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Science and biology teaching and training for citizenship in the context of the environmental collapse: who, what, and how do we teach?

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ABSTRACT

This essay discusses Science and Biology teaching in the context of the environmental collapse, based on three key questions: “Who do we teach?”, “What do we teach?”, and “How do we teach?”. The answers to these questions are based on two main assumptions: the materiality of the subjects involved in the teaching process and the historical and dialectical nature of social and natural processes. Therefore, we argue that: (i) Science and Biology teaching should consider the people involved in education, their concrete conditions of existence, and societal and citizenship projects in dispute; (ii) the health-environment interface should be examined as an element of contextualization, overcoming reductionist and holistic approaches; and (iii) a link between Historical-Critical Pedagogy (HCP) and Science, Technology and Society (STS) teaching, based on the Latin American Thinking on Science, Technology and Society (PLACTS), is a powerful tool for transforming teaching, not only as an instructional process, but also as a space for training critical citizens who are aware of the social and environmental dynamics. Thus, we aim to provide support for a critical and up-to-date reflection on these issues, contributing to the construction of educational practices in science teaching aligned with progressive movements

KEYWORDS: Scientific Education; Education for citizenship; Science and Technology; Historical-Critical Pedagogy.

Ensino de ciências e biologia e a formação para a cidadania no contexto do colapso ambiental: o que, para quem e como ensinar?

RESUMO

O ensaio problematiza o ensino de ciências e biologia no contexto do colapso ambiental, com base em três questões centrais: “Para quem ensinamos?”, “O que ensinamos?” e “Como ensinamos?”. As respostas a essas questões são construídas a partir de dois pressupostos principais: a materialidade dos sujeitos envolvidos nos processos de ensino e o caráter histórico e dialético dos processos sociais e naturais. Nesse sentido, defendemos que: (i) o ensino de ciências e biologia deve considerar os sujeitos da educação, suas condições concretas de existência e os projetos de sociedade e cidadania em disputa; (ii) a interface entre saúde e ambiente deve ser explorada como um elemento de contextualização, superando abordagens reducionistas e holísticas; (iii) uma articulação entre a Pedagogia Histórico-Crítica (PHC) e o ensino Ciência, Tecnologia e Sociedade (CTS), fundamentada no Pensamento Latino-Americano em Ciência, Tecnologia e Sociedade (PLACTS), é uma poderosa ferramenta para transformar o ensino, não apenas como um processo instrucional, mas também como um espaço de formação de cidadãos críticos e conscientes das dinâmicas sociais e ambientais. Com isso, buscamos fornecer subsídios para uma reflexão crítica e atualizada sobre essas questões, contribuindo com a construção de práticas educativas no campo do ensino de ciências alinhadas a correntes progressistas.

PALAVRAS-CHAVE: Educação Científica; Educação para a cidadania; Ciência e Tecnologia; Pedagogia Histórico-Crítica.

INTRODUCTION

The escalation of the environmental crisis, now reaching a stage of environmental collapse (Marques, 2023), alongside the rise of scientific denialism and obscurantism, has made it crucial for these issues to be addressed in science and biology teaching. The environmental question, i.e., the relationship between society and nature, has been part of the international political agenda since the second half of the 20th century, driven by the increasingly frequent and severe occurrence of various environmental problems worldwide. These include accelerated deforestation, water pollution, highly unequal access to drinking water, soil degradation and desertification, deteriorating air quality in major urban centers, waste disposal challenges, global warming, and climate change. In the initial training of science and biology teachers, Fisch and Schnorr (2024) emphasized the importance of discussing the connection between environmental degradation and the emergence of new epidemics.

Considering this backdrop, this essay aims to problematize the approach to science and biology teaching, posing three fundamental questions: “Who do we teach?”, “What do we teach?”, and “How do we teach?”. To answer each of these, the following assumptions will be considered: the materiality of the subjects involved in the teaching processes and the historical and dialectical nature of social and natural processes. Acknowledging the limitations of an essay in fully addressing these questions, we propose the following: first, we will respond to the question “Who do we teach?”, discussing the demands of education for citizenship and the various meanings of this term nowadays, including those propagated by common sense and fake news, such as the notion of the “good citizen” (Costa, 2021). We argue that, considering the current sociopolitical context, science teaching must take into account who the subjects of education are, their concrete conditions of existence, and the societal projects in dispute. This reflection is crucial to challenge the hegemonic meanings of citizenship in our society, which are often associated with exclusion, authoritarianism, and the denial of rights.

Next, we will address the question “What do we teach?” by utilizing the interface between the concepts of health and environment, using them as a contextualizing element in science teaching. We contend that these concepts should be critically and dialectically examined, taking into account contemporary demands and the challenges posed by environmental collapse (Marques, 2023). This entails not only selecting relevant topics but also problematizing epistemological aspects and teaching methods to contribute to the development of scientific education that is committed to social and environmental justice.

