996a) developed and validated an instrument capable of assessing the scientific literacy of high school seniors, the TBSL. The test consists of 110 items, in the "true-false-don't know" format, based on five sections of *Science for All Americans*, a program developed by AAAS Project 2061, which establishes recommendations on the knowledge and skills that all American students should have in science disciplines upon completing high school (AAAS, 1989).

The TBSL items cover "important ideas and attitudes about science, the understanding of which has been considered by hundreds of experts, with the aim of encompassing the sense of the scientifically literate individual" (Nascimento-Schulze, 2006, p. 102). To this end, the test is divided into three distinct subtests, based on the three constitutive dimensions of scientific literacy proposed by Miller (1983): nature of science, knowledge of the content of science and impact of science and technology on society.

Another available instrument is the TOSLS, developed and validated by Gormally et al. (2012) based on the

> key definitions provided in education policy documents and reviews in order to define the major facets of scientific literacy for this instrument (AAAS, 1993, 2010; National Academy of Sciences, 1997; Organisation for Economic Co-operation and Development, 2003; Sundre, 2003; Picone et al., 2007; Holbrook and Rannikmae, 2009; Bray Speth et al., 2010). (Gormally et al., 2012, p. 336).

The TOSLS consists of 28 multiple-choice items specifically designed to assess the quality of scientific information and arguments presented in the media by scientists, using evidence and data. According to the authors, the items are "contextualized around real-world problems, for example, evaluating the reliability of an Internet site containing scientific information or determining what would constitute evidence to support a fitness product's effectiveness" (Gormally et al., 2012, p. 365).

The authors suggest that the TOSLS be administered at the beginning and end of the educational process so that it is able to detect gains in learning between the pre- and post-test. In this way, the TOSLS aims to identify the gap between the scientific literacy that is being taught by teachers and being learned by students (Gormally et al., 2012).

The SLA, developed by Fives et al. (2014), represents one of the few instruments developed to assess the scientific literacy of students in Middle School. According to the authors, the competencies and skills considered necessary for scientific literacy used in the construction of the SLA were based on documents proposed by science education agencies, such as AAAS, NSTA, NRC and OECD (Fives et al., 2014). From these documents, six components of scientific literacy were generated: the role of science, scientific thinking and doing, science and society, literacy in scientific media, mathematics in science and scientific motivation and beliefs (Fives et al., 2014).

The instrument is divided into two distinct sections, SLA-Demonstrated and SLA-Motivation and Beliefs. The first section consists of 26 multiple-choice items related to the cognitive components of scientific literacy, such as the role of science, scientific thinking, the relationship between science and society, and the importance of mathematics in science. The second section contains 25 items in Likert scale format, which examine the affective components of scientific literacy, such as self-efficacy, personal epistemology for science, motivation, and beliefs (Fives et al., 2014).

The GSLQ, proposed by Mun et al. (2015), consists of 48 items that assess scientific literacy about habits of thought, character and values, science as a human activity, and metacognition and self-management. Developed to assess high school students, the instrument is based on the concepts of scientific literacy proposed by studies that represent a synthesis of research on scientific literacy (Mun et al., 2015).

The ScInqLiT, developed by Wenning (2007), assesses different scientific literacy skills, such as: identifying and controlling variables; recognizing and analyzing alternative explanations and models; drawing appropriate conclusions from evidence; understanding and analyzing data; constructing and interpreting graphs; developing hypotheses; designing experimental procedures; and identifying problems to be investigated (Wenning, 2007). According to the author, the test is based on the document *Science and Its Ways of Knowing* and should not be interpreted as a performance test, but as an instrument capable of identifying weaknesses in students' understanding, improving educational practice and evaluating the effectiveness of the educational program regarding scientific investigation skills. Composed of 35 items, the ScInqLiT is intended for students in Middle and High School.

Finally, the ALCE, developed by Coppi et al. (2023b), assesses students' scientific literacy skills at the end of Middle School, in the cognitive domains of understanding, analyzing and evaluating phenomena, problems and everyday situations that involve knowledge and content skills developed in the subjects of Natural Sciences and Physical Chemistry (Coppi et al., 2023b). The instrument consists of 34 items, in an adapted true-false format, based on the main Portuguese curricular documents in force, and presented as a useful tool to identify possible gaps between teaching objectives and students' proficiency in scientific literacy and for teachers to reflect on the methodologies, lesson plans and strategies used in the classroom to change them to better develop students' scientific literacy (Coppi et al., 2023b).

