



Paulo Freire in Science Education: Trends and Articulations between Scientific Literacy and the STSE Movement

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Abstract

This work aims to articulate Paulo Freire's studies and the field of science education. We focus on the scientific literacy (SL) perspective and on the mediations on Science, Technology, Society, and Environment (STS/STSE) Education. In his work, the roles of literacy and dialogue are a key to understanding both the common grounds and tensions with scientific literacy and STS/STSE. We recognize that Freire is present in the foundations of STS/STSE studies, however there is still a distance between this body of work and SL in Brazil, especially in its deeper social senses. This is a significant theoretical and practical challenge, as it is necessary to emphasize socio-political assumptions on science education in view of the unfavorable scenario for Brazilian education in its entirety.

Keywords SCIENCE EDUCATION • SCIENCE EDUCATION • DIALOGIC ACTION • LIBERTARIAN PEDAGOGY

Paulo Freire na Educação em Ciências Naturais: Tendências e Articulações com a Alfabetização Científica e o Movimento CTSA

Resumo

O presente trabalho teórico tem como objetivo apresentar articulações entre os estudos de Paulo Freire e o campo da educação científica. Para tal, nos centramos na perspectiva da Alfabetização Científica (AC) e nas mediações da Educação em Ciência, Tecnologia, Sociedade e Ambiente (CTS/CTSA). A alfabetização e o papel do diálogo em Freire são destacados para a compreensão de paralelos e tensões com a alfabetização científica e CTS/CTSA. Reconhecemos que uma fundamentação em Freire é presente em estudos CTS/CTSA, entretanto ainda existe um distanciamento de correlações teóricas entre Freire e AC no Brasil, principalmente em seus sentidos sociais mais profundos. Tal fato, configura-se enquanto um desafio teórico e prático; é necessário que seus pressupostos sociopolíticos ganhem ênfase na educação em ciências diante da constatação de um cenário desfavorável para a educação brasileira em sua totalidade.

Palavras-chave EDUCAÇÃO CIENTÍFICA • ENSINO DE CIÊNCIAS • AÇÃO DIALÓGICA • PEDAGOGIA LIBERTADORA

Introduction

Today, we live in a tragic moment caused by the outbreak of the Covid-19 Pandemic. This historical episode, similar to others that occurred in the country in past centuries, has always had the involvement of different social and political instances. There were many actors and disputes, especially between sanitary measures to maintain life and the pressure for the return of economic production (Chalhoub, 1996). It is often said in enthusiastic circles that no one will leave this pandemic without minimally understanding that science is linked to political, economic, social, cultural, and ideological aspects at both local and global scales. Also, that the pace of scientific production is slow, that it involves risks, and that the distribution of science products is uneven. But is it so?

If on the one hand, the importance of scientific communication is highlighted in social debates, on the other, there is little questioning of the historical role of science education (SE) in the appropriation of scientific knowledge involving the pandemic. To what extent is science denuded by contemporary events? And is it in fact being understood, appropriated, and directed to individual care and collective actions by society? How are the movement and contradictions in scientific practice, or the elaboration of scientific knowledge being considered for the construction of critical visions and actions, as presented by Paulo Freire in “Pedagogia do Oprimido” (2018)?

We believe in the existence of a problem of historical nature involving structural issues in science education that has been endorsed by a well-structured project to undermine the credibility of our educational and cultural institutions as well as their professionals. Added to this, there are problems of an epistemological and ontological order due to the banking concept of education, which has become tradition in formal, non-formal scientific education, and even in scientific communication. This tradition is based on the imposing and dissertation practice of educational and communicative processes, where an educator narrates and leads the student to the mechanical memorization of pre-established contents — rendering them “full” of knowledge, but without their effective understanding of such knowledge or meaning to the components (Freire, 2018). Notwithstanding the extensive advance in the criticism of this banking education, it is still present in educational practice, from the design of educational curricula and programs to textbooks and more “innovative” teaching methodologies. This creates an urgent need to look at Paulo Freire’s ideas and their interconnections with practices of science education and knowledge. We agree with Barcellos (2020), as there will be no scientific education as long as there is a hierarchical practice rendering students into deposits of unconnected knowledge. It is necessary to assume “Freirean radicalisms in order to jolt the reality of Brazilian education in an attempt to move it forward” (Barcellos, 2020, p. 1498).

The history of SE in Brazil has been studied by several researchers in the field. The so-called SE renewal from the late 1950s and throughout the 1960s highlighted the institutions and actors involved, both national and international, explaining their motivations, the interests of different social groups, and the different views on its

complexity (Krasilchick, 1987; Selles & Ferreira, 2005; Valla & Ferreira, 2012). Later moments have been equally analyzed, enabling to expand and reflect on the subject, while also generating huge amounts of data. Unfortunately, these have not always been used to guide public investment policies in education nor science teaching, in particular.

In Brazil, the 1980s and 1990s were marked by the expansion of SE with a focus on scientific literacy (SL) as a result of both public and private investments. In 1983, the Education for Science/SPEC I Subprogram of the PADCT was created (a federal program launched at the end of the dictatorship, managed by CNPq with support from CAPES and FINEP), picking up the need to invest in science education improvements. This program promoted the formation of leaders and researchers who strengthened this field and who struggle to produce, until today, relevant knowledge for its development, as well as providing critical analysis.

Marandino (1991), in her master's thesis, identified the presence of five trends in science education in academic productions from theses, dissertations, events, and congresses in the field, national and international. They were: (a) contributions from the philosophy of science; (b) contributions from the history of science; (c) cognitive approaches; (d) approach of science to social problems and; (e) linking science education with the affirmation of schools as a factor of social transformation. The last two trends pointed out at that time were separated by the fact that (d) referred to an international movement concerned with problematizing the history, use and impacts of S&T on society, and (e) included this concern but understood from Paulo Freire's ideas, that problematizing S&T would require transforming social reality.

From this perspective, educating and teaching science would enable awareness and humanization, promoting dormant potential and the development and transformation of society. In the liberating pedagogy, which inspired SE practices and research, the teaching objectives arise from the historical-social context, with the important participation of all involved parties. Here, the educator is the encouraging, provocative, and dynamic agent of the learning process, and no longer a transmitter of knowledge. This process, according to Freire (2018), takes place through dialogic action. Currently, we can say that many authors work on the articulation of the (d) and (e) trends in Brazil, although they also highlight limitations and distances in relation to the use of Paulo Freire's ideas in SL. Some of these many references guided the reflections that we summarize in the following pages.