Finally, we will discuss the question "How do we teach?" by integrating two theoretical frameworks – Historical-Critical Pedagogy (PHC) and Latin American Thinking on Science, Technology, and Society (PLACTS). We believe that these frameworks offer promising pathways for developing pedagogical practices that connect content with social reality, fostering the education of individuals who can critically analyze the social structure they are part of and create real possibilities for its transformation.

By highlighting these three key issues, we do not aim to present prescriptive approaches, but rather to provide insights for critical and updated reflection,

helping to develop educational practices in science teaching that are aligned with social transformation and engaged critical citizenship.

"WHO DO WE TEACH?" EDUCATIONAL DEMANDS FOR CITIZENSHIP IN SCIENCE EDUCATION.

From the early years of elementary school, science teachers have faced a major challenge in their daily routines of connecting scientific content to the social issues that shape their students' lives, particularly those from public schools. Most of these students come from the outskirts of large metropolitan areas, marked by inequalities in access to information, cultural and leisure facilities, scientific knowledge, and even the lived experience of urban life. These limitations restrict the possibilities of broadening their worldview, which is largely dominated by religious institutions presenting views marked by sectarianism, moralism, and the countercultural asceticism of Pentecostal groups (Mariano, 2008). This unequal access results in limitations regarding the familiarity with which these students move through different spaces, imprinting on them a habitus shaped by the dispositions internalized by agents occupying specific positions within the social space (Bourdieu, 1990).

Thus, a poorly qualified and abstract view of citizenship in Brazil does not present real transformative potential for science teaching practices. The connection between science teaching and social issues must always be made without losing sight of the other two questions – *what* do we teach and *how* do we teach – which are separated here merely for organizational purposes, as they are closely interconnected. Therefore, it is essential to coherently relate the content to be taught to the reality of both the teacher, as a worker, and their students, while also considering the material conditions of the environment where the social practice occurs.

Positioning teaching practices based on the concrete conditions in which they occur leads us to recognize that, inevitably, teaching is characterized by encounters with others who are marked by inequality. Therefore, we face a dual challenge as teachers, whether in higher education or basic education: an epistemological challenge and an ontological one. The former concerns how we understand the production of scientific knowledge, its validation criteria, and, consequently, the possibilities and limits of articulating epistemologically distinct forms of knowledge. The latter involves reflecting on the human dimension through the category of labor, specifically within the context of teaching and its relationship with students.

The connection between the epistemological and ontological dimensions of teaching practice is not achieved without risks and challenges. At times, one of these poles may be excessively emphasized at the expense of the other. There are approaches, for instance, that prioritize scientistic proposals, naively presenting science as a neutral, objective activity, immune to power relations, that shows reality while overlooking the dialogue with students' realities, as well as critical realist perspectives within the philosophy of science itself. On the other hand, some approaches emphasize culturalist and postmodern interpretations, which, to a certain extent, go so far as to challenge the very possibility of delineating the basic nature of scientific activity (Haack, 2023), thereby opening up the field of

science and biology education to all forms of explanation, regardless of their real explanatory potential, methodological procedures, and contexts of production and circulation. At times, the expansion of participants in this field translates into advocating for the inclusion of explanations in science and biology education that incorporate religious, magical, teleological, vitalistic, and animistic components. Opposing this type of inclusion does not mean ignoring the importance of dialogical approaches in the classroom or an environment where different viewpoints are discussed concerning scientific knowledge. Rather, it means defending the idea, as emphasized by El-Hani and Bandeira (2008), that the aim of developing students' strong critical skills is more likely to be achieved if we educate them to be pluralists, rather than radical relativists.

Regarding the ontological challenge of teaching practice, the task of building meaning between specific content and students' lives is not solved by adopting an individualistic approach to the teaching-learning process. Instead, it requires considering the concrete subjects, based on the structural aspects that organize their lives in society, mediated by the capitalist mode of production, and the position they occupy within it. In this regard, authors linked to HCP have mentioned the distinction between the empirical student and the concrete student: 'that is, the individual whom the educator must teach synthesizes within themselves the social relations inherent to the society in which they live and in which their education process takes place' (Saviani, 2019, p. 183). The same applies to the teacher, who should be understood as a worker shaped by the relationships established within the broader social practice and their specific teaching practice.

