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Relationships between scientific literacy, democracy, and citizenship: contributions to the debate[+*Δ]

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Abstract

In this theoretical article, we examine the relationships between scientific literacy (SL), democracy, and citizenship. In light of dialectical thinking, we use the categories of totality and historicity to analyze conceptions of SL in their respective socio-historical contexts, returning in a qualitatively superior way to the concrete, highlighting contradictions related to the alienation of the political dimension of SL — contradictions that, we argue, must be overcome through the process of negation, preservation and overcoming of SL in relation to its immanent political character.

Keywords: *Scientific literacy; Democracy; Citizenship; Science Education.*

I. Introduction

Scientific literacy (SL) is a widely discussed topic in national and international literature (Laugksch, 2000; Sasseron; Carvalho, 2011; Valadares, 2021 Barcellos; Coelho; Kauno; Marandino, 2022). According to Valadares (2021), over the last 20 years, largely due to the influence of critical theories, publications on SL have addressed ideals of democracy and citizenship from the perspective of preparing individuals to make socially responsible decisions in both the private and public spheres. This movement is highly relevant in societies governed by universal suffrage and is seen as a way of dispelling authoritarian and technocratic ideas.

[+] Relações entre alfabetização científica, democracia e cidadania: contribuições para o debate

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However, there are criticisms of the superficiality with which concepts such as democracy and citizenship are associated with SL (Reis; Oliveira, 2014; Pinhão; Martins, 2016; Autores, 2022a; Rosa; Lima; Cavalcanti, 2023; Carnio, 2024).

Although there is criticism of the superficiality of the relationship between SL, democracy, and citizenship, few studies analyze this issue from a dialectical and historical perspective. Faced with this problem, we conduct a theoretical study, understood by Martins and Lavoura (2018) as one that involves the selection of a corpus to be studied and analyzed, with a view to defining a problem, accompanied by justification and hypothesis. To this end, we focused on important texts that map the history of SL, such as Shamos (1995), Laugksch (2000), and Sasseron and Carvalho (2011), to problematize the relationships between scientific literacy, democracy, and citizenship. We argue that these three categories should be thought dialectically, to highlight the contradictions to be overcome, considering the demands of scientifically literate people in Brazil.

Dialectics is indispensable for understanding phenomena in which human beings are simultaneously investigators and part of the problem being investigated (Pinto, 2020c). According to Adorno (2022, p. 116), the dialectical process refers to "the parts, that is, the particular moments, and the whole, the concept, which must continually change according to criteria derived from the experience of the particular". However, "[...] there is no recipe for how this can be effectively achieved, but the essence of dialectics is precisely not to be a recipe, but rather an attempt to allow truth to designate itself".

We chose to employ the dialectical categories of historicity and totality to reflect on the movement of transformation and development of the interconnections between SL, democracy, and citizenship, in the respective socio-historical contexts in which they were forged, highlighting the contradictions that, according to Adorno (2022), drive the overcoming of phenomena.

Concerning totality, we emphasize that we do not intend to exhaust the interconnections between SL, democracy, and citizenship, nor do we commit ourselves to an abstract or metaphysical understanding of totality, which claims to be capable of knowing everything. We start with the principle that:

> *The particular moment is not a part of a mechanical totality that can be composed of such parts. Each moment has within itself the possibility of developing, from itself, all the richness of the content of totality, so that within a dialectical totality, particular moments carry within themselves the structure of totality* (Ataide, 2020, p. 22).

Totality can assume the status of an auxiliary methodology in unveiling a portion of mediated reality. It is based on this understanding that we carry out the analytical and synthetic movements, back and forth, in the investigation of a given reality (Ataide, 2020). The category of historicity is essential for understanding the complex relationships that are established in the successive moments fixed by history, since, by existing, human beings historicize the chronological duration of reality (Pinto, 2020c).

In this sense, we analyze the history of SL seeking to establish interconnections with contemporary ideas of democracy and citizenship; then, we return to this concrete in a qualitatively superior way, in a totality richer in multiple determinations and relationships, which allows us to understand the internal contradictions in the course of this process. Álvaro Vieira Pinto points out that:

> *[...] dialectics interprets the process of reality by seeing in it a succession of phenomena, each of which only exists as a contradiction to previous conditions, only arises through the negation of the reality that engenders it, and will prove productive of new objective effects* (Pinto, 2020c, p. 192).

The position of contradictions and their successive resolutions lead to a subsequent state, which harbors new contradictions, restarting this infinite movement (Pinto, 2020c).

Therefore, this article does not aim to review how the concepts of democracy and citizenship appear in publications on SL. Throughout sections II, III, IV, and V, we review the history of SL, with an emphasis on US publications and context, since Brazilian science education has traditionally been influenced by the trends in the Global North, especially the United States (Krasilchik, 2000). Thus, we built a foundation for section VI, where we reflect on a totality: the movement of transformation and development of the interconnections between SL, democracy, and citizenship, highlighting contradictions that, in the Final Considerations, we seek to overcome, aiming to elevate SL to another level.

II. The search for a public understanding of Science

For Shamos (1995), the trajectory of scientific literacy (SL) begins with the defense of a public understanding of Science, before the very coining of the term *scientific literacy*. Several historical European figures endorsed this movement. Francis Bacon (1561–1626), for instance, advocated the teaching of science to the masses, arguing that the true purpose of science was to “improve the lot of man,” removing him from the vagaries of nature.

In the 18th century, public demonstrations of scientific experiments in areas such as Botany, Geology, and Astronomy were common, although restricted to elites, as they were paid events. Napoleon Bonaparte was enthusiastic about science: he founded the *École Polytechnique* in 1793 and, through the Napoleonic Reforms, definitively included science in the basic school curriculum. He saw Science as having practical uses, especially military and economic ones, encouraging its teaching among soldiers and attracting young people to military careers. This utilitarian perspective influenced other European leaders in the 19th century, driving the inclusion of science in school curricula.