Since the 1950s, the literature on scientific and technological literacy (STL) has grown and strengthened while arguing that SE should favor understanding the nature of science, its processes, and its historical, political, social, and economic implications (Aikenhead, 1985; Auler & Delizoicov, 2001). This expansion of the SL discussions is articulated with a movement entitled relations *between Science, Technology and Society* (STS). The evolution of studies from these perspectives led to works which increasingly showed the need for SE to promote the participation and engagement of people for the effective promotion of SL (Bucchi & Trench, 20014; Daza-Caciedo, 2013; Santos, 2007; Valladares, 2021).

Thus, research and some educational practices leaned even more on the idea that science and technology have invaded the daily lives of people who now have the need to understand, take positions, engage, and participate in the various dimensions of knowledge production, and even science itself as a sociocultural practice. This context strengthens the STS or STSE¹ movement, which seeks to provide the elements for individuals to understand science so they can critically act within their reality. Works dealing with the relations between STSE in education and scientific communication pursue promoting a reflective, critical, and committed analysis with a perspective of science that breaks away from dogmatic, ahistorical and neutral views. This vision assumes science as a human undertaking, poised, ideological, political and, therefore, a social construction (Scalfi et al., 2020). For decades, many works in the area, have highlighted the importance of including STSE relations and controversial themes during educational actions in formal, non-formal, and informal spheres of education (Delicado, 2009; Pedretti, 2002; Santos & Auler, 2011).

The described context strengthens the insertion of Freire's thought in SE, especially in Brazil. More than that, Santos (2008a) defends a humanistic vision of science teaching from the educational perspective of Paulo Freire, seeking to overcome what he considered at that time as reductionist visions of the STS movement. According to the author, the interrelationships between Science, Technology, and Society in science education should move towards a more radical approach in regard to social implications.

This encompasses, in Freire's perspective, a political education that seeks to transform the rational model of excluding science and technology into a model aimed at justice and social equality. Recovering these discussions in science education enables a recontextualization of the STS movement. (Santos, 2008a, p. 111)

Throughout the 1990s and 2000, SL and the STS/STSE movement have been widely studied in Brazil by several research groups from different regions of the country (Auler, 2002; Lorenzetti & Costa, 2020; Marandino et al., 2018; Santos, 2007; Sasseron & Carvalho, 2011; Santos & Mortimer, 2001). Some researchers have articulated these perspectives with the work of Paulo Freire, thus we seek to carry out a theoretical analysis of the relationships built from of this literature. Freire is a Brazilian educator and researcher whose work is centered on the idea of education as a political, dialogic, and joint search of new situations for collective life. The issue of dialogicity, the problematizing and contextualized approach, and education as a possibility of social transformation, among other concepts in his works have also been explored in the literature addressing SL and the STS and STSE relations.

For the construction of this text, we relied on Demo (1995, 2000), which characterizes theoretical research lines as relevant for elaborating and unveiling theoretical reference frameworks. For the development of this research, we adopted

1 Depending on the authors and the perspectives they defend, STS or STSE expressions are used, including the environment as one more topic. Vilches, et al. (2011) analyze the relationship between the two terms and their contexts of use.

procedures such as mastering the reference authors themes and the existing production on the subject, the development of a distinct personality on the issue in focus, and the production of creative knowledge with critical verve. Thus, we present a theoretical synthesis based on emerging discussions in our academic paths and in the bibliographic production of studies involving Paulo Freire's pedagogy. In addition, we take as a basis some of the articulations that have been proposed between the perspective of SL and the STSE movement throughout the history of SL in the country, with the objective of bringing reflections on the potential they present in our current context. To this end, we build the following line of argument:

- 1) Starting from the theoretical references of Paulo Freire, SL and STSE relations, we explore the processes of inserting Freire's thought in Brazilian SE over the years.
- 2) We present Freire's basic ideas that support his understanding of literacy and how they are linked or parallel to some definitions and perspectives of SL. Soon after, this last aspect is reinforced by the insertion of the STSE approach in dialogue with SL and by the contributions of authors who articulate Freire to this perspective, towards an education in critical and humanistic sciences.
- 3) We assume the "critical verve" and raise, based on our current concerns and debates, the potential of these articulations, but also the limitations that can be overcome in a process of (re)approximation with some of Freire's theoretical constructs.

Finally, we identify possible trends in this movement and advocate for more radical paths that seek a deeper articulation between Freire, STSE and SL in research carried out in Brazil

The insertion of Paulo Freire's thought in science education

Paulo Freire's studies in the universe of scientific education gained strength from the 1980s onwards. Brazil was going through its redemocratization process, which allowed an advance in the readings and studies of authors considered inappropriate by the dictatorship. Freire himself returned to the country in 1979. Also, this factor starts to build new visions for SE as "problem solving didactics" that in some cases incorporates social and contextual issues into the learning processes in science education practices (Cassiani & Marin, 2020). This fertile field introduces studies such as masters and doctoral degrees carried out at the USP Institute of Physics/IFUSP and at the USP Faculty of Education conducted by Demétrio Delizoicov Neto (1982, 1991) and Marta M. C. A. Pernambuco (1981, 1994). Both were educators and researchers in the field of science education and had close collaboration with Paulo Freire. These partnerships occurred both during the time when Freire was in exile and acted as a consultant on educational reforms in Portuguese colonies in Africa, particularly in Guinea-Bissau, as well as during the period when he assumed the Municipal Secretary of Education of São Paulo (1989 to 1991) during Luiza Erundina's term (1989–1993).

The Guinea-Bissau experience has been exhaustively analyzed by Delizoicov (1982) in his master's degree. In his doctoral thesis, Delizoicov (1991) analyzed this and other projects that involved the articulation of science teaching with Freire's ideas. The experience in Guinea-Bissau, carried out in cooperation with the country's Ministry of Education from 1979 to 1981 focused on the "Training of Natural Science Teachers" in order to teach in early education schools. José Angotti, who also developed his doctorate in the field of physics teaching during this period at IFUSP, coordinated the same project during the 1980s and 1981. Another project based on Paulo Freire was "Teaching Science based on Community Problems," developed since 1984 in Rio Grande do Norte, and coordinated by Marta Pernambuco. Such initiatives, associated with other actions, strongly impacted research and practices in the field of SE during the period, and actually unfolded into public policies.