Regarding international assessments, two instruments are of great importance in the assessment of scientific literacy: PISA and TIMSS. PISA is an international assessment programme organised by the OECD and carried out every three years since 2000. It is aimed at 15-year-old students in OECD countries and partner economies and its main objective is to provide indicators capable of assisting the process of developing public education policies in participating countries (OECD, 2017b).

The assessment covers the areas of knowledge of reading, mathematics and science and adopts a literacy perspective. In the area of reading, PISA assesses the extent to which students are able to use their reading skills to interpret different types of texts that they are likely to come across throughout their lives. In mathematics, the use of mathematical knowledge and skills to solve different numerical and spatial challenges and problems is assessed. In the area of science, PISA assesses the ability to use scientific knowledge and skills to understand, interpret and solve scientific situations and challenges (OECD, 2017b).

PISA emphasizes the application of knowledge and skills learned at school to solve problems and challenges in everyday situations. More than assessing students' mastery of specific school content, the PISA assessment analyzes the

> ability to use their knowledge and skills to meet real-life challenges. This orientation reflects a change in curricular goals and objectives, focusing more on what students can do with what they learn at school. (OECD, 2017b, p. 22).

In the area of science, the focus of the 2006 and 2015 tests, scientific literacy is assessed, which is more related to Roberts' vision II (Valladares, 2021), which is defined by PISA as "the ability to engage with science-related issues, and with the ideas of science, as a reflective citizen" (OECD, 2017a, p. 22) and requires skills to

> explain phenomena scientifically – recognise, offer and evaluate explanations for a range of natural and technological phenomena; evaluate and design scientific enquiry – describe and appraise scientific investigations and propose ways of addressing questions scientifically; interpret data and evidence scientifically – analyse and evaluate data, claims and arguments in a variety of representations and draw appropriate scientific conclusions. (OECD, 2017a, p. 22).

TIMSS is also an international comparative assessment. Sponsored by the International Association for the Evaluation of Educational Achievement (IEA), TIMSS has assessed the knowledge of students in grades 4 and 8 in mathematics and science every four years since 1995. The results of the assessment allow for a comparison between the educational levels of students in the participating countries and assist in decision-making and monitoring of curricular reforms and teaching practices in mathematics and science (NCES, 2018). Although TIMSS does not explicitly mention the term scientific literacy, it is possible to verify its presence in the assessment framework (IEA, 2017), being more associated with Roberts' vision I of scientific literacy (Valladares, 2021). This makes it clear that as students' understanding of science develops, "they can become informed citizens capable of distinguishing scientific fact from fiction and understanding the scientific basis of important social, economic, and environmental issues" (IEA, 2017, p. 29).

Science assessments for grades 4 and 8 differ in content, but are based on the same cognitive domains: knowing, applying and reasoning. According to the IEA (2017), in fourth grade,

> there is more emphasis at the fourth grade on life science than its counterpart, biology, at the eighth grade. At the eighth grade, physics and chemistry are assessed as separate content domains and receive more emphasis than at fourth grade, where they are assessed as one content domain (physical science). The three cognitive domains (knowing, applying, and reasoning) are the same at both grades, encompassing the range of cognitive processes involved in learning science concepts, and then applying these concepts and reasoning with them. (p. 30)

Regarding the instruments most used in the literature presented, it can be seen that they are based on different programs, parameters and references of scientific literacy. In addition to the fact that each instrument was developed for a specific country and context, these differences can also be associated with the issues previously discussed, especially in the concept of scientific literacy. With reference to international assessments, it can be seen that these are based on specific scientific literacy objectives and that, regardless of the concept used, they provide, in addition to comparisons between the participating countries, individual reports that aim to contribute to decision-making regarding education in each country.

CONCLUDING REMARKS

The study aimed to provide a critical and historical approach to the characteristics most discussed by the scientific community regarding scientific literacy and demonstrated that the great debate surrounding this topic is based mainly on five disagreements: the theoretical perspective, the translation of the words literacy and literate and the term scientific literacy and their respective meanings, the definition of the concept of scientific literacy and the way to assess it.