Part of the public interest in Science during this period was driven by the English philosopher Herbert Spencer (1820-1893), whose work spread the need to teach Science to the masses. His thinking fits into the context of the creation of the public schools and the definition of their content. Lucas and Machado (2002), in dialogue with Leonel (1994), point out that industrialization forced European countries to establish state-run, secular, and compulsory schools. In France, for instance, tensions between the bourgeoisie and the working class demanded the creation of an educational system that would unite the social classes, forming citizens capable of exercising universal suffrage and developing values such as solidarity. Science education was part of this project.

In some countries, National Education Systems emerged, intending to train skilled labor to expand markets, under a patriotic and moralizing bias (Galiani; Machado, 2004). Spencer aligned himself with this utilitarian view, valuing scientific knowledge above all else and rejecting classical teaching methods. For him, scientific education would prepare individuals for social competition, analogous to natural selection. He coined the expression “survival of the fittest” and articulated this idea with his liberal ideals: the fittest, scientifically trained, would win in the market.

Although he did not use the term “social Darwinism,” Spencer is often associated with it. He advocated private schools, arguing that compulsory public education would support students who were “inherently unfit” to compete. For him, science education should prepare individuals to adjust to the demands of the world, mirroring the workings of nature (Lucas; Machado, 2002). While many countries were moving towards public education, Spencer remained opposed, fearing the loss of privileges for the British elite, which would require educational restructuring to preserve their interests (Shamos, 1995).

Another striking feature of his thinking is his opposition to the influence of religion in Education. An agnostic, he advocated knowledge based on reason, focusing on content and teaching methods, with a view to maximizing the development of mental faculties. For him, effective teaching should be practical, moralizing, and capable of preserving social order (Lucas; Machado, 2002).

Biologist Thomas Huxley shared many of these ideas, stating that only a liberal education would guarantee true culture. Spencer's ideas influenced the United States, one of the cradles of SL, contributing to a moderate break with classical teaching. This influence is relevant because Science Education in Brazil was and continues to be strongly impacted by American models.

It is clear, therefore, that the defense of a public understanding of science evolved into an offering to the masses, as capitalism demanded formal scientific knowledge. Simultaneously, school education was incorporated into the discourse of democratization of knowledge, essential for forming “sovereign” citizens, endowed with ethical and social responsibility — even though the competitive individualistic ideal remained widespread.

III. Scientific literacy in the American context

In the United States, movements aimed at promoting public understanding of Science emerged after Science education was included in Primary and Higher Education curricula. At the time, a pragmatic and utilitarian conception of Science prevailed, aligned with the interests of agro-industrial development and the consolidation of the USA as an economic power. Between the 18th and 19th centuries, Education was seen as an instrument for sustaining capitalist ideology. For Benjamin Franklin and other intellectuals, science should contribute both to productivity at work and to a rational understanding of the existence of God. In the words of Horace Mann, one of the leading advocates for the implementation of a National System in the USA in the mid-19th century:

> *But if education is distributed equitably, it will draw property along with it, through the strongest attraction; for to date, no group of intelligent and practical men has ever remained permanently poor. Property and labor, in different classes, are essentially antagonistic; but property and labor, in the same class, are essentially fraternal* (Mann, 1963, p. 106, cited in Galiani; Machado, 2004, p. 126).

At the end of the 19th century, the U.S. experienced a strong industrial development driven by colonial exploitation in Latin America, gradually shifting the center of capitalism from Europe to North America. Despite persistent economic inequalities, the nation was marked by a sense of strength and achievement after the War of 1812 and the strengthening of political democracy. National unity, secured by the principles of the Declaration of Independence (1776), favored the flourishing of Science, unlike what was observed in some European countries (Galiani; Machado, 2004).

The crisis of 1873 was overcome with heavy investments in steelmaking, and after the Civil War (which ended in 1865), the Northern states expanded their economic and cultural influence. In this context, there was a significant expansion of universities, science promotion agencies, and proposals to create a national department in this area. Scientific education, previously marked by Benjamin Franklin's utilitarian bias, underwent significant changes, reflecting the growth of Science itself, which gained autonomy and distanced itself from immediate practical applications (Shamos, 1995).

In the 1880s, the greatest philosophical change occurred with the decline of religious influence and the weakening of utilitarianism in science education. The *Committee on the Function of Science in General Education* (1938) emphasized intellectual training based on observation, thinking, and laboratory activities, with a focus on abstract skills and preparation for higher education. Science could now be practiced for purely theoretical purposes.

At the end of the 19th century and beginning of the 20th century, the imperialist race for markets led to arms races that culminated in World War I (1914–1918). The war boosted the economy of the US, a major supplier to the Allies. In contrast, post-war Europe faced economic devastation, the redefinition of colonies, and the growth of regimes such as fascism, Nazism, and Soviet socialism (Galiani; Machado, 2004).

Meanwhile, the US followed a liberal model, aligned with *laissez-faire*. Industry advanced with the Fordist system and the organization of General Motors, which increased productivity but also structural unemployment. The moderate break with classical education, influenced by Herbert Spencer, consolidated the presence of the sciences in school curricula.

Even so, until the 20th century, few students went beyond the elementary level, and schooling was restricted, despite scientific growth (Shamos, 1995).

During this period, there was a prevailing belief in the “magic” of technique and in the ideas of Jean Baptiste Say (1767-1832), who argued that supply created its own demand. The abundance of products and lower wages would encourage consumption and, consequently, production. However, in practice, the model proved unsustainable: with rising unemployment and falling domestic consumption and exports, the crisis worsened. The pace of industrialization continued, sustained by Fordist and Taylorist methods, masking the signs of the crisis that would culminate in the New York Stock Market Crash in 1929 (Galiani; Machado, 2004).

The crisis divided liberals: some rejected state intervention, while others, such as John Dewey (1859–1952), advocated social participation in the distribution of wealth. Dewey, a staunch liberal, saw education as a means of preserving democracy and avoiding profound social upheaval. For him, politics should be subordinated to science, and education, based on the scientific method, would produce critical, autonomous, and participatory citizens, capable of promoting a more just distribution of social goods (Batista, 2009).