From this perspective, it is essential to consider teachers' increasingly precarious working conditions. The most visible forms are the growing wage devaluation, temporary contracts, part-time teachers (without an employment contract with the state, paid only for the classes they teach), as well as outsourcing, *pejotization* (where professionals are hired as independent contractors through their own legal entities, rather than as formal employees), and uberization (where professionals work on demand, typically through apps). These are new ways of labor precarization in teaching (Silva, 2020). In addition to this, for science and biology teachers, it is important to mention that there are insufficient working conditions in terms of school infrastructure. What stands out, in particular, is the lack of laboratories, most of which are in poor condition. According to Brasil (2020), these spaces are found in only 12.5% of schools (8.6% of public schools, where 95.7% of them are federal, and 28.3% of private schools). Moreover, there are insufficient teaching materials for science education, present in only 15.1% of schools (11.5% of public schools, in which 59.6% of them are federal, 7.7% municipal, and 29.4% private), and the lack of public funds for field trips, such as visits to science museums. Only 11.5% of the Brazilian population aged 16 to 70 visited a museum in 2022 (Centro de Gestão e Estudos Estratégicos [CGEE], 2024). Therefore, the teaching practice is not disconnected from the characteristics of society, more specifically, from the material conditions of life in Brazil, which contribute to the construction of a certain sense of citizenship, resulting from 'the intense urbanization, territorial fragmentation, and the enormous socio-spatial inequalities that mark vulnerability and the socio-environmental processes of vulnerability, as well as numerous health problems, a Latin American phenomenon' (Porto et al., 2015, p.527). Therefore, it is crucial to

discuss citizenship in science and biology teaching aiming to problematize the question 'who do we teach?'

This is a scenario that helps understand the escalation of the environmental crisis as a result of two factors: (1) a mode of production that is rooted in an uncritical technoscientific discourse, which linearly associates science with progress, without questioning the foundations of this progress, the model that underpins scientific production, the structure of society that supports it, and its main beneficiaries; (2) the very rise of denialism and the relativization of the importance of explanations produced by science.

In this context, which compels us to urgently transform the productive relations that structure our social organization, what does it mean to be a citizen or to educate for citizenship? The productive process to which we are subjected is not limited to the assembly line of factories, but also encompasses the way we relate to one another, to life in its broadest sense, and our very constitution as human beings. Therefore, the concepts of citizenship, and more specifically those related to education for citizenship, must consider contradictions of the capitalist system, rather than the notion of citizenship limited to formal rights and institutional participation, which is common in the liberal tradition.

EDUCATION FOR WHAT KIND OF CITIZENSHIP?

The concept of citizenship varies according to the political-economic model adopted by a society, meaning that there is a type of citizen for each type of society (Bobbio, 2010). In classical liberalism, citizenship is defined as a set of individual rights, where the State acts only to ensure the freedom of individuals' actions, without interfering in their economic interests. This promotes an atomistic rationality that, although formally egalitarian, maintains existing inequalities (Rodrigues et al., 2015). This model legitimizes the inequality and exploitation inherent in capitalism, preserving the hierarchies and monopolies of the system, and is effectively accessible only to a small group of individuals with the power to impose their interests in social relations.

This conception is close to the common-sense notion of citizenship, which is understood merely as a set of rights and duties. It is common to hear the expression 'everyone wants rights but not duties,' as if citizenship were defined solely by a set of rules that determine who is or is not considered a citizen. Nowadays, there is a rupture in this idea, where some citizens are seen as not fulfilling their duties, while others do – and these are regarded as the 'good citizens,' deserving of rights. By reinforcing this separation, the category of 'good citizen' contributes to the consolidation of the liberal vision of citizenship, which focuses on individual rights at the expense of social rights, such as housing, health, and education. As a consequence, inequalities are downplayed, and citizenship is seen through a meritocratic lens that endangers the understanding of citizenship as a fundamental right. It is in this context that Galeano (2002), in his article entitled '*Nem direitos, nem humanos*,' critiques the common-sense liberalism spread by the Universal Declaration of Human Rights

These ideological discursive strategies are spread in contemporary Brazilian society to undermine the universal meaning of the category 'citizen,' thereby

opening the door to the exclusion of certain groups, while reinforcing stereotypes and hierarchies regarding citizenship. Therefore, these are discourses that present a dual dimension. On the one hand, they inherit the liberal concept of citizenship as a common good, available to all members of society, thus contributing to the mystification of the just nature of the liberal democratic social contract. On the other hand, they openly legitimize what the liberal concept of citizenship conceals —that is, the exclusion of a significant portion of society. As this deliberate exclusion often materializes in policies aimed at the physical elimination of parts of the population, such actions cannot be legally justified in a rule-of-law state, but instead seep into common-sense discourse. In other words, through ideological strategies that reject established scientific consensuses and mobilize political and/or religious rhetoric, which are characteristic of scientific denialism (Vilela & Selles, 2020), a simplified and distorted interpretation of existing social relations is produced. Given the widespread influence and circulation of these ideas in contemporary society, we cannot ignore their impact on the subjectivity of our students and the risk of fostering a distorted self-image based on such ideas (Costa, 2021).

Thinking about citizenship without falling into the trap of directly and linearly linking it to schooling or its contents, thereby adhering to a classical liberal view of citizenship, we can draw on the reflection proposed by Freire:

> Sometimes I think that we speak of citizenship as if it were a concept, very abstract, with a particular magical force, as if, when the word citizenship is pronounced, automatically, everyone would win it. Or as if it were a gift that politicians and educators gave to the people. It's not that. It must be made clear that citizenship is a production, a political creation (Freire, 2004, p. 127).