The book "Ousadia no Diálogo" (Daring in Dialog), published in 1993 and organized by Nídia Nacib Pontuschka with the participation of authors such as Demétrio Delizoicov and Marta Pernambuco, reports the partnership that took place between public school educators, university professors, and intellectuals in the city of São Paulo. These professionals worked on the implementation of science education from Freirean and interdisciplinary perspectives in the municipality's curriculum. At the time, Paulo Freire was the secretary of education, and the initiative aimed to promote the quality of education in primary schools. These efforts focused on interdisciplinarity, problematizing the knowledge of different actors in the educational process, the relationship between content/generative theme, the reality of students, dialogic action, and school autonomy.

In addition to this book, some of the experiences articulated between SE and Freire's ideas were summarized in the works "Science Teaching Methodology", published in 1991 by Demétrio Delizoicov and José Angotti, and "Science Teaching: fundamentals and methods", published in 2002, and includes authors of the previous work, as well as Marta Pernambuco. The books present the social relevance and historical production of science, the organization of the science teaching methodology based on the assumptions of Freire's thematic investigation, and on the three pedagogical moments. Such methodological construction has guided a series of researches and teaching practices using assumptions of thematic investigation, problematization, dialogue, praxis, and awareness. This includes developments in research on basic education curricula from the Freirean thematic approach (FTA) (Klein et al., 2020; Paniz et al., 2018), along with STS/STSE assumptions also marked by the idea of theme generators (Auler; Dalmolin, 2009).

Throughout the 2000s, we noticed a systematic insertion of Paulo Freire's thought in STS/STS education. This resulted not only from the affinities and possibilities for proximity, but also from a need to discuss the meanings of an educational movement based on historical and cultural specificities of Latin America and, more specifically, in Brazil. This period emphasizes the productions associated to professors Simoni Gehlen, Roseline Strieder, Cristiane Muenchen, Décio Auler, and Irlan von Lisingen. Also in the

2000s, researcher Wildson Santos, now deceased, introduces debates on the insertion of Paulo Freire's thought in SE, mainly by correlating socio-scientific issues (SSI) and STSE to Freirean theories in the project Teaching of Chemistry and Society, where was coordinator (Santos, 2009) together with professor Gérson Mól.

It is important to point out that since at least the 1970s, Paulo Freire's thought has also been used as a reference in the area of environmental education, which maintains articulations with the field of science education. Dias (1991), in an article about the fifteen years of environmental education in Brazil at the time, reveals the articulations of this area with Freire's progressive, critical and transformative ideas. Such articulations, over the years and with the development of research and practices, gave shape to the trend entitled *critical environmental education*, which focused on analyzing the social dynamics that lie at the base of environmental issues while considering the political character and praxis transformative pedagogy. As Dickmann (2015) points out, understanding environmental education along these lines is based on the Freirean perspective of discovering the world-nature and the world-culture, making it possible to think of an education focused on the environment within a critical perspective, which overcomes the man-world dichotomy. According to this author, this view "does not accept the scientific objectification of nature as a provider of raw material for the production of consumable objects, and the human being, as a consumer of goods, but moves towards the construction of a new environmental rationality, where its principle is the sustainability of life and the Planet, societies, and all living beings" (p. 42).

Moreover, it is important to remember other connections, such as education in the countryside, an area in which the insertion of Freirean thinking is notable, such as the rural schools instituted by the Landless Workers Movement (MST). More recently, the development of popular education practices and dissemination in science and technology, such as Coletivo Embraza Ciência, has been developing a proposal for scientific dissemination among the vulnerable socioeconomic population in the city of São Paulo. These are linked to assumptions of Freire's popular education along with the synthesis of current debates on STS/STSE and scientific literacy.

In this item, we present some of the ways in which science education has been approaching and incorporating Paulo Freire's ideas into pedagogical practices and research in the area. Next, we will discuss how the concepts of literacy and dialogue were being appropriated in science teaching literature, promoting the construction of the SL process based on Freire.

Literacy and dialogue according to Freire as a basis for Scientific Literacy

In this item we bring some of the articulations found in the literature on science education between SL and Paulo Freire's ideas. A first aspect that draws attention in this movement concerns the concept of literacy. Freire states that literacy should not be reduced to the teaching of letters, syllables and words within a process in which the educator fills the empty heads of the students (Freire, 1989). On the contrary:

as an act of **knowledge** and a **creative act**, the literacy process has in the student, its subject. The fact that he needs the educator's help, as in any pedagogical relationship, does not mean that the educator's help should nullify his creativity and his responsibility in the construction of his written language and in the reading of this language. When taking for example, an object, such as the one I have between my fingers now, both teacher and student, feel the object, perceive the sensed object and are able to verbally express the sensed and perceived object. [...] Literacy is the creation or assembly of written expression and oral expression. This assembly simply cannot be done for the student by the educator. There is a moment in which it becomes a creative task. (Freire, 1989, p. 13, emphasis added)

For Freire (1989), literacy is the domain of reading and writing in conscious terms, "it is to understand what is read, and write what is understood" and "it implies a self-training which can result in the active posture of a person in their context" (Freire, 1989, p. 41). Therefore, this is structured along with the process of critical awareness, based on problematizations of reality, where an autoctonous vocabulary is capable of attributing deep, diverse, and connected meanings between words and the world in which they live.

This path, defined by the criticism and the overcoming of banking education, was traced by Freire in "Pedagogia do Oprimido" (Freire, 2018). Based on the Theory of Dialogical Action and Thematic Research, the idea of Freirean literacy directs the pedagogical praxis towards a horizontal relationship, drawing from life contexts, and promoting autonomy, listening, dialogue, engagement, and respect between educators and students.

Dialogicity is an understanding made by all participants in the educational process, of contexts forged from contradictions. In social practice, these constitute limiting situations. Such situations are obstacles to be overcome by the educational process from the methodological path that involves coding-problematization-decoding, and it must be deciphered and perceived in a conscious and critical way by students in order to overcome immobility in the face of such realities (Freire, 2018).