Dewey's ideas were in line with the post-1929 context, in which the crisis of capitalism fueled strikes and workers' revolts. The promise of equality propagated by the universal suffrage masked social inequalities and the concentration of opportunities, in a scenario in which totalitarian regimes were growing in various parts of the world (Galiani; Machado, 2004).

By educating individuals who were aware of their social responsibilities and guided by scientific knowledge, schools would gradually contribute to the transformation of society. The educational system should expand opportunities and reduce social inequalities, promoting collective participation in the political, economic, and social spheres (Galiani; Machado, 2004).

To implement this proposal, the school would function as a "miniature society", encouraging democratic decision-making based on scientific knowledge acquired through *inquiry* using the scientific method. This would develop the “scientific habits of mind” advocated by Dewey, who proposed teaching centered on life and activity, combining theory and practice, with the student as the protagonist of their own learning (Zômpero; Laburú, 2011). These habits would be cultivated through stages such as problem definition, solution proposal, development, experimental testing, and conclusions — the basis of what is recognized today as Inquiry-Based Learning.

According to some authors, Dewey's work also supports the foundations of scientific literacy (SL) by stating that everyone would benefit from science education, provided that it was not restricted to training future scientists. His “scientific habits of mind” were considered precursors of SL indicators in adulthood. In 1930, John Miller began the systematic study of SL by seeking to define and evaluate these habits (Shamos, 1995). The first concrete attempt in this direction was made by Davis (1935), of the University of Wisconsin, who identified the following as scientific attitudes: (i) openness to change in the face of new evidence; (ii) search for truth without prejudice; (iii) understanding of cause-and-effect relationship; (iv) judgment based on facts; (v) distinction between facts and theories.

Shamos (1995) identifies this initial phase of SL as “idea management”, marked by the efforts to define and evaluate scientific literacy. However, the University of Wisconsin's initiatives were hampered by a lack of consensus and clear parameters on the concept.

Dewey's work also explained the relationships between SL, democracy, and citizenship. For him, democracy is a way of life based on sharing experiences, cooperation, and active participation in building society. It is not restricted to electoral processes, but requires the cultivation of values such as solidarity, tolerance, and social responsibility. In this context, schools should be spaces for egalitarian coexistence, collective decision-making, and the development of democratic habits. Citizenship, in turn, requires continuous education, participatory habits, and a social intelligence focused on the common good. Dewey proposed a “democratic individualism”, in which freedom is only fully realized when the individual recognizes themselves as part of social associations (Van Der Ploeg, 2020).

Despite the prestige of Dewey's ideas in the field of Science Education, they were never widely implemented. Shamos (1995) points out that many educators recognized the importance of stimulating scientific thinking but did not know how to put it into practice. Furthermore, critics point to a certain idealism in conceptions of democracy as a “way of life”, as they do not consider the limitations imposed by power structures, inequalities, and conflicts between individual freedom and the common good (Cabral, 2017; Dalbosco; Mendonça, 2020). This distances his ideas from the realities of underdeveloped countries.

The Great Depression demanded new economic approaches. John Maynard Keynes' ideas on state intervention in the economy, aligned with Dewey's thinking, influenced Franklin Roosevelt's (1933-1945) formulation of the New Deal. The plan promoted economic reorganization, stimulated employment, and improved living conditions without breaking with the principles of capitalism. However, it was World War II that reactivated the US economy, consolidating its global leadership (Galiani; Machado, 2004).

The 1940s marked a hiatus in Science Education, followed by industrial growth driven by post-war peace. The use of nuclear energy highlighted scientific and technological power and consolidated the idea that science could promote social good (Bazzo; Von Linsingen; Pereira, 2003). A “social contract” was then formed, associating scientific and technological progress with collective well-being. Science, previously understood as neutral, came to be considered a strategic state instrument (Bazzo, 1998).

This model justified large investments in scientific research and the promotion of careers in Science and Engineering. For those who did not follow this path, scientific education should foster active and critical citizenship, in line with Dewey's ideas, in favor of liberal democracy (Shamos, 1995).

During the Cold War, science education gained strategic importance. The dispute with the USSR demanded constant technological and scientific development, supported by a population that understood the importance of this race. Thus, scientific training was seen as a guarantee of national security and ideological cohesion around the democratic model (BATISTA, 2009). In this context, curriculum programs were created to develop scientific methods and attitudes in students. Starting in 1954, the *National Science Foundation* (NSF) began to fund educational initiatives, such as the *Physical Science Study Committee* (PSSC) program, which would later be disseminated in Brazil (Shamos, 1995).

On October 4, 1957, an event transformed science education in the US: the launch of Sputnik by the USSR. This milestone in the space race shook American convictions about the effectiveness of the current developmental model (Bazzo; Von Linsingen; Pereira, 2003). The most severe criticism fell on education aimed at training scientists, which was considered obsolete, driving curricular reforms and investments in science education, characterized by a strong experimental appeal and the preparation of future researchers.

Fears that the USSR would surpass the US in technological and scientific achievements led Congress to significantly increase NSF funding, strengthening its authority and investment capacity. In 1958, the National Defense Education Act (NDEA) enabled reforms in school infrastructure and the acquisition of teaching materials to improve science education. According to Shamos (1995), over the next two decades, the resources allocated to these reforms exceeded the investments made in the construction of nuclear bombs five years earlier. This led to a period known as the "alphabet soup of programs", due to the proliferation of initiatives with different acronyms.

Science and Mathematics education began to identify and recruit students with greater aptitude for scientific and engineering careers. At the same time, efforts were intensified to broaden public understanding of Science, to strengthen popular support for government investments and measures, especially those related to military science. Universities began to require scientific knowledge in their selection processes and to offer compulsory courses in various areas. The SL movement consolidated in the 1950s, strongly influenced by the context of the Cold War and the need to promote public understanding of Science (Shamos, 1995).