When we talk about educating for citizenship, we sometimes overlook the fact that students are already citizens, as they are living in a society shaped by political, economic, social, and cultural processes. These processes shape the values and beliefs that circulate and position us both in terms of the rights ensured by law and those that are, or not, granted depending on the class, race, gender, sexuality, or ethnicity in question. This reductionist perspective of citizenship can and should be a point of critical reflection in our practices, both in basic and higher education, because it is by developing critical awareness about this political construct that we will be able to overcome it.

The concept of citizenship is closely linked to different interpretations of democracy. As such, it involves both vertical relationships, between the State and the citizen, and horizontal relationships, among citizens themselves. Each democratic model presents variations of these relationships, leading to different models of citizenship that range from the classical liberal tradition to more progressive approaches that promote the effective participation of broader social groups in society. This diversity calls for teachers and researchers in the field of science education to take a clear stance when positioning citizenship education as a central objective of our work. It is therefore essential to consider the underlying meanings of citizenship embedded in the assumptions that shape various pedagogical approaches, whether critical or not (Saviani, 2008).

Bearing this in mind, regarding citizenship and education, we turn to Arroyo (2010) for arguments to challenge the utopian, linear relationship often assumed

between these two concepts. This reevaluation is based on the following aspects: (i) a reflection on history from a non-evolutionary perspective, aimed at demystifying the success of the capitalist enterprise and shedding light on the contradictions that sustain social inequality; (ii) a questioning of the direct association between levels of schooling and levels of political participation in the pursuit of social transformation; and (iii) a critical assessment of "the weight attributed to knowledge and education in shaping the destiny of individuals and social classes" (Arroyo, 2010, p. 81), recognizing the existence of political education spaces beyond the school setting, such as social movements (ibid., 2010). More broadly, rethinking the citizenship–education pairing means grounding it in the real world and breaking away from certain pedagogical discourses centered on education for harmonious social coexistence, as the ongoing process of becoming a citizen is marked by conflict, imbalance, and inequality.

The proposal for a dialectical relationship between citizenship and education, developed in this essay, is politically grounded in the response to the question we posed: who are our students? For the most part, they are characterized by limited access to economic and cultural capital, which results in a narrow range of choices — religious, cultural, housing, employment, access to information, among others. In a class-based society marked by deep socioeconomic inequalities, this perspective reflects a commitment to transforming the structures that reproduce students' living conditions. From this standpoint, the notion of education for citizenship is not grounded in an abstract or generic model of the citizen and society, but rather begins with the student as a concrete subject, whose position stems from the structural aspects that organize society. Ignoring or downplaying the material conditions in which most students live means contributing to the silencing of the factors that, in various ways, help to maintain and reproduce their social positions. Thus, the role of schooling in citizenship education is not limited to the simple transmission of disinterested concepts and content, but lies in using such knowledge to foster a non-naturalized understanding of one's own situation and the concrete conditions that make change possible.

This notion of citizenship is consistent with an educational approach that rejects models designed to offer the working class a narrowly defined, technically oriented training aimed solely at integration into the labor market. In contrast, science teaching should ensure that members of the working classes have access to knowledge that enables them to critically understand and engage with the consequences of technological innovations in the world of work, as well as the role often played by science in promoting production flexibility, capital accumulation, and environmental degradation. Moreover, such an approach to science teaching must avoid naive, binary views of science, recognizing it instead as a contested field capable of ongoing reflection on the knowledge it produces (Bourdieu, 2024). As a result, scientific activities are able to: (i) formulate critiques of itself and produce responses capable of supporting insurgent movements and alternative models of production (such as agroecology); (ii) discredit supremacist explanations supposedly grounded in biology; (iii) develop technologies that remediate pollution; (iv) inform the development of public policies that ensure the preservation of environmental quality; (v) regulate working conditions that protect workers' health.

Considering reflexivity as a constitutive element in scientific knowledge production, researchers should be committed to social justice and human emancipation, overcoming instrumental reason (Bourdieu, 2024). In line with this view and with Bourdieu's conception of scientific activity as a field of disputes, we adopt a materialist, dialectical, and historical perspective of science to understand natural phenomena and processes, to defend a particular view of science and its teaching. One consequence of this stance for science and biology education in the context of citizenship education, within the framework of environmental collapse (Marques, 2023), is the dialectical treatment of the themes of health and environment.

"WHAT DO WE TEACH?" HEALTH AND ENVIRONMENT AS POTENTIAL THEMES FOR CITIZENSHIP EDUCATION IN SCIENCE AND BIOLOGY TEACHING

Health and the environment are closely interconnected. Issues, such as pollution, access to natural resources, quality food, and decent living conditions, directly impact populations' health. In turn, citizenship is expressed by ensuring access both to the knowledge required to participate in society and to democratic spaces for the exercise of individual autonomy. Developing students' critical awareness regarding the social structure in which they are embedded, shaped by scientific and technological production, is essential for the political construction of citizenship within the context of science and biology classes. Therefore, when we advocate for scientific education that enables participation in promoting public health policies and environmental preservation, we cannot disregard the actual conditions of the social practices in which we operate. Given the unequal characteristics of society and, more specifically, the material conditions of life in Brazil, proposals guided by these objectives are not easily implemented in public educational institutions and face numerous challenges that extend beyond what happens within the walls of schools or universities.