It is understood that, despite the semantic differences observed in the translations and meanings of the original words, most authors use the words literate/*letrado*/*literato*/*alfabetizado* as synonyms, when referring to an individual who is able to read and write, but who is also the holder of knowledge. Regarding the use of these three terms, in Portugal, the term *literacia científica* is preferred, while in Brazil the terms *letramento científico* and *alfabetização científica* are preferred, depending on the theoretical meanings of the researchers. In the Portuguese language, this way of understanding the translation of literate and, consequently, of literacy, associates the latter more with the meaning of *literacia*/*letramento* than with that of *alfabetização*, since, as previously discussed, the meaning of *alfabetização* is more related to the ability to read and write.

For many authors, especially in Brazil, the debate about the use of the terms *letramento científico* or *alfabetização científica* seems to be much more linked to the field of research in linguistics and language teaching than to the field of research in science teaching. This fact reinforces the idea that the adoption of one term or another can be understood based on the theoretical perspectives adopted.

Regarding the concept of scientific literacy, it has moved from a transmissive view of scientific knowledge to a sociocultural view, which considers the relationship between science teaching and society, and, finally, to a transformative view, committed to the participation, emancipation, engagement and social impact of citizens and aligned with the values of equity and social justice.

However, the concept of scientific literacy encompasses a multitude of meanings that generally associate it with the understanding of science. To consider it not only as a synonym for public understanding of science, as recommended by some authors, but also to consider it as a broad concept and establish a synthesis concept, resulting from the analysis carried out in this study, a definition is proposed that assumes scientific literacy as the understanding of the scientific enterprise and the conscious use of scientific and technological knowledge to solve problems, to explain natural phenomena in everyday life, as well as for active participation in debates on scientific issues that involve society, supported by scientifically and technologically based arguments, allowing the individual to act as a citizen.

The process of assessing scientific literacy became a focus of interest mainly after the 1980s, when many studies aimed to assess the level of scientific literacy of individuals. Most instruments developed before 2000 assessed only one dimension of scientific literacy. For the other instruments, it was found that they assessed different skills and content related to scientific literacy.

Nevertheless, it is clear that a large number of studies that developed scientific literacy assessment instruments during both periods do not clearly present the processes for collecting validity evidence used in the construction of the instruments and, when they do present them, they appear to be weak and incomplete. The study also reveals the small number of scientific literacy assessment instruments, especially for students in the second cycle of middle school.

At the international level, PISA and TIMSS, in addition to acting as large-scale comparative assessments, carry out a diagnosis of the situation of scientific education in each participating country, providing important indicators of the level of scientific literacy of the responding students.

In summary, the study reveals some complexity in translating and adapting concepts between different languages and contexts. Despite this issue, the theoretical perspective of the authors has a great impact on the choice of using one term or another. It also shows that there is no solid and immutable concept of scientific literacy and it changes over the years and according contexts and historical moments, among other factors. It also points to the need to develop new instruments for assessing scientific literacy for the various sectors and actors in society, including classroom assessment instruments, in order to obtain more information for improving science education. Finally, it demonstrates that scientific literacy is the subject of international studies and, despite controversies, it is presented as the main objective of science teaching.

The debate presented here is particularly relevant for science teaching, since the aspects discussed directly reflect the idea and interpretation of what scientific literacy is and how to assess it. Consequently, when dealing with issues involving scientific literacy, these aspects must be clear and contextualized with current sociocultural implications.

In this sense, it is suggested that the scientific community, in future research on the concept of scientific literacy, take a position on these factors that generate controversy, for example, explaining why the term is used and defining its meaning. Although this positioning does not necessarily result in the end of discussions regarding these aspects of scientific literacy, it can help to reduce misunderstandings and ambiguities, contributing to the development and interpretation of the concept and, consequently, to science education in general.

REFERENCES

AAAS. (1989). *Project 2061: science for all americans*. Oxford University Press.

Benavente, A., Rosa, A., Costa, A. F. & Ávila, P. (1996). *A literacia em Portugal*. Fundação Calouste Gulbenkian.

Bybee, R. (2016). Scientific literacy. In R. Gunstone (Ed.), *Encyclopedia of science education* (pp. 944–946). Springer.

Bybee, R. (2012). Scientific Literacy in Environmental and Health Education. In A. Zeyer & R. Kyburz-Graber (Eds.), *Science | Environment | Health: Towards a Renewed Pedagogy for Science Education* (pp. 49–67). Springer Netherlands. https://doi.org/10.1007/978-90-481-3949-1_4

Chassot, A. (2000). *Alfabetização científica: questões e desafios para a educação*. Editora Unijuí.