In this scenario, SL moved away from Dewey's ideals, being driven by the interests of the space race and the competition for global scientific and technological leadership. Citizenship was reduced to a lack of discerning public participation, induced by government support as a means of expressing democracy. SL processes prioritized the learning of scientific concepts and the development of technical skills, in-depth for future scientists and more general for those who would be prepared to support government decisions. This pragmatic approach facilitated the measurement of SL and consolidated its instrumental character.

IV. The first attempts to measure SL in the US

Laugksch (2000), based on Roberts (1983), points out that many researchers began studies on SL without adequately clarifying the definitions used, resulting in multiple interpretations of the movement and increasing the diversity of conceptualizations. Roberts (1983) exemplified this issue by citing Gabel (1976), who developed a theoretical model of SL based on an extensive set of conceptualizations present in the literature. The study revealed such a variety of interpretations that the concept of SL ultimately encompassed almost everything that was discussed in science education. This multiplicity of definitions continued to grow between the late 1970s and the early 1980s.

Despite the lack of conceptual consensus, SL gained relevance among scientists and educators. Paul Hurd is credited with coining the term *scientific literacy,* which was published in 1958 in *Science Literacy: Its Meaning for American Schools*, one year after the launch of Sputnik. Pella, O'Hearn, and Gale (1966), through a literature review of 100 articles published between 1946 and 1964, identified essential characteristics of a scientifically literate person: understanding the nature of science, scientific ethics, fundamental concepts, the distinction between science and technology, and the relationship between science and society.

Despite optimism about the impact of the reforms, the results fell short of expectations. According to Shamos (1995), this period marks the second phase in the history of SL, in which implementation attempts were carried out, but without significant improvements in public understanding of issues such as nuclear war, cancer, pollution, and environmental issues.

Snow (1962), cited in Laugksch (2000), argues that differences in the conception of SL were intensified by the separation between intellectuals and scientists, represented by "two distinct cultures". Showalter (1974), reviewing research on SL over 15 years, identified seven dimensions of the concept, highlighting aspects such as the application of scientific knowledge, the use of scientific reasoning in decision-making, values compatible with Science, understanding of the relationships between Science, technology, and society, an expanded view of the Universe, and technical skills associated with scientific knowledge.

Shen (1975) proposed three categories for SL: practical, involving knowledge applicable to health and nutrition; civic, focused on the exercise of citizenship and participation in decisions about Science, technology, and society; and cultural, related to the appreciation of Science as one of humanity's greatest constructs. Civic SL aligned with the need to define the essential knowledge for maintaining democratic processes in a technological society, while the cultural dimension tended to be restricted to an academic and intellectual elite.

The oil crisis in the 1970s caused economic recession and cuts in investments in Education, affecting curriculum reforms and SL (Batista, 2009). NSF resources were significantly reduced, influenced by questions about the effectiveness of the programs implemented (Shamos, 1995). This financial hiatus persisted until the mid-1980s, when funding resumed (Galiani; Machado, 2004).

In 1981, upon assuming the presidency, Ronald Reagan announced his intention to dismantle the NSF. Scientists and educators reacted by claiming a supposed crisis in science education, based on reports that pointed to low SL rates, a deficit in teacher training, and students' lack of interest in scientific careers. Shamos (1995) suggests that this mobilization was a political strategy to avoid funding cuts. Public pressure led to the restoration of investments, ending the alleged crisis without the identified problems being resolved.

Other interpretations of the educational crisis of the 1980s include Bloch (1986), cited in Laugksch (2000), who attributes the situation to the economic rise of Japan, South Korea, Taiwan, and Singapore. With these countries competing globally, especially in industry, technical and scientific training came to be seen as essential for development. The decline in scientific production in the US, compared to other powers, generated greater interest in SL, consolidating its relevance to the present day.

Shamos (1995) considers that the third phase of SL corresponds to the policies and actions implemented since 1980, which remain in force. Branscomb (1981, p. 5, our translation) investigated studies on SL in Latin America and proposed the following definition: "the ability to read, write, and understand systematized human knowledge". The author also identified eight categories of SL: (i) methodological, (ii) professional, (iii) universal, (iv) technological, (v) amateur, (vi) journalistic, (vii) scientific policies, and (viii) public policy on science, each linked to a specific context.

In 1983, the *Journal of the American Academy of Arts and Sciences* devoted a special issue to the discussion of SL and the challenges of science education in the USA. In the same year, Miller (1983) published a conceptual review on SL, influencing several authors by proposing a model for measuring SL levels in the adult population of the USA. This work was driven by the publication of Gabel (1976), which highlighted the multiplicity of interpretations of the term SL. Miller's (1983) multidimensional and delimited model contributed significantly to the consolidation of the concept of SL (Laugksch, 2000).

Miller (1983) defined three dimensions for SL in scientific and technological societies: understanding the norms and methods of Science; mastery of key scientific terms and concepts; and knowledge of the impact of Science and technology on society. The author emphasized that, in a democratic society, the level of scientific literacy of the population influences political decisions related to science. The concepts of Shen (1975) and Miller (1983) may have inspired researchers to structure SL in three dimensions, axes, or perspectives.

Arons (1983) expanded on Miller's (1983) approach, proposing 12 attributes for SL, with an emphasis on intellectual skills, such as recognizing scientific concepts as human constructs; differentiating observation from inference; and developing and testing hypotheses. His interpretation relates SL to the ability to correctly use scientific knowledge and reasoning in problem solving and decision making in personal, civic, and professional contexts (Laugksch, 2000).

In 1985, the *American Association for the Advancement of Science* (AAAS) launched *Project 2061*, a three-phase reform of Science, Mathematics, and Technology Education to strengthen SL among the population. The initiative maintains that it is not necessary to expand the curriculum content, but rather to improve its approach, aligning with the recommendations of *Science for All Americans* (SFAA).

The first phase established a conceptual basis, identifying essential skills and attitudes for schooling. The second phase involved scientists and educators in the formulation of curriculum models adaptable to different institutions, as well as initiatives for teacher training, development of educational materials, and school organization. The third phase seeks to mobilize collective actions over a decade or more to achieve the objectives of the previous phases (AAAS, 1995).