Industrialization and urbanization have brought about environmental issues that led to new approaches to health, especially concerning the most disadvantaged segments of the population, comprising predominantly Black individuals, who occupy sacrifice zones (Bullard, 2005). Thus, any in-depth debate on the relationship between health, environment, and citizenship must take into account the real conditions of access to quality of life, which are not limited to discussions on the content of specific subject areas, and include social and political issues (Rios, 2020). Through this integrated approach, we can dialectically understand the relationships between health and the environment; when analyzed separately, the discussion clearly fails to reveal the complexity of the issue.

Given that we are living in a historical moment marked by environmental collapse (Marques, 2023), with an increase in the frequency and intensity of extreme weather events, issues related to health and the environment are becoming key in the field of science and biology education. The aim is to contextualize scientific knowledge and bring core content closer to social issues. This thematic preference was highlighted by Högström and colleagues (2024) in their review of the literature on socio-scientific issues in science education across various international databases, in which they identified 157 articles on practices in

primary and secondary schools addressing two main themes: environment and sustainable development; and health and technology.

In the doctoral research entitled "*Inter-relação saúde e ambiente na escola brasileira: Uma revisão sistemática de literatura em dissertações e teses de 2013 a 2022"* [The Interrelation between Health and Environment in Brazilian Schools: A Systematic Literature Review of Dissertations and Theses from 2013 to 2022], Rocha (2023) analyzed 17 master´s theses and one PhD dissertation, concluding that only seven of them effectively established such an interrelation. The most successful were those grounded in a broad concept of health. The author explains that articulating health and environment within the school context is not easily achieved due to structural and organizational aspects of the institutions, as well as the use of concepts that do not allow for the construction of this interface in a complex manner.

The results obtained by the author are similar to those identified in a survey conducted with collaborators in the proceedings of the following events: *Encontro Nacional de Pesquisa em Educação em Ciências* (1999 a 2021) [the National Meeting on Research in Science Education], *Encontro Nacional de Ensino de Biologia* (2005 a 2022) [the National Meeting on Biology Teaching] and *Encontro Nacional de Ensino de Ciências, da Saúde e do Ambiente* (2005 a 2022) [the National Meeting on Science, Health, and Environmental Education]. In this review, 36 studies addressing the interface between health and environment in science education were found. Content analysis revealed strong support for the integrated use of health and environment, as well as for closer connections between science teaching, environmental education, health and/or nutrition education, among others. An example of this is the case of science teaching grounded in the principles of agroecology. The reviewed texts highlight the potential of these themes and educational fields to make science and biology education more oriented toward citizenship education. However, they do not clarify the theoretical and practical aspects that enabled this potential, as most cases prioritize one concept over the other (Viana & Pinhão, 2025).

These reviews show that, despite the focus on using health and environment as contextual themes with potential for citizenship education, this integration is complex and still insufficient to support practices that foster critical education aimed at empowering students' effective political participation. In light of this, we consider it essential to conceptually define the relationship between health and environment from a dialectical perspective, proposing a rupture with exclusively biomedical and ecological explanatory models, as well as a critical reflection on the split between human beings and nature/organism and environment found in positivist approaches.

Health and the environment constitute an important conceptual pair for revisiting the human–nature dichotomy and adopting a dialectical stance toward the biological and social aspects in the health–illness process. According to Monken et al. (2008), at least three aspects make this pair fundamental: (1) the focus on public health; (2) opposition to biological determinism and the industrial economic model, which promote alienation from nature; and (3) the growing demand from social movements for environmental protection measures that safeguard humanity. Along the same lines, studies by Wallace (2020) have shown

that several recent pandemics and epidemics originate from ecosystem destruction driven by the agribusiness production model.

In addressing the relationship between these themes, there is a noticeable oscillation in epistemological approach between holism and causality—whether multicausality or unicausality. Causality is a feature of modern science that, as Lewontin (2000) points out, is closely linked to the social reorganization shaped by industrial capitalism, characterized by an atomized society whose view of nature is reductionist. Reductionist thinking relies on the idea that the whole can be understood solely through the study of its individual parts. The whole would be the result of its parts, just as society comes to be understood as the product of competition among individuals. This conception of society and the assumptions that structure it are also reflected in the constitution of modern science, whose turning point lies in the "clear distinction between cause and effect" (Lewontin, 2000, p.16).