Chassot, A. (2003). Alfabetização científica: uma possibilidade para a inclusão social. *Revista Brasileira de Educação*, *22*, 89–100. https://doi.org/10.1590/S1413-24782003000100009

Council of the European Union. (2018). *Council recommendation of 22 may 2018 on key competences for lifelong learning* . Official Journal of the European Union.

Coppi, M., Fialho, I., & Cid, M. (2023a). Assessing portuguese elementary school students' scientific literacy: application of the ALCE instrument. *Social Sciences*, *12*(7), 374. https://doi.org/10.3390/socsci12070374

Coppi, M., Fialho, I., & Cid, M. (2023b). Developing a Scientific Literacy Assessment Instrument for Portuguese 3rd Cycle Students. *Education Sciences*, *13*(9), 941. https://doi.org/10.3390/educsci13090941

Coppi, M., Fialho, I., & Cid, M. (2023c). Scientific literacy assessment instruments: a systematic literature review. *Educação Em Revista*, *39*, e37523. http://dx.doi.org/10.1590/0102-4698237523-T

Cunha, R. B. (2017). Alfabetização científica ou letramento científico?: Interesses envolvidos nas interpretações da noção de scientific literacy. *Revista Brasileira de Educação*, *22*(68), 169–186. https://doi.org/10.1590/s1413-24782017226809

DeBoer, G. E. (2000). Scientific literacy: another look at its historical and contemporary meanings and its relationship to science education reform. *Journal of Research in Science Teaching*, *37*(6), 582–601. https://doi.org/10.1002/1098-2736(200008)37:63.0.CO;2-L

Dias, G. F. (1991). Os quinze anos da educação ambiental no Brasil: um depoimento. *Em Aberto*, *10*(49), 3–14.

Dionísio, M. de L. (2007). Educação e os estudos atuais sobre letramento. *Perspectiva*, *25*(1), 209–224.

Freire, P. (1989). *A importância do ato de ler: Em três artigos que se complementam*. Cortez.

Freire, P. (2018). *Pedagogia do oprimido*. Paz e Terra.

Fives, H., Huebner, W., Birnbaum, A. S., & Nicolich, M. (2014). Developing a measure of scientific literacy for middle school students. *Science Education*, *98*(4), 549–580.

Gormally, C., Brickman, P., & Lutz, M. (2012). Developing a test of scientific literacy skills (TOSLS): measuring undergraduates' evaluation of scientific information and arguments. *CBE Life Sciences Education*, *11*(4), 364–377.

Howell, E. L., & Brossard, D. (2021). (Mis)informed about what? What it means to be a science-literate citizen in a digital world. *Proceedings of the National Academy of Sciences of the United States of America*, *118*(15), 1–8. https://doi.org/10.1073/pnas.1912436117

Hurd, P. D. (1958). Science literacy: Its meaning for American schools. *Educational Leadership*, *16*(1), 13–16.

IEA. (2017). *TIMSS 2019 - assessment frameworks*. IEA.

INEP. (2015). *OECD PISA 2015 - programa internacional de avaliação de estudantes - matriz de avaliação de ciências*. http://download.inep.gov.br/acoes_internacionais/pisa/marcos_referenciais/2015/matriz_de_ciencias_PISA_2015.pdf

Kauano, R. V., & Marandino, M. (2022). Paulo Freire na Educação em Ciências Naturais: Tendências e Articulações com a Alfabetização Científica e o Movimento CTSA. *Revista Brasileira de Pesquisa Em Educação Em Ciências*, e35064. https://doi.org/10.28976/1984-2686rbpec2022u521548

Kleiman, A. (1995). Modelos de letramento e as práticas de alfabetização na escola. In A. Kleiman (Ed.), *Os Significados do Letramento – Uma nova perspectiva sobre a prática social da escrita* (pp. 15–61). Mercado de Letras.

Krasilchik, M., & Marandino, M. (2004). *Ensino de ciências e cidadania*. Moderna.

Laugksch, R. C. (2000). Scientific literacy: a conceptual overview. *Science Education*, *84*(1), 71–94.