The project defines that a scientifically literate individual must: understand the natural world; master scientific concepts and principles, as well as the relationship between Science, Mathematics and Technology; and apply scientific thinking in individual and social contexts (AAAS, 1995).

Discussions about science education in the US have been strongly influenced by the SFAA's interpretation of SL, whose main arguments involve: (i) self-fulfillment, preparing individuals to lead their lives responsibly; and (ii) socioeconomic needs, linking the country's future to the scientific education of the population (Fourez, 1989).

Hazen and Trefil (1991) differentiated between *doing* and *using* Science: the former is restricted to scientists, while the latter is related to SL. According to Laugksch (2000), this definition is based on the concept of *cultural literacy*, proposed by Hirsch (1987), which maintains that effective communication requires familiarity with the subject and language by all involved. SL, in this sense, refers to the knowledge necessary for interaction between experts and the public. Hirsch, Kett, and Trefil (1988) listed 5.000 terms and phrases essential to SL, while Brennan (1992) cataloged 650 scientific topics, aiming to establish a minimum framework for Science education.

Wynne (1992) explored SL from a social perspective, arguing that citizens are not mere consumers of Science, but users of knowledge that must be contextualized. The way in which the population perceives and employs scientific knowledge is directly linked to its understanding of the content, methods, organization, and control of Science in a given context.

During the 1989 presidential race, George H. W. Bush proposed the *America 2000* plan, promising that by the year 2000, U.S. students would be world leaders in science and mathematics, and the entire population would be literate and able to compete in the marketplace and exercise their citizenship. In 1994, President Bill Clinton signed *Goals 2000* into law, a program of financial incentives for states committed to educational reform. Subsequently, the George W. Bush administration implemented *No Child Left Behind*, and the Barack Obama administration launched *Race to the Top* (Shamos, 1995).

V. Assessment of actions and new ideas

Shamos (1995) conducted a critical analysis of SL movements in the US, highlighting the broad scope and multiplicity of definitions as urgent challenges in the field. The author considers SL to be a utopia, as it has been worked on, and proposes its replacement with an approach closer to “scientific awareness” or “scientific appreciation”. This alternative would prioritize the knowledge necessary for the public to recognize Science as a human construct, understanding its norms, practices, and vocabulary, in addition to choosing, in a "scientific court" model, which experts follow. Thus, there would be a democratic bias, even if it were admitted that certain topics require specific expertise. Shamos' (1995) proposal stands out for highlighting the gap between scientists and non-scientists, resulting from the level of specialization in Science.

However, this concept raises an elitist bias, assuming that scientific knowledge is restricted to experts, with the population merely having to accept it. Shamos (1995) draws attention to this issue by quoting Aldous Huxley, who stated in *Brave New World* that a society governed by experts and ignorants would be an enslaved society. At the same time, the author argues that, on many issues, even experts do not reach a consensus, raising the question of how a non-scientist citizen could position themselves in the face of these differences. Referring to Niccolò Machiavelli, in *The Prince*, Shamos reinforces that “a man's wisdom is revealed in his ability to distinguish dangers and choose the lesser of them”.

Roberts (1983) states that SL has become a comprehensive concept, incorporated as a purpose in science education and in political discourse on education. According to Laugksch (2000), among the various existing definitions, SL is often treated as synonymous with public understanding of Science. Sasseron and Carvalho (2011) point out that, regardless of the terminology used, these discussions converge toward a common goal: to promote actions that expand the domain and application of scientific knowledge to generate benefits for humanity, society, and the environment.

A closer examination, however, reveals that this apparent convergence hides conceptual differences that reflect the interests of the groups involved and their target audiences. Thus, different definitions and forms of SL assessment are formulated, establishing varying criteria for determining what characterizes a scientifically literate individual. In a review of the concept of *scientific literacy*, Laugksch (2000) identified four major interest groups in the promotion of SL: (i) **Science Educators**: focused on the training of students in basic education. The group is concerned with the relationship between SL and educational objectives, addressing issues such as teacher training, curriculum, teaching methods, and resources, as well as the skills that a scientifically literate individual should demonstrate; (ii) **Social scientists**: interested in public participation and support for Science and technology policies. They work with the population's perceptions, attitudes, and sources of information on these topics, targeting adults as their audience; (iii) **Sociologists of Science and educators**: they adopt a sociological approach to SL, analyzing the construction of scientific authority and investigating how the population interprets and negotiates scientific knowledge in everyday life, focusing on adults; and (iv) **Researchers of non-formal and informal education**: they study the development of SL in spaces such as museums and zoos, targeting the entire population.

The delimitation of these groups helps to understand the multiple definitions and interpretations of SL developed since the 1950s. Laugksch (2000) suggests that the term SL resembles words such as "freedom" and "happiness", whose meaning is widely desirable, but varies depending on who conceptualizes them and the context in which they are used. This flexibility generates ongoing debates, although there are common characteristics.

Díaz, Alonso, and Mas (2003) treat SL as a continuous process, linked to the sociocultural conditions of individuals. This makes it impossible to formulate a universal model to define or apply SL in Science classes, since specific objectives vary according to the sociocultural context. Laugksch (2000) emphasizes that accepting SL as a social construct implies recognizing different concepts and parameters situated locally and temporally, according to the socioeconomic, cultural, and historical context of each nation, state, or community.

Table 1 summarizes the catalogued SL concepts, revealing that the proposals reflect the interests of the socio-historical context in which they were formulated. Some convergences emerge from the defense of learning language, laws, principles, and the nature of science as a basis for enabling individuals to develop scientific reasoning, make socially responsible decisions, and improve intellectual skills. These elements are inherent to Science, even though teaching is sometimes limited to conceptual content. They can be developed in various educational approaches, even at different levels, including those apparently distant from the SL movement.

Table 1 – Summary of understandings about SL.