This distinction enables an understanding of the relationship between organism and environment, as well as between humans and nature, based on the alienation of the organism from the external world that influences it, resulting in the creation of separate internal and external environments. As Lewontin (2000, p. 16) states, "causes are internal and external, and there is no mutual dependence between them." The same author notes that, in modern biology, living beings are perceived as organisms determined by their genes, leading to the idea that we can fully understand the human being through genetic mapping. This atomistic view of the world, according to which the internal environment exclusively determines our actions upon the external environment, has been so internalized that the separation between human and environment is rarely questioned. Thus, the world is described by the existence of an internal environment, shaped by genes, and an external environment, which acts upon this genetic base not only by selecting or eliminating individuals but also by conditioning how genetics is expressed.

In response to genetic determinism and unicausality, theoretical currents have emerged that advocate for a view of the environment as an inseparable whole, returning to medieval holistic thinking through the Gaia hypothesis. However, this perspective overlooks that, although all phenomena are interconnected, they can still be understood by examining their individual parts, as well as the relationships between them. Both approaches fail to present alternatives that enable addressing the environmental crisis in ways that facilitate effective change. The solution does not lie in genetic manipulation or the application of isolated techniques, nor in the ï view that there is a harmonious and unified environment being destroyed by humans. An alternative approach to understanding the relationship between organism and environment is the idea of the dialectical construction of this relationship, called constructionism, instead of adaptationism, which, broadly speaking, emphasizes the centrality of genes:

> (...) with the environment as an integral part of their production and activity; therefore, we cannot, in turn, make the mistake of assuming that organisms confront an autonomous external world. The environment influences organisms only through its interaction with their genes. The internal and external are intrinsically interconnected. (Lewontin, 2000, p.128).

In dialogue with the author, health can be understood from a dialectical perspective when we consider its social determination, establishing a direct link with the materiality of biological and social processes—that is, between the internal and external environment, the body and its surroundings. This approach shifts the focus of the health–illness process away from strictly medical and physiological factors, broadening the analysis to include the determinants that produce health inequities. It is not merely a list of factors, as suggested by the World Health Organization (WHO) through the notion of social determinants of health, which would explain inequality, but rather a recognition of the structuring role of the capitalist model in shaping productive processes and its direct implication in collective illness processes (Garbois et al, 2017).

Considering the different epistemological positions, we understand that causality, holism, and dialectics are approaches in scientific knowledge production, but they address the relationship between organism and environment in different ways. It can be observed that causality, based on biological and genetic determinism, has become the most widespread paradigm in scientific knowledge production, including its ramifications for misinterpretations of social relations (Levins & Lewontin, 2022).

This brief presentation highlights that there is no homogeneity among the epistemological approaches to the relationship between health and environment, a pair that can therefore be interpreted through different orientations. In this regard, we consider the dialectical perspective the most suitable for science education committed to citizenship education. The material aspects of the climate crisis affecting everyone's lives must be included when selecting content that allows for an articulation between citizenship, health, and environment in science education, highlighting the contradictions that constitute the dialectical relationships between the social and the biological aspects

Does merely incorporating these themes into the teaching–learning process truly amount to educating for citizenship and upholding democratic principles? We assess that by highlighting the fragmented and non-relational view of urgent aspects of our daily lives, as well as the inseparability of human and nature, the epistemological discussion proposed in this work can develop students' critical capacity regarding the different dimensions that structure a social problem. This proposed revision of concepts helps students reconnect and fosters new perspectives on what to teach. However, this is not sufficient, not even when considered in isolation from the challenges related to the didactic process and the pedagogical conditions of the work. Therefore, it is important to reflect on how we teach and who we teach. Regarding students, we must avoid the fallacy of a univocal relationship between schooling and citizenship. Having said that, we are aware of the difficult task of balancing various demands in real teaching–learning contexts; for this reason, we will present some non-prescriptive examples of content with potential for science and biology teaching committed to the dialectical approach between health and environment and to the production of critical-emancipatory teaching–learning processe

CONTENT FOR CRITICAL CITIZENSHIP IN SCIENCE AND BIOLOGY TEACHING

The environmental movement is marked by a clash between two opposing perspectives: a critical one, which links the debate to a particular model of society and proposes its transcendence, and a reformist one, which advocates for palliative measures aimed at reforming the productive system. The former, radical environmentalism, is guided by scientific data and does not downplay forecasts regarding the problem; the latter, moderate environmentalism, adopts an eco-friendly reformist stance, "based on behavior changes in small individual actions" (Layrargues, 2024, p. 80), thus flirting with subtle denialism. As a consequence, moderate environmentalism minimizes and naturalizes the environmental collapse, presenting a scenario far milder than it actually is. There is also a denialist and conspiracist far-right anti-ecologist group that completely rejects the environmental crisis. These two denialist groups ultimately defend the capitalist system's modes of production and consumption. According to Layrargues (2024), it may be more important to combat subtle denialism, as it represents the hegemonic discourse on the environmental issue, exemplified by the ideology of sustainable development in UNESCO's 17 Sustainable Development Goals (SDGs).