Laugksch, R. C., & Spargo, P. E. (1996a). Construction of a paper-and-pencil test of basic scientific literacy based on selected literacy goals recommended by the american association for the advancement of science. *Public Understanding of Science*, *5*(4), 331–359. https://doi.org/10.1088/0963-6625/5/4/003

Laugksch, R. C., & Spargo, P. E. (1996b). Development of a pool of scientific literacy test-items based on selected AAAS literacy goals. *Science Education*, *80*(2), 121–143. https://doi.org/10.1002/(SICI)1098-237X(199604)80:2<121::AID-SCE1>3.0.CO;2-I

Lima Santos, N., & Gomes, I. (2004). Literacia: da escola ao trabalho. *Revista Da Faculdade de Ciências Humanas e Sociais*, *1*, 169–177.

Lorenzetti, L. (2017). Alfabetização Científica na educação em ciências. *ACTIO: Docência Em Ciências*, *2*(2), 13.

Lorenzetti, L. (2023). Promovendo a alfabetização científica e tecnológica no contexto escolar. *Educação por escrito*, *14*(1), e45045. https://doi.org/10.15448/2179-8435.2023.1.45045

Marandino, M., Kauano, R., & Martins, L. (2022). Paulo Freire, educação, divulgação e museus de ciência naturais: Relações e tensões. *Cadernos de Sociomuseologia*, *63*(19), 91–103. https://doi.org/10.36572/csm.2022.vol.63.07

Martins, M. de L. H. (2010). *Processos discursivos de (re)construção do conceito de literacia: o papel dos media* [Dissertação de Mestrado, Universidade do Minho, Braga, Portugal].

Miller, J. D. (1983). Scientific literacy: a conceptual and empirical review. *Daedalus*, *112*(2), 29–48.

Miller, J. D. (1998). The measurement of civic scientific literacy. *Public Understanding of Science*, *7*(3), 203–223.

Mun, K., Shin, N., Lee, H., Kim, S. W., Choi, K., Choi, S. Y., & Krajcik, J. S. (2015). Korean secondary students' perception of scientific literacy as global citizens: using Global Scientific Literacy Questionnaire. *International Journal of Science Education*, *37*(11), 1739–1766. https://doi.org/10.1080/09500693.2015.1045956

Nascimento-Schulze, C. M. (2006). Um estudo sobre alfabetização científica com jovens catarinenses. *Psicologia - Teoria e Prática*, *8*(1), 95–106.

NCES. (2018). *U.S. TIMSS 2015 and TIMSS advanced 1995 & 2015 technical report and user's guide*. National Center for Education Statistics, Institute of Education Sciences.

Nelson, G. D. (1999). Science literacy for all in the 21st century. *Educational Leadership*, *57*(2), 14–17.

NRC. (1996). *National science education standards*. National Academies Press.

OECD. (2017a). PISA 2015 - assessment and analytical framework: Science, reading, mathematic and financial literacy and collaborative problem solving. In *OECD publishing*. OECD Publishing. http://dx.doi.org/10.1787/9789264281820-en

OECD. (2017b). *PISA 2015 - technical report*. OCDE Publications.

Oliveira, M. C. D., & Linsingen, I. V. (2019). Reflexões acerca da educação CTS Latino-Americana a partir das discussões do grupo de pesquisa Dicite da UFSC. In S. Cassiani & I. Linsingen (Eds.), *Resistir, (re)existir e (re)inventar a educação científica e tecnológica*. UFSC/CED/NUP.

Queiruga-Dios, M. Á., López-Iñesta, E., Diez-Ojeda, M., Sáiz-Manzanares, M. C., & Dorrío, J. B. V. (2020). Citizen science for scientific literacy and the attainment of sustainable development goals in formal education. *Sustainability (Switzerland)*, *12*(10). https://doi.org/10.3390/su12104283

Richetti, G. P., & Milaré, T. (2021). O óleo no nordeste brasileiro: aspectos da (an)alfabetização científica e tecnológica. *Revista Brasileira de Pesquisa em Educação em Ciências*, e29065. https://doi.org/10.28976/1984-2686rbpec2021u11871215

Roberts, D. (2007). Scientific literacy/Science literacy. In S. K. Abell & N. G. Lederman (Eds.), *Handbook of research on science education* (pp. 729–780). Lawrence Erlbaum Associates.