Author(s)	Characteristics of SL and/or scientifically literate individuals
Dewey (1930s)	Investigation and resolution of social problems through the scientific method; training of critical, participatory, autonomous citizens who are increasingly less dependent on the State; development of scientific habits of mind.
Davis (1935)	A literate person: willing to change their opinion in the face of new evidence; seeks the whole truth without prejudice; understands the concept of cause and effect; judges based on facts; can distinguish between fact and theory.
Pella; O'Hearn; Gale (1966)	A literate person should: understand the nature of Science; know about the ethics of Science, basic concepts, and differentiate Science and technology; and understand the relationships between Science and society.

Showalter (1974)	A literate person should: understand the nature of scientific knowledge and know how to apply concepts, laws, and principles appropriately; use scientific reasoning to solve problems and make decisions; have attitudes compatible with the values defended by Science; understand and appreciate the relationships between Science, technology, and society; have developed a richer, more satisfying, and exciting conception of the Universe through their continuing scientific education; and have numerous manipulation skills associated with Science and technology.
Shen (1975)	Three-phase SL: practical, civic, and cultural.
Branscomb (1981)	SL corresponds to the ability to read, write, and understand systematized human knowledge.
Arons (1983)	A literate person should: recognize scientific concepts as human constructs; understand the difference between observation and inference; be able to develop and test hypotheses; mobilize this knowledge to solve problems and make decisions in personal, civic, and professional spheres.
Miller (1983)	Three-fold SL: understanding of norms and methods; of key terms and concepts; and of the impact of Science and Technology on society; committed to political decisions.
Hirsch (1987)	Cultural literacy: mastery of the language necessary for communication with scientists and experts.
Hirsch; Kett; Trefil (1988)	Focus on the terms and phrases that would be part of discussions in which every literate person should be able to participate.
Hazen; Trefil (1991)	Knowledge necessary to understand public issues related to Science, which involves a set of facts, vocabulary, concepts, history, and philosophy.
Brennan (1992)	Emphasis on basic terms and concepts that everyone should understand.
Wynne (1992)	Public perception and use of the content, methods, and processes of Science, and how scientific knowledge is organized and controlled.
Shamos (1995)	Acquisition of scientific norms, practices, and vocabulary for communicating with scientists for decision-making purposes.
AAAS (1995)	Familiarity with the natural world; understanding of the main concepts and principles of Science; interrelationship between Science, Technology, Mathematics, and society; ability to think scientifically.
UNESCO (Ayala, 1996)	A competent workforce aimed at economic and social well-being, exercise of participatory democracy.
Díaz; Alonso; Mas (2003)	SL articulated the sociocultural characteristics of individuals and places; therefore, variable.

Intellectual skills range from the enriched and exciting conception of the Universe suggested by Showalter (1974) to the cultural SL proposed by Shen (1975), focused on the desire to understand Science as a great human construct. However, these approaches do not explain the purpose of acquiring these skills, suggesting that their merit lies in the intellectual value of being scientifically literate. In other words, scientific knowledge would be an enriching element for individuals educated in the 21st century, comparable to an appreciation of the arts, music, and literature. In this sense, SL would contribute to the promotion of intellectual culture (Laugksch, 2000).

SL, focused on decision-making, especially in socio-scientific issues (SSI), stands out for its central role in preserving democracy. Thus, it can be said that SL involves the acquisition and mobilization of scientific knowledge to inform qualified and responsible decisions in individual and public spheres.

Over the last two decades, influenced by critical theories and STS studies, some works on SL have adopted a more radical approach, advocating the articulation between scientific training, social participation, and emancipation. From this perspective, SL seeks to foster pedagogical practices committed to social justice, the valorization of plural knowledge, and collective action in contexts of inequality.

Valadares (2021) points out that much research on SL does not consider that the experiences of participation, emancipation, and social transformation in Science vary according to factors such as class, ethnicity, and gender. For this approach to be effective, it is necessary to establish more precise conceptual frameworks on participation and emancipation, guiding educational practices aimed at social transformation. This reasoning can be extended to the concepts of democracy and citizenship, as it would be inconsistent for the former to be treated superficially, while the latter receives a critical approach.

VI. Back to the relations between SL, democracy, and citizenship

After reviewing the history of scientific literacy (SL) in connection with ideas of democracy and citizenship in their respective contexts, we return to this topic in a qualitatively superior way, in a richer totality of multiple determinations, to analyze the contradictions to be overcome, considering the demands of the scientifically literate people in Brazil.

A certain public domain of Science has become a necessity for production in the modern era, being indispensable to the model of society in which we live. This scenario has been known since the institutionalization of scientists as science workers — one who sells their labor in exchange for capital — and the transformation of laboratories/research centers into places of production. Science and industrial capitalism go hand in hand.

Being conscious and intentional work, the primary driver of Science is the constant need to increase the productive forces that sustain human existence. The result of this collective productive action can be considered a means of production, "because it is originally and ontologically destined to produce the existence of those who produce it" (Pinto, 2020c, p. 93).

Science is, therefore, a social means of production and a socially consumable product, integrated into the culture of society.

One of the results of scientific work is the production of objects of use, which are transformed into commodities by the elites who hold ideas (culture) and wealth. By monopolizing Science, these groups manufacture consumer goods and obtain more capital to reinvest in scientific work, in a cycle that feeds back and intertwines Science and economics. This dynamic highlights the impossibility of scientific neutrality, as the economy will always favor a certain class. The dominant groups will determine the purpose of Science, its methods, and the means of dissemination — such as Science Education — seeking to preserve the social order that suits them.

If functional, SL will have a utilitarian character, as in the perspective of the United Nations Educational, Scientific and Cultural Organization (UNESCO), which links it to "[...] a competent workforce, for the economic and healthy well-being of the social fabric and of each person, and for the exercise of participatory democracy" (Ayala, 1996, p. 1). The Scientific Literacy of the National Common Core Curriculum follows this same orientation (Rodrigues; Pereira; Mohr, 2021).