The ongoing environmental crisis today stems from a long process of separation between society and nature. In Modernity, the transition from feudalism to the capitalist mode of production resulted in a metabolic rift between humanity and nature. This rupture occurs as private ownership of the means of production is established, the countryside becomes dependent on the needs of the cities, and exchange value prevails over use value. These practices prevent, for example, the return of nutrients to the soil at the same rate they are consumed, which is partially compensated by the intensive use of chemical fertilizers, pesticides, and other techniques aimed at artificially increasing productivity without regard for natural cycles. At a certain point, especially from the 1970s onward, the physical and biological limits of the planet were exceeded, resulting in the contemporary environmental crisis or, in current terms, environmental and climate collapse (Marques, 2023).

Various topics in the natural sciences, especially biology, can be addressed, enabling students to develop a more critical understanding of natural phenomena, biogeochemical cycles, relationships among living beings, as well as ecosystems and communities considered in concrete terms. In other words, it is essential to highlight human-made interventions within capitalist society, as well as natural dynamics. In this framework, contextualization in science teaching must be reconsidered based on the concrete reality produced by the structure of the capitalist mode of production, which extends beyond merely including everyday issues. Thus, as Santos (2007) emphasizes, it is not about creating an artificial link through simple exemplification of content in daily life. Instead, what we propose is to start from real problematic situations to seek the knowledge necessary to understand and solve them, using topics related to scientific content through their social, economic, environmental, and ethical aspects.

Considering this, for example, topics related to water can be presented through a perspective that incorporates the hydrological cycle, while also discussing watershed management, and the treatment, distribution, and right to potable water as eminently political issues. Other examples include the destruction

of biomes and ecosystems linked to the expansion of agricultural frontiers driven by agribusiness activities; the impacts on nature and human health caused by chemical colonialism (Bombardi, 2023); and the emergence of epidemics and pandemics resulting from the destruction of natural areas by agribusiness.

The nature of science, as content to be taught, has been widely emphasized by the Science, Technology, and Society (STS) teaching model. Even while recognizing science as a human endeavor that bears the marks of the capitalist mode of production, and as knowledge that contributes to the maintenance and/or expansion of social inequalities, STS considers the potential for its implications in the opposite direction. Science can critically examine itself and generate models and responses that can support insurgent movements, as it operates within a heterogeneous field of competing forces. Thus, science should not be confused with the uses that can be made of it.

The way we define the content to be taught should not be restricted to showcasing how it has been used to dominate disadvantaged groups. This reorientation of the approach allows us to simultaneously escape both the mystification of a neutral and disinterested science and the view of science as merely an instrument of domination, multiplication of capital accumulation mechanisms, and environmental degradation (Levins & Lewontin, 2022). Consider, for example, the concept of *recampesinização* (returning to small-scale, diversified, and often traditional farming practices) advocated in Van der Ploeg's (2008) work. This practice involves shifting the emphasis from production to strengthening agricultural worker multifunctionality—that is, using the same resource base to generate a wide range of products and services in the face of the threat posed by large food empires. Another example of the dialogue between scientific production and resistance movements to agribusiness can be found in Almeida (1999), who discusses the alliance between agrarian science professionals and rural social movements in southern Brazil. In this context, two distinct understandings of agriculture are in conflict: agribusiness and family farming. It is also scientific knowledge that critically analyzes, in works such as those by Sauer and Balestro (2013) and Altieri (2012), the global expansion of transgenics and monocultures for biofuel production, as well as concepts and methods for managing agroecosystems.

An emblematic case to be explored in the history of science and its social uses is that of the tobacco industry (Oreskes & Conway, 2010). In partnership with scientists, a set of arguments was constructed to support the continued availability of this product, despite evidence of its harmful effects on human health, both through direct and indirect use. Similarly, the food industry has faced numerous accusations of forming alliances with research institutions to sustain the market for ultra-processed foods, despite widespread and well-documented criticism. (Nestle, 2019).

Knowledge of issues such as these contributes to a less simplistic and univocal view of science, whether in basic education, initial teacher training, or ongoing professional development. This, in turn, enables classroom discussions on topics such as the sustainability of modes of production; the implications of transgenic use for the social structure of rural areas, biological diversity, and the health of farmers; and the importance of family farming for valuing local resources, producing quality food, and conserving natural resources.

"HOW DO WE TEACH?": CONNECTIONS BETWEEN HCP AND STS EDUCATION

Given the contextual aspects presented, two movements within the field of education seem promising for guiding the discussion between citizenship, environment, and health: Historical-Critical Pedagogy (HCP) and the Latin American Thinking in Science, Technology, and Society (PLACTS). Although the STS movement has several strands and lacks a unifying epistemology, the main South American authors within this movement share a critical perspective on scientific activity with HCP, as well as the societal model underpinning it. Thus, we will conduct a theoretical analysis of the convergences between both frameworks, seeking elements or concepts to help us address the final question of our work, "how do we teach?", relating it to the previous ones. For this purpose, we start from the premise that the concepts of health, environment, and citizenship serve as a guiding axis for science teaching practices engaged with the material reality structuring Brazilian society, rather than being limited to an abstraction of what it means to be a citizen. Thus, meaningful practices linked to contexts can contribute to greater participation and, consequently, to conscious and critical judgments of problems, aiming at intervention in decision-making, which is the aim of genuine democratic participation (Schwan & Santos, 2021).