Similarly, SE authors have assumed SL as a process of appropriation of science as a language to be made reflectively (Chassot, 2003), transposing more internalist meanings of scientific activity into a path to "transform men and women into citizens" (Martins, 2007, p. 58). Also, the importance of contextualization and meaning is highlighted by Bybee (2016) and more recently, there have been investigations and propositions that articulate SL, participation, and engagement for social transformation (Valladares, 2021).

In this sense, we can identify important parallels and connection points of SL with literacy in Freire, as it seeks to unveil the scientific universe based on collaboration and union between educators and students. This promotes the creative/transforming act and casts value on a student's reading of the world, who will in turn, according to pedagogical praxis, put themselves in a dialectical relationship with scientific knowledge in a process similar to what Freire (2018) calls cultural synthesis.

Based on this reading, Auler and Delizoicov (2001) argue that there are two perspectives at play with regard to STL: a reductionist one, and an expanded one. For the authors, the reductionist perspective would be committed to the unidirectional transmission of scientific contents, which brings us closer to both the banking and anti-dialogical perspective in teaching strategies and in the definition of formal and non-formal education programs. The expanded vision of STL, on the other hand, is related to a progressive scientific education, based on Freirean assumptions, aimed at overcoming myths related to Science and Technology (S&T), which are established in educational processes from a reductionist perspective. These myths are: technocratic decision models based on scientific visions, scientific and technological salvationism, and technological determinism which has as its core the idea that technological progress defines social configurations in a single, absolute, and unquestionable path of “progress” (Auler & Delizoicov, 2001). For the authors and in our reading, these myths reinforce aspects that distance scientific and technological knowledge from the reality of people being educated.

The two perspectives pointed out by Auler and Delizoicov (2001) had already been, to some degree, announced by Marandino (1991), when she mapped SE trends and separated the one that sought to bring science closer to social problems from the one that pointed to science teaching with the school’s affirmation as a factor of social transformation. These differences reveal that epistemological and methodological conceptions are at stake when analyzing the literature on SL. According to Auler and Delizoicov (2001), the reductionist perspective is marked by the cognitive deficit model, making knowledge abstract and disconnected, non-problematic, and emptied of possibilities for debate, argumentation (fundamental characteristics of the nature of science), or democratic political action centered on a culture of participation (Santos & Auler, 2019). Such elements are fundamental for making conscious decisions regarding S&T, mainly for a critical reading of reality based on knowledge and skills emerging from the study of natural sciences.

We consider that the aspects related to the reductionist perspective of SL are close to the concepts of a culture of silence and cultural invasion (Freire, 1981; 2018) as determinants for understanding Freire’s educational idea. Freire (1981) states that in the culture of silence there is no popular participation in the historical processes of society, making the masses mute and pruned of their creativity and participatory potential. Thus, the advent of the fatalist ideology is marked:

The fatalistic, immobilizing ideology that animates neoliberal discourse is running rampant in the world. With an air of post-modernity, it insists on convincing us that we can do nothing against the social reality that, from historical and cultural, becomes “almost natural”. Phrases like “this is reality, what can we do?” or “unemployment in the world is an end of the century fatality” expresses well the fatalism of this ideology and its unquestionable immobilizing will. (Freire, 2013, p. 21)

Overcoming fatalism, the culture of silence, in Freire's architecture of thought is above all promoting the liberating dialogue that "is a democratic communication, which invalidates domination, and reduces obscurity by affirming the freedom of participants to reshape their culture" (Freire & Shor, 2008, p. 123). As a theoretical category, dialogue is a political-humanizing process that is based on the problematization of reality from the interaction and sharing of thoughts by different people who, in common agreement, are directed to concrete actions (Freire, 2018). However, Freire raises a series of questions regarding the existence of this dialogue: it cannot start from a position of authoritarianism or superiority of knowledge, one must recognize the shared ignorance of the people involved in this act. Thus, it proposes to protagonize the pronunciation of the world by the masses.

The meanings given by Freire to literacy as a dialogical process were appropriated by science education authors who work with SL. Santos (2008) states that dialogue has been treated with importance in SE educational processes, especially those based on sociocultural perspectives of learning. However, he points out that in order to incorporate the Freirean conception, it is indeed necessary that the teaching and learning objectives are clearly related to social and political issues.

Some SE investigations structure their basis on ideas previously indicated by Freire. We highlight the works of Sasseron and Carvalho (2008; 2011), as they are references in the Brazilian literature on the subject. The authors adopted, from resurgent debates about the dissonances and proximities between the terms: scientific enculturation, scientific literacy and scientific literacy, using the latter. They do this based on the interpretation of the concept of literacy in Freire, proposing three basic axes for SL: (a) basic understanding of terms, knowledge and fundamental scientific concepts related to the construction of scientific knowledge in order to apply them in everyday situations; (b) understanding the nature of science and the ethical and political factors surrounding its practice, relating to the unfinished nature of science and the human and social character inherent in scientific investigations; and (c) understanding the relationships between science, technology and society. For Sasseron (2015), the axes mark major guidelines and run through canonical points of the science curriculum both for the classroom and for actions in the school's extra-curricular spheres. The author also states that "Although the three structuring axes may not be present in all classes, it is necessary that they are equitably considered throughout the development of a theme" (p. 57).

The works of Anna Maria Pessoa de Carvalho and Lucia Sasseron present the articulation between the assumptions of SL and Freire's basic idea of literacy, especially on the potential for connecting studies on the nature of science and STS relations. However, it seems to us that when discussing the implementation of SL proposals based on the axes and indicators associated with them, — (a) organization and classification of data; (b) raising and testing hypotheses, (c) explanations and predictions and (d) logical and proportional reasoning, Sasseron (2015) emphasizes aspects related to the

internal dimensions of science production and the cognitive abilities of individuals, considering a certain symmetry between scientific thinking, or scientific culture, and critical thinking. This perspective is reinforced by the central role given to investigation and argumentation in the author's proposal.

It is important to clarify that we are not opposed to, nor criticize the importance of working on these aspects in science education. What we underline is that the defended perspective ends up treating the social and political aspects of science in relation to society (which would be within the STS dimension) in a way that is still insubstantial against its real possibilities, limiting and/or conforming to delimited abilities by the scientific doing/thinking used in "challenging" moments. This perspective does not necessarily represent an immediate and reflexive action on reality, an aspect closer to Freire's literacy concept.