In certain circumstances, the work of elites will be to slow the progress of knowledge in specific communities, aiming to preserve the ideas and values that sustain the status quo. Thus, "[...] every society has the Science that is useful and necessary to preserve the current system" (Pinto, 2020c, p. 155). The delay, therefore, is not the result of chance, error, or metaphysical factors, but rather the expression of a concrete purpose. The influence of capital in defining the purpose of science, as well as its implications, is not an individual ethical problem for researchers, but a problem of objective reality.

Scientific illiteracy becomes a policy where economic production does not require the public mastery of science. In underdeveloped countries, marked by primitive modes of production and underemployment, there are countless work activities that can be performed with poor training in Science (and other areas). From a social point of view, there is no culture of public participation — nor mechanisms that favor it — in decision-making processes involving Science and technology, nor is there any interest in the population directing such processes, given their susceptibility to manipulation and control through magical readings of the world.

Thus, illiteracy (scientific, political, linguistic, etc.) should be understood as an intentional educational policy, rather than a failure resulting exclusively from teaching methods, teacher training, or teaching resources — although these elements significantly influence the process. The organization, planning, and financing of the educational system lead certain segments of the community to literacy and others, which make up the majority, to illiteracy or poor and functional literacy (Pinto, 1982; 2020a; 2020b; 2020c). Thus, a first synthesis emerges: SL is subordinate to the interests of capital. Scientific and technological knowledge and its conditions of production will be delimited by the elites as a way of maintaining control over these strategic resources.

There is also an intrinsic relationship between capitalism and modern democracy. Both emerged at the end of the 18th century, when the expansion of political rights for the popular strata — historically excluded — resulted from pressure from the working class and technical advances in the industrial system. In addition, many of the concessions made to metropolitan workers came at the expense of the exploitation of the colonies of the Global South. Capitalism coexists without difficulty with the expansion of civil, political, and citizenship rights, as long as such expansion does not question the logic of capital accumulation (Lamas; Oliveira, 2017).

The linking of SL to democracy and the exercise of citizenship emerged as a historical convenience in the context of the 1929 Crisis and was consolidated during the Cold War, operating as a strategy of false empowerment of the masses. The American conception of democracy became an instrument of influence over the West, especially over colonial nations marked by democratic inexperience and uncritical admiration for the models of developed countries. The definition of democracy is not questioned, acquiring a static and universal character; it is assumed that free elections are sufficient to guarantee popular power, as long as their results are respected. Concepts such as the "dictatorship of the bourgeoisie" are glossed over, and the right to private ownership of the means of production becomes unquestionable, regardless of the democratic model or political system (Lenin, 1977).

The review by the Barcellos e Coelho (2022a) reveals that there are studies that defend the SL among the population by recognizing that the expansion of democratic participation can be distorted by limited critical thinking. In this sense, SL is understood as a means of qualifying popular participation in decision-making processes, constituting an authentic expression of critical and responsible citizenship. Such a process would strengthen democracy — and not "a" democracy — in which the population decides on the direction of science and technology.

Even in countries with established universal suffrage, public participation in the direction of Science tends to be limited or nonexistent, due to mechanisms related to the social positions of individuals, which condition their possibilities for action. In poorly educated or illiterate populations, this process is even more pronounced, as Science and its products have little direct influence on their lives; access to the technical tools generated by Science is restricted by capital. In these contexts, only the elites have the necessary framework to define the direction of Science, its production, and its education, and they do so according to their class interests (Pinto, 2020c).

This is, broadly speaking, the scenario observed in underdeveloped countries, where elites claim to represent the interests of society as a whole. They also uphold a discourse of pure Science, supposedly free from interests other than the national common good, socially propagating the mistaken idea that Science alone will solve problems such as hunger, poverty, and other ills attributed exclusively to the lack of scientific progress — and not to the absence of social progress (Pinto, 2020c). Controlling the means of production and propagation of culture, the ruling classes act to preserve the order that favors them, after all:

> *The ideas of the ruling class are, in each epoch, the ruling ideas; that is, the class that is the dominant material force in society is, at the same time, its dominant spiritual force. The class that has at its disposal the means of material production also has at its disposal the means of spiritual production, so that the thoughts of those who lack the means of spiritual production are subject to it at approximately the same time.*

Thus, a second synthesis emerges: scientific literacy (SL) can, in fact, qualify participation in decision-making processes, both in the personal and public spheres. However, it is essential to question what type of participation we are dealing with. This requires recognizing that there is no such thing as a “general democracy,” since every democracy - like every dictatorship - is always the democracy of a class. They are dialectically related concepts (Lenin, 1977). Each democratic model presupposes an ideal citizen (Rosa; Lima; Cavalcante, 2023), and the notion of citizenship implies a democratic scenario in which power relations operate between the State and citizens, as well as between citizens themselves (Pinhão; Martins, 2016).

In the bourgeois state, committed to the interests of the ruling class, there is a dissociation between democracy and freedom, while citizenship becomes an instrument for legitimizing the capitalist mode of production, through social rights, regulations, and laws that sustain the bourgeois order (Marx, 2010). From this process emerges the “citizen of rights”, in which meritocratic logic and individualism attribute to the subject the responsibility for systemic transformations, based on the duties and prerogatives that sustain citizenship, rather than *a single* citizenship (Carnio, 2024).

Thinking in totality allows us to understand that the simply “knowing Science" is insufficient for the full exercise of citizenship and democracy. These concepts cannot be universalized or discussed in isolation, at the risk of being reduced to abstractions. The conceptions of SL listed in Table 1, because they are detached from the political dimension, constitute instruments of alienation, producing subjects who are literate only in the maintenance of static and universal conceptions of democracy and citizenship. From this perspective, universal suffrage would be sufficient to realize the will of the majority, consolidating democracy, and citizenship would be reduced to access to rights, without, however, guaranteeing real possibilities for decision-making or social transformation.

This analysis can be extended to the national context, given the historical tendency to import, translate, and apply US curriculum models uncritically (Krasilchik, 2000). The influence of capitalist powers continued in the following decades, especially in discussions about Science, Technology and Society (STS), citizenship education and SL. In the 1990s, the advance of neoliberalism, combined with the actions of the World Bank and the OECD, shaped Natural Science curricula under the logic of colonial, cultural, and capital domination — although there are movements of resistance and hybridization (Ostermann; Rezende, 2020).