Roberts, D. (2011). Competing visions of scientific literacy: The influence of a science curriculum policy image. In C. Linder, L. Östman, D. Roberts, P. Wickman, G. Erickson, & A. MacKinnon (Eds.), *Exploring the landscape of scientific literacy* (pp. 11–27). Routledge.

Rother, E. T. (2007). Revisão sistemática X revisão narrativa. *Acta Paulista de Enfermagem*, *20*(2), v–vi. https://doi.org/10.1590/S0103-21002007000200001

Rudolph, J. L. (2023). Scientific literacy: Its real origin story and functional role in American education. *Journal of Research in Science Teaching*, *61*(3), 519–532. https://doi.org/10.1002/tea.21890

Sasseron, L. H., & Carvalho, A. M. P. (2008). Almejando a alfabetização científica no ensino fundamental: a proposição e a procura de indicadores do processo. *Investigações Em Ensino de Ciências*, *13*(3), 333–352.

Sasseron, L. H., & Carvalho, A. M. P. de. (2011). Alfabetização científica: uma revisão bibliográfica. *Investigações Em Ensino de Ciências*, *16*(1), 59–77.

Shamos, M. H. (1995). *The myth of scientific literacy*. Rutgers University Press.

Siarova, H., Sternadel, D., & Szőnyi, E. (2019). *Research for CULT Committee – Science and scientific literacy as an educational challenge*. European Parliament, Policy Department for Structural and Cohesion Policies.

Silva, M. B. e, & Sasseron, L. H. (2021). Alfabetização científica e domínios do conhecimento científico: Proposições para uma perspectiva formativa comprometida com a transformação social. *Ensaio: Pesquisa Em Educação Em Ciências*, *23*, e34674. https://doi.org/10.1590/1983-21172021230129

Soares, M. (2002). Apresentação. *Educação e Sociedade*, *23*(81), 15–19.

Soares, M. (2004a). Alfabetização e letramento: Caminhos e descaminhos. *Revista Pátio*, *29*, 96–100.

Soares, M. (2004b). Letramento e alfabetização: As muitas facetas. *Revista Brasileira de Educação*, *25*, 5–17. https://doi.org/10.1590/S1413-24782004000100002

Teixeira, F. M. (2013). Alfabetização científica: questões para reflexão. *Ciência & Educação*, *19*(4), 795–809.

UNESCO. (1999). *Declaration on science and the use of scientific knowledge and the science agenda - Framework for action*. UNESCO.

UNESCO. (2019). *Marco de competencias de los docentes en materia de TIC*. UNESCO.

UNESCO. (2020). *Adverse consequences of school closures*. UNESCO.

Valladares, L. (2021). Scientific literacy and social transformation. *Science & Education*, *30*(3), 557–587. https://doi.org/10.1007/s11191-021-00205-2

Viechneski, J. P., Lorenzetti, L., & Carletto, M. R. (2012). Desafios e práticas para o ensino de ciências e alfabetização científica nos anos iniciais do ensino fundamental. *Atos de Pesquisa Em Educação*, *7*(3), 853–876. http://dx.doi.org/10.7867/1809-0354.2012v7n3p853-876

Wenning, C. J. (2007). Assessing inquiry skills as a component of scientific literacy. *J. Phys. Tchr. Educ. Online*, *4*(2), 21–24.

World Economic Forum. (2015). *New vision for education - Unlocking the potential of technology*. World Economic Forum®.

Yacoubian, H. A. (2018). Scientific literacy for democratic decision-making. *International Journal of Science Education*, *40*(3), 308–327. https://doi.org/10.1080/09500693.2017.1420266

Submitted: 11/29/2023
Preprint:11/10/2023
Approved: 08/02/2024

AUTHOR CONTRIBUTIONS

Author 1 - Conception and development, methodological design, literature review, data collection and processing, active participation in data analysis and interpretation of results, writing of the final text.
Author 2 - Conception and development, methodological design, critical review of the text and addition of significant parts.
Author 3 - Conception and development, methodological design, critical review of the text and addition of significant parts.

DECLARATION OF CONFLICT OF INTEREST

The authors declare that there is no conflict of interest with this article.

ACKNOWLEDGMENTS

This work had national funds through FCT – *Fundação para a Ciência e a Tecnologia, I.P.*, under the Research Grant with reference UI/BD/151034/2021 and DOI 10.54499/UI/BD/151034/2021.