As Auler and Delizoicov (2001) and Santos (2008a) warn us, there are potentials, but also limitations in the articulation between the theoretical elements of Paulo Freire's thought and SE. For example, political and social aspects are sometimes absent, or treated in a secondary way, in addition to not always clearly explaining how the relationship between educators and students takes place. We understand that working with SL from the Freirean perspective implies considering both the conceptual aspects and those related to the nature of science and the social, cultural, democratic, political, and economic dimensions that structure the reality where the educational work will take place. Additionally, as pointed out by Santos (2008a; 2008b), they are the basis of SL as a humanization process.

Thus, the planning of engagement and participation strategies regarding the relations between science, technology and society and environment is included. Consistent with these criticisms, some currents of STS/STSE education in SE explore the interactions between science and society, promoting contextualized, politicized, critical and complex views in SL processes. Thus, it implies the promotion of social and environmental changes, mobilizing society to go beyond the understanding of scientific information and engaging in processes of reflection, decision-making and action on S&T issues that impact our lives and our well-being (Pedretti & Nazir, 2011).

Based on the analysis of the STS/STSE movement in the SE, as well as the formulation of the perspective of SL based on these relationships, we identified more intense and coherent articulations with Freirean ideas and we will address this topic in the following item.

Scientific literacy from the STS/STSE perspective and articulations with Freirean ideas

The concern with SL in several countries was related to scientific and technological development. For Deboer (2000), this concern was driven in Europe and the USA during the 17th and 18th centuries, and throughout the 19th and 20th centuries, significant social events changed the way in which science began to be seen by society. World War II, social and environmental tragedies (such as the accelerated degradation of natural

environments in the post-war period, famine, and the advent of pesticides), as well as the launch of Sputnik by the Soviet Union in 1957 exemplify some of the events that led countries like the USA to engage in the training of young scientists and the development of a scientifically literate population. These events had direct impacts on the science curriculum proposals in these locations (Hurd, 1998; Krasilchik, 1987; Marandino et al., 2018).

According to Marandino et al., (2018), the panorama described strongly influenced the educational assessment processes developed throughout the 20th century. The authors state that:

In June 1958, the report produced by the Rockefeller Foundation in the USA on how the educational system could be used to more efficiently prepare people for a rapidly changing world, argued for scientific literacy. In October of the same year, Hurd published an article coining the term “scientific literacy” to refer to the new challenges of science education, being the first researcher to use it (Deboer, 2000). For Roberts (2007), however, the work of Pella et al. (1966) represents one of the first attempts to provide an empirical basis for the definition of SL, emphasizing the relationship between science and society, the ethical dimension, the nature of science, among other aspects. (Marandino et al, 2018, p. 3)

Since then, different perspectives have been worked within the scope of the SL discussions. Similar to the reductionist and extended STL propositions discussed by Auler and Delizoicov (2001), for Roberts (2007), SL can be understood from two global views: the one that focuses on the interior of orthodox science and emphasizes the understanding of scientific concepts and the development of science skills; and the one that goes beyond concepts and incorporates decision-making into everyday life related to science. The latter is influenced by social, political, economic and ethical dimensions, and this view of SL has been strengthened from the expansion of the CTS/STSE movement in different contexts.

In addition to issues such as participation and engagement, the proximity of SL with the STS/STSE movement highlights the relevance of working in educational and dissemination practices, and with aspects related to socio-scientific and socio-technical issues in order to develop an education committed to a better and socially fairer world (Hodson, 2013). Furthermore, the defense of approaching contemporary and controversial themes in science and technology and their relations with society has been considered as part of the SL process by several authors, including Latin Americans (Colciencias, 2011; Daza-Caicedo, 2013).

In the international literature, Pedretti & Nazir (2011) state that promoting education from the STSE perspective means exploring the interfaces between science and the social world in order to prepare students so that they can understand socio-scientific issues, make informed and responsible decisions, and act in its context. Hodson (2013), supported by the work of Pedretti & Nazir (2011), argues that the understanding of science in its sociocultural context must be prioritized, and the critical involvement

of individuals to be able to solve problems through action must be promoted. Alsop and Benzce (2014) and Valladares (2021) deepen the dimensions of critical involvement and action from an emerging movement, aimed at promoting science education that encourages activism.

The authors who study the STS/STSE approach propose that educational processes consider the subjects' abilities to: (i) understand socio-scientific issues, (ii) formulate their own views and points of view on these issues, (iii) recognize social, political, and economic forces that influence scientific and technological activities, (iv) make decisions in a responsible and informed manner (considering moral and ethical components) and (v) act upon their reality (Hodson, 2013; Pedretti & Nazir, 2011). As Albe & Pedretti (2013) point out, the teaching of socio-scientific subjects is oriented towards developing a type of citizenship that prioritizes understanding and participation, and also promote the empowerment of students to reflect on moral principles that involve their own lives as well as the physical and social worlds around them. This means recognizing, as Meyer & El-Hani (2019) clarify, that there are uncertainties and different degrees of confidence in the findings of science. This is an important and necessary way to generate new knowledge, even if it can be questioned at some point, or placed into dialogue with other fields.

The vision of SL associated with the STS/STSE movement has more recently marked academic production and pedagogical practices in SE at national and international levels. However, it is possible to state that SL and the STS/STSE movement developed from distinct concepts of science, from the way of seeing the relationship between science and society to the present concepts of education, and this reverberates in the dialogue with Freirean assumptions. Santos (2008), a Brazilian author recognized for his work in this interface, and always aware of its limitations, states that:

Marking the differentiation between an STS vision with a Freirean focus is fundamental to differentiate positions. These often naively present themselves with the argument of social relevance to hide their discourse of maintaining the status quo on the oppression processes that mark the globalizing world of our times. (Santos, 2008, p. 123)

It is for this reason that in the SE area, the articulation between the STS/STSE movement and the thought of Paulo Freire gains strength in authors who work and research especially in the Latin American context, taking as a premise an emerging educational process in science from regional specificities. Auler & Delizoicov (2015) propose the articulation of Freire's pedagogical theories with a theoretical current called "Latin American Thought in Science-Technology-Society" (the acronym in Portuguese is PLACTS) which emerged in Latin America, specifically in Argentina, during the 1960s. This current questions the technological transfer of imperialist bias to developing countries at the expense of the contextualized and critical development of a Scientific Technological Project (STP) aimed at social demands (Dagnino, 2008). Thus,