Even some concepts formulated in Brazil, such as those of Chassot (2018) and Sasseron and Carvalho (2011), remain anchored in an uncritical dimension and devoid of political meaning. Chassot (2018, p. 84) defines SL as "the set of knowledge that would enable men and women to interpret the world in which they live". For him, being scientifically literate means reading the language in which nature is written, and scientific education would help to understand the need to transform the world for the better. However, it is not made explicit how such a transformation can be promoted, nor is it clarified what a "better world" would ultimately be.

Sasseron and Carvalho (2011) propose three structural axes: (i) a basic understanding of fundamental scientific terms and concepts; (ii) an understanding of the nature of science and the ethical and political factors that surround it; and (iii) an understanding of the relationships between science, technology, society, and the environment. In essence, these axes do not stray far from the classical aspects of SL described by Laugksch (2000), especially the three-faceted perspectives of Shen (1975) and Miller (1983), which continue to influence contemporary syntheses on the scientifically literate subject.

However, these projects lack clarity regarding how literate individuals can participate in and transform the world, considering the concrete limitations of citizenship and democracy in Brazil. Our country currently has a constitution based on a model of representative democracy centered on political parties. The people do not have direct mechanisms for calling plebiscites or referendums, and historically, the state does not consult the population broadly on relevant decisions. Participatory democracy, in this context, is seen as an extreme situation that must be overcome. Parliamentarians and parties show no interest in such practices, as they believe that politics should be exercised through elected representatives. There is a deliberate effort to curb direct participation initiatives (Espíndola, 2012).

This perpetuates a simplistic view that social problems stem solely from poor choices in public representatives — who are either unprepared or corrupt — and that the solution lies in educating critical and (scientifically) literate citizens, who are capable of electing more competent politicians who, in turn, will resolve social dilemmas.

The review by Rosa, Lima, and Cavalcante (2023) on citizenship education in Science Education revealed the predominance of liberal or socializing democratic models, to the detriment of effective participatory proposals. The discourses of teachers and students are aligned with national policies and reinforce the formation of passive citizens, without real investment in practices that promote participatory citizenship. Pinhão and Martins (2016, p. 11) state that "the discourse of citizenship education, in addition to structuring bourgeois society, has been appropriated by the market". This is a dominant narrative that hides the contradictions that permeate social relations.

Analysis based on the categories of totality and historicity allows us to highlight three contradictions: (i) SL aims to educate democratic citizens, but does so based on abstract ideals, ignoring the historical conflicts and structural exclusions that shape these very ideals — which creates tension between the abstract universal and the concrete particular; (ii) the promise of emancipation is anchored in a predefined model of the subject, denying the real autonomy of the individual in formation; (iii) there is a conflict between the prescriptive nature of science in decision-making processes and the democratic ideal based on plurality and deliberation. By not problematizing these contradictions, SL raises a fundamental question: how to reconcile the epistemic authority of science with the democratic principles of participation and plurality?

We propose that overcoming these contradictions requires a process of *aufhebung* — negation, preservation, and overcoming — of SL. This implies negating its alienated, depoliticized, and functionalist form; preserving aspects such as the acquisition of fundamental scientific knowledge and the desire for critical participation in public life; and overcoming it through a project that recognizes its political character, addressing democracy and citizenship as historical and contested categories. Such a project must conceive SL as the critical formation of political subjects and recognize the plurality of knowledge and forms of participation as constitutive elements of democracy.

Despite advances in the criticality of discussions linking SL to emancipation and social justice in recent decades (Valadares, 2021), Brazilian science education is moving in the opposite direction. The National Common Core Curriculum (NCCC) commits Science Education to Scientific Literacy — one of the translations of *scientific literacy*, as well as scientific education. However, Rodrigues, Pereira, and Mohr (2021) point out that this approach refers to positive principles that reinforce the paradigm of efficiency and technical rationality. It favors the development of skills for solving everyday problems, to the detriment of critical reflection on historical, philosophical, and sociological issues in science. This utilitarian and market-oriented bias, sustained by the strong influence of private institutions in the NCCC Movement (Costola; Borghi, 2018), is in line with the neoliberal and neoconservative advances that have marked the Brazilian political scene since the 2016 coup.

VII. Final considerations

Social transformations have influenced conceptions of scientific literacy (SL), which, in turn, have impacted society by being materialized in the education of students. It is not, therefore, a cause-and-effect relationship, but a dialectical relationship, in which the category of contradiction is essential for us to recognize that education is placed at the service of the elites, while at the same time enabling the production of critical knowledge that underpins the understanding of contradictory social relations and practices that sustain privileges, allowing us to glimpse ways of confronting and overcoming them (Pires, 1998).

This understanding allows us to recognize the existence of successful actions aimed at students' SL, which offer valuable contributions to their education, some of which have been highlighted in our previous works (Barcellos; Coelho, 2022a; 2025). In a way, such actions constitute extreme measures in the fight against scientific illiteracy and make overcoming a SL alienated from its political dimension a possible dream. To this end, it is essential to conceive of it as an educational goal from a counter-hegemonic, liberating perspective committed to humanization, linked to a project for society and oriented toward social inclusion and participation — a necessary condition, though not sufficient, condition for human integration. As Freire (2021, p. 141) teaches: “in dialectical perception, the future we dream of is not inexorable. We must make it, produce it, or it will not come about in the way we more or less wanted”.

This possibility can be glimpsed, for example, in Kauano and Marandino (2022) and in Barcellos e Coelho (2022b), whose works point to a criticism that will not be imposed from outside, but will emerge from within the context itself. We consider the contribution of this article to be the demarcation of the urgency of critique of the debates on SL, democracy, and citizenship, with a view to advancing toward more politicized discussions. Far from exhausting this debate, we believe it is pertinent to deepen investigations in the context of teacher training and work, aiming at the materialization of other SL proposals that overcome imported recipes that are alien to our reality.

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