PLACTS defends the conception of a research agenda, of a STP based on Latin American demands. Freire supports the conception of curricula based on local elements also considering the Latin American context. In both, new social actors enter the scene, verbalizing and placing their demands on the agenda. (Auler & Delizoicov, 2015, p. 286)

In the same way, Oliveira and Linsingen (2019), Brazilian authors, analyze the STS movement and affirm the existence of two traditions: the European one, organized in a more academic way; and the North American, pragmatic and concerned with the social and environmental consequences of technological products. These authors also point to the existence of a third Latin American strand originating from PLACTS, in order to consider the regional peculiarities in the STS movement. For them, Paulo Freire's ideas are articulated in this context with decolonial pedagogy.

The key point highlighted by Freire was to emphasize the responsibility of thinking critically, confronting conditions of exploitation and oppression, in addition to the struggle against racial, gender, and class discrimination (Freire, 1996). Principles that speak on decolonial pedagogy, and which also support Latin American STS Education theory (Oliveira & Linsingen, 2019, p.183).

Oliveira and Linsingen (2019) critically view the idea that there is a homogeneous "south" and assume the decolonial perspective of education, which denounces the continuity of colonial forms of domination, including the hegemonic view of modern science. Hence, they corroborate with several authors on the consequences of civilizing actions regarding the knowledge of non-Eurocentered cultures as these were excluded, omitted, silenced, and ignored. Thus, different authors, point to the need of denouncing the hierarchization in modern culture (man/woman, white/black, written/oral, West/East) and defend that Latin American STS education works towards deconstructing concepts that have become universal and naturalized in order to give visibility to other forms of knowledge.

The problematization about the S&T conceptions of the CTS/STSE movement was already being raised even before the articulation with the decolonial perspective. Rosa and Auler (2016) pointed out the convergences between STS education in Latin American contexts and Freirean thought. At first, they are based on the critical stance of STS education towards a culture of participation in issues related to S&T, opening paths to overcoming a culture of silence (Freire, 1981; 2018) built around these issues. Like Oliveira and Linsingen (2019), they warn about the nature of the construction of the STS movement in the context of the Northern Hemisphere (from European scholarship to social regulation in developed countries) and its implications for the concept of participation:

A participation that, in general terms, is limited to "post" stages, such as post-definition of the research agenda, or post-execution of technological projects. A common language for this type of participation consists of: evaluating positive

and negative impacts of S&T on society and the environment, enhancing the former, and attenuating the latter, and evaluating its implications. In addition, a post-consumption participation, where seeking alternatives to alleviate the problem of produced waste is up to education. (Rosa & Auler, 2016, p. 205)

For the authors, this participation centered on the “post” is a direct result of the cult of the myth of scientific neutrality that fosters the linear model and technocratic decisions. Thus, they dialogue with Freire when proposing to overcome the culture of silence that “reinforces an idea that society has no potential to change the dynamics of scientific-technological development, thus becoming increasingly passive in the face of this development” (Rosa & Auler, 2016 p. 214). The promotion of a culture of social participation is the result of an educational process that moves towards overcoming the culture of silence, based on dialogicity and listening to social movements within educational spaces (Santos & Auler, 2019).

Consequently, it can be assumed that education based on the precepts of the PLACTS perspective, on decolonial pedagogy, and on Freirean thought breaks with SL trends such as the reductionist (Auler & Delizoicov, 2001) and the internalist view. The latter that Roberts (2007) indicates as centered only on scientific products and processes. Once it is embedded in these conceptions, there is a principle of neutrality and universality of European and colonial science that the listed theoretical perspectives seek to deconstruct. Brulon (2020), when discussing the role of museums and science production from the perspective of modernity and coloniality, emphasizes that this took place in a context of imperial domination. This, in fact, is also linked to the production of knowledge over those who are to be dominated. For him, several authors argue about the need for Europe to invent a periphery — in terms of goods, thought and culture — in order to be thought of as a superior center.

Such a conception points to the deconstruction of a hegemonic historiographical point of view on the contact of Europe with other non-European continents, starting from the understanding that the metropolis never discovered (*descoberto*). This latter was, in fact, constructed as object and material, and covered up (*encoberto*), assimilated into a universal discourse and a single linear temporality. In this sense, the domain of thought meant a subordination of bodies to the mind of the sovereign subject that was, after all, at the base of the knowledge produced by the colonization process. (Brulon, 2020, p. 6)

The idea of a universal science that overlaps other forms of knowledge is also articulated within Freire’s concept of cultural invasion. As defended by Barcellos (2020), cultural invasion implies the superposition of a worldview, considered superior, over another (Freire, 1970). There is no room for the existence of other worldviews. Just a wrong view that needs to be replaced by a correct one” (Barcellos, 2020, p. 1501). In this context, it is necessary to look at the subject of scientific literacy, and to ask ourselves what “science” we want to promote literacy.

For Hodson (2017), the meaning of scientific literacy is not unique and neutral: it can change according to the social context and it is a product of its time and space. For this reason, according to this author, the meaning of scientific literacy does not easily cross national and cultural barriers and cannot be transferred comfortably from one era to another. Like other terms, scientific literacy has a historical, social, cultural, political, and economic origin that traces its establishment. Like other terms, it has been undergoing criticism, changes, and adjustments arising from social and cultural demands from different contexts and from the struggles of people and groups interested in promoting true dialogue and true transformations brought about by praxis.

Most of the statements by the aforementioned authors are located in the school's space-time. Here, however, we refer to a broader sense that involves other educational and social contexts, promoting the entry of society into decision-making processes related to S&T, including research agendas with the objective of regional development. Therefore, STS/STSE education must break through silences and encourage participation that brings existential and regional problems, their correlations with scientific and technological issues, as well as their demands.

We can understand that the dialogue with Freire in the works of the aforementioned authors is centered on the problematizing cycle that starts from limit-situations, limit-acts, and construction of a viable novelty (Freire, 2018). In this perspective, both questions related to S&T and the experiential questions that make up the “knowledge of experience made” are configured as concrete and historical dimensions of a given reality. Due to this, they are challenging (imbedded in limit situations) and lack the dialogical educational process (limit act) to be reformulated as something unprecedented and viable. This is characterized, on the cognitive level, by potentializing the reading of the world through the systematization of critical awareness and, at the material level, by transforming actions directed by praxis (Freire, 2018).

This entire process is characteristic of the pedagogy of liberation, which directs overcoming what Freire (1981) markedly describes as the “culture of silence”. Silence imposes itself in the process of cultural domination, whose dominating/colonizing agents manifest themselves in the construction of an oppressive reality. This, in turn, constitutes a docile and obedient society, where the scientific universe also imposes itself when considering fads and traditions of a hegemonic modern science that do not communicate with existential or educational needs in Brazil.

The potentials and limitations of building a bridge between Paulo Freire and Scientific Literacy

The most current perspectives of SL incorporate the necessary conceptual issues, aspects related to the nature of science, and training for citizenship, often involving STS relations (Sasseron & Carvalho, 2008), participation, and engagement (Valladares, 2021). Here we return to what Santos (2008b) lays as structuring an articulation between scientific education in Freire's humanistic perspective: the need to put into practice social

and political action on a specific reality in which students live. Therefore, it is important to ask ourselves to what extent, in SL approaches, are scientific and technological concepts mobilized by problematizing dialogues on contradictions and limit-situations related to specific realities of the Brazilian people? How does the nature of science and the STS/STSE relations problematize the scientific processes considering social, economic and political issues that permeate the daily lives of our people? To which prism are we attributing the construction of skills associated with “slogans” such as the promotion of “citizenship” and “decision making”? Is this a prism of useful pragmatism — with a neoliberal bias — that promotes individualization and reproduction of discursive promises of an elitist citizenship (Cassiani & Marin, 2020)? Or is it humanistic, political, transformative, and sometimes revolutionary prism towards democratic participation for scientific and technological sovereignty at local, national and Latin American levels — as proposed by PLACTS?

There are many challenges for the development of a dialogical-problematizing, humanist pedagogical practice in the dissemination of scientific knowledge that is also able to respect different and transforming knowledge. We can cite limitations arising from the history of science itself and how this field was legitimized as a form of valid and “true” knowledge. The very controversial nature of science, its production, and control mechanisms by its dominant groups and institutions are potential barriers for achieving the transformative utopia proposed by Freire. We can also cite the banking perspective as a limiting aspect for the in-depth implementation of Freire’s ideas, where ideas about teaching and learning (including teacher training within degrees, generally divided between reference and pedagogical areas) were gradually incorporated and became hegemonic throughout the history of education. In certain historical moments, political and social issues also brought constraints for the Freirean emancipatory project to be fully assumed in science education.

Such challenges also seem to worsen at present time. Faced with an undeniable crisis of truth and information, dialectically structured by the rise of a promiscuous relationship between neoliberalism, an abject right-wing extremist and, the monumentalization of hegemonic modern science as proposed by Barcellos (2020), we reflect on the possibility of a clearer proximity between the objectives of SL, learning, and Freire’s praxis category. Kauano (2019), based on Marxist and Freirean reflections on praxis, finds that processes of learning scientific concepts - when mobilized with other knowledge sources — structure awareness, thus becoming a driving force for conscious actions on a given reality. For Freire (2018), liberation, arising from knowledge, “is not something that is deposited in men. It is not a hollow, mystifying word. It is praxis, which implies the action and reflection of men on the world in order to transform it” (p. 93).

Based on the premise of unity between action and reflection, theory and practice placed in the Freirean formulation of praxis, we return to some of the SL related objectives of decision-making and citizenship and allow reflecting about the current moment: neutralizing coronavirus vaccines. It is possible to make the right decision to participate in the vaccination process because, based on scientific evidence, and not fake-news,

each individual gesture collaborates with society. However, most developing countries face serious problems in accessing and distributing this scientific and technological asset (in addition to the obstacles generated by denial policies in several countries, as well as in Brazil). Therefore, the issue of citizenship presents itself in a complex way and in contexts with harsh specificities, with discussions about the need for an organized struggle to guarantee fundamental rights to collective life, especially for historically marginalized groups (Teixeira, 2009).

Cassiani and Marin (2020) successfully formulate this problem, based on diverse decolonial views in the context of biology education, pointing out that even the concept of citizenship can be excluding, patriarchal, and Eurocentric: “when we imagine the “good citizen” that we say we want to train, do we also imagine a transgender person, an indigenous person, or a black woman?” (p. 35). When we return to Freire’s dialogic-problematizing educational praxis, we could affirm that in Brazil the issue of vaccines takes on a series of meanings that go beyond “evidence-based vaccination.” It involves equal distribution between social classes, the conceptualization of social vulnerability (not just the universal idea of risk groups), access of the indigenous, black, or transgender population, homeless people, immigrants, and people living from precarious work. Additionally, it is important that there is an understanding of some aspects of world geopolitics, denial politics and actions, the role of pharmaceutical companies as large capitalist companies, and the vaccine itself as a commodity.

Such discussions should not only be centered on political figures and/or specialists, but on democratic popular participation in various forms and decision-making processes. That is, the relationships between science, technology and society are constituted by a series of extremely contextualized social contradictions that need to be understood by the population (whether by the school, by non-formal education, or by scientific communication) in an articulated manner with the concepts, processes, and attitudes that constitute scientific knowledge.

Like Valladares (2021) and Santos (2008a), we stress that it is necessary that the SL and STSE relations in science education promote social participation based on reflecting about the various contradictions that arise between science and the world. In a Freirean reading, as Rosa and Strieder (2021) put it, “STS education postulates from the overcoming of scientific-technological neutrality and the assembly of mechanisms for participation in social science-technology issues” (p. 5). It is this constant search for understanding the totality of knowledge and practices that branch out and materialize into actions that critical awareness is formulated. This is the basis for participation and action, and in fact, what transforms reality (Freire, 2018). With that we ask: which citizenship is targeted with SL? Which scientifically literate citizen are we referring to? One who looks at a drop of water with curious eyes or who and from a sense of collectivity, takes the bucket to fill it at the door of a government palace? At present, we are talking about a SL that generates, above all, indignation.

Furthermore, on the complexity of the current moment, we live in a context in which the SE connections and, in particular, the SL with Freire's ideas are even more necessary. The coronavirus pandemic gains new magnitudes as it takes place in a time of crisis on truth due to massive misinformation as a political and ideological strategy, as well as the rise of an authoritarianism supported by historical revisionism and science denial.

This scenario makes Barcellos (2020) reflect on the following question, based on his interpretation of scientific banking education. How is it possible to confront the rise of a disinformation culture when scientific knowledge is presented in a doubly authoritarian way: one where people are seen as ignorant, hollow, and by this very nature, subject to domination and control for deterministic and developmental purposes?

In the construction of such questions, Barcellos (2020) resorts to dialogicity and Paulo Freire's concept of cultural invasion. Nevertheless, he also connects to the thoughts of Bruno Latour and Boaventura Souza Santos in a critical narrative of hegemonic science, essentially positivist, and colonial vision which still seems to be reproduced, and disregards debates about its nature, philosophy, and sociology.

Therefore, we note the importance of problematizing, how the use of Freire's assumptions has been given to the promotion of a non-banking literacy process mediated by the STS/STSE relations in the teaching and dissemination of science. This promotion is committed to becoming a driver of articulation and social mobility that overcomes fatalisms and old neoliberal tactics of domination and dehumanization. It is necessary to overcome mythical and scientific views based on the absolutization of ignorance (Freire, 2018), as these may not be strong enough to dispute narratives arising from a new and obscurantist universe that is being established due to its anti-dialogical nature.

Final considerations

Based on the historical view regarding the insertion of Paulo Freire's pedagogy in SE, especially in its articulation with SL and STS/STSE education, we identified two main research and practice trends that were developed over the years and which continue being forged into formal pedagogical practices and science communication:

Epistemological tendency: discussions on science views and the problematization of the nature of science from Freirean theoretical and philosophical contributions. This trend can be divided into two:

Focus on the nature of science: problematizes the historical, social, political, economic, and cultural dimensions of science and its production within educational processes. Some examples are the works of Auler and Delizoicov (2001), Santos (2008), Rosa and Auler (2016), Marandino et. Al., (2020).

Focus on decolonial thinking: of more recent origin, it is supported by currents that elaborate decolonial, intersectional, and sociopolitical thoughts (class, race, gender and sexualities, environment) crossed by questions of science,

also encompassing the need to question and reformulate educational work in science. Some examples are the productions of Oliveira and Linsingen (2019) and Cassiani and Marin (2020), Barcellos (2020), among others.

Methodological trend: develops Freirean contextualization, problematization, and dialogical methodology based on thematic investigation, and also using generating themes as the main guide when developing science teaching-learning strategies and discussions on natural science curricula. In it, the central element is a construction of contextualized, interdisciplinary teaching-learning strategies aimed at decoding and acting on reality. Examples are the works by Delizoicov et al. (2002), Auler and Dalmolin (2009), Solino and Gehlen (2016), Paniz et al. (2018) and Watanabe (2019), and several others.

We emphasize that these two trends are not mutually exclusive, which help us understand the paths of Freire's thought in science education which enables tracing points of connection with SL. It would be contradictory in an analysis based on Freire to assume that in the different authors the methodological tendency does not assume its epistemology. Furthermore, we are fully aware that developing the SL process from the Freirean perspective poses a series of challenges from which we are not exempt.

Promoting a return to Freire in science education conceived from scientific literacy and STS/STSE relations does not mean only understanding the assumptions for literacy linked to categories such as dialogicity and praxis. It is also a way to position ourselves and question the current structure of educational policies and educational institutions and scientific communication. It brings the need to reveal tensions, power games, forms of control, and the interests of fundamentalist groups, censors, and private individuals who stand against secular and public Brazilian education.

Bearing in mind the challenges here presented, we consider that not only formal education, but also non-formal education and science communication can support and effectively promote resistance actions. However, this can only happen if there is space for other forms of knowledge and other voices which include alternative views of reality from those proposed by science and placed in forthright dialogical action: how can we discuss social isolation in a universal way without listening to and dialoguing with homeless working people living in squats, people in different communities with distinct specificities, or people living on the streets? It seems to us that scientific neutrality and universality is only applicable to restricted and distant realities from the concrete world of Latin America and, in particular, from Brazil.

We are moving towards a perspective of scientific literacy contextualized to Brazilian and Latin American specificities, based on the important contributions of several authors in the area presented throughout this text. Thus, in addition to reinforcing the objectives of SL such as learning concepts, reflection, critical analysis, assessment of possibilities, risks and decision-making, we also encourage understanding the different contradictions of different realities and their limit situations, listening, dialoguing,

and respecting the diversity of opinions and knowledge. Dialogue, understood as a humanizing and problematizing process of reality, of interaction and sharing of different thoughts, promotes a dialectical relationship with scientific knowledge in order to make the so-called cultural synthesis (Freire, 2018). We defend that SL-based education works towards politicizing debates on STS/STSE, denouncing social inequalities, respecting and ethically discussing differences and diversities, favoring democratic participation, emancipation and the transformative action of groups, as well as social actors within their context.

We live in violent times. Our historical social problems during the pandemic, the result of a systematic relationship of oppression, once again erupt with a project of death, cultural erasure, and the withdrawal of our unique and genuinely Brazilian happiness. Mentioning here an oppressive tactic of control and silencing. We return to Freire's words;

there is no way to talk about hope if one's arms are crossed and waiting passively. In fact, those who wait in pure waiting live a time in vain. Waiting only makes sense when, full of hope, we struggle to materialize an announced future (Freire, 1981, p. 48).

Working with these tensions in educational and dissemination contexts is not an easy task, but we understand that there is no educational process that is free from challenges, contradictions, and hope. In this scenario, aligning ourselves in relation to Freire (2018) and taking an epistemic position about our practices and research represents, today, finding the common ground with the “*esfarrapados*” (ragged ones). Additionally, finding common ground with the world while seeking an unprecedented-viable in science that is combative, participatory, diverse, ethical and therefore truly democratic.

Acknowledgments

We thank FAPESP and CNPq for funding projects that allowed us to compose and write this article.

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Disclosure statement

No potential conflict of interest was reported by the authors.

Compliance with Ethical Standards

The authors declare this study was conducted following ethical principles.