Regarding how HCP and STS education address the relationships among these elements, we consider it fruitful to revisit their contributions, highlighting their points of convergence and divergence. According to Teixeira (2003), the differences between the two are not sufficient to create opposition, given that both view education as a tool for developing democratic and emancipatory contexts. The author identified the possibility of articulation between the two approaches based on five points of convergence: (1) social practice; (2) educational objectives; (3) teaching methodologies; (4) content; and (5) the role of the teacher. Despite the limitations of rapprochement between these perspectives, these points may help to formulate a proposal to revisit the questions raised in this text.

HCP, as a counter-hegemonic pedagogical theory, was developed in opposition to non-critical pedagogical theories (Traditional Pedagogy, New Pedagogy, and Technicist Pedagogy) and to critical-reproductive theories (Theory of the Education System as Symbolic Violence, Theory of School as an Ideological State Apparatus, and Theory of the Dualist School). Since its earliest formulations, it has sought to overcome the dichotomy between theory and practice, content and teaching methods, teacher and student. On one hand, Traditional Pedagogy emphasizes content and the figure of the teacher, relegating teaching methods and the role of students to secondary importance. On the other hand, New Pedagogy and Constructivism (and, in their current forms, active methodologies) shift the focus to teaching methods and students. Unlike both approaches, HCP avoids relying solely on content or on advocating innovative methods and techniques as the ultimate solution to teaching challenges.

Regarding STS, it is important to differentiate it from HCP by the fact that it is not a pedagogical theory but a stream of thought that also unfolds into an educational perspective. The development of PLACTS originated in Argentina at the end of the 1960s, at a time when the country had great scientific and technological potential. In Brazil, STS-related research began in the 1980s, similarly to Spain. The work produced in Spain on STS education was more widely addressed

by science education researchers in Latin America than that produced by PLACTS, leading to a lack of broader discussion on this continent about public policies and "science and technology capacity-building for social development" (Dagnino, 2014, p. 159). Despite variations in STS education, it generally marks a split with cognitivism and recognizes contextual aspects as fundamental to problematizing scientific content in its nonlinear relationship with technology and society. For the sake of this essay, however, we understand that the concept of PLACTS, as presented by Dagnino et al. (1996), is the most appropriate, as it offers a critical approach that interprets science and technology as social processes deeply linked to political projects and the historical conditions of Latin America. This perspective contrasts with technocratic views and proposes a science committed to autonomous, democratic, and socially just development.

HCP is based on the defense of the triad content-form-recipient (Saviani, 2021; Martins, 2015), establishing itself "(...) as the primary requirement in teaching planning. As such, none of these elements alone, stripped of the connections that bind them, can effectively guide pedagogical work" (Martins, 2015, p. 297). For the sole purpose of organizing this text, we separate the issues of content, form, and recipient.

Considering that the role of the school is the socialization of knowledge historically produced by humanity in its most elaborated forms—namely, scientific, philosophical, and artistic knowledge—means assuming that "school has the role of enabling new generations to access the world of systematized, methodical, and scientific knowledge. It needs to organize processes and discover forms appropriate to this purpose. This is the central issue of school pedagogy" (Saviani, 2021, p. 66). Selecting classical content, that is, "what has withstood the test of time, having validity that transcends the moment in which it was formulated" (Saviani & Duarte, 2012, p. 31, apud Malanchen, 2016, p. 171), proves to be an important criterion. The classical is, in itself, a unity between content and form and, when transformed into school content, can be worked on through different didactic forms (Duarte, 2021, p. 109). Thus, HCP does not adopt a prescriptive stance or a recipe to be followed, opening up possibilities for using "different strategies, techniques, and didactic procedures to be evaluated in the course of pedagogical work by relating at least four elements: who is teaching, who is learning, what is being taught, and under what circumstances the educational activity takes place" (*ibid.*).

However, some guidelines are fundamental. One of them is to recognize social practice as both the starting point and the aim of the teaching-learning process. Social practice is identified by Teixeira (2003) as a possible convergence between HCP and STS, which can be attributed to STS emphasis on social problems, addressed in didactic sequences as both the initial and final point. In this approach, one of the main aims is the education of the subject for decision-making, argumentation, and participation in the public sphere. Delizoicov et al. (2002) organized the construction of STS didactic sequences in dialogue with Freirean thought, assigning to the problematization of content in social life a centrality analogous to the emphasis given to social practice in HCP by Saviani (2021). Delizoicov et al. (2002) structure a teaching methodology based on three pedagogical stages: (1) initial problematization, (2) knowledge organization, and (3) application of knowledge. The initial problematization aims to present real

situations or issues about which students have some level of knowledge and can debate. In the second stage, the teacher presents knowledge related to the topic that is relevant for understanding the entirety of the initially presented issue. Finally, students use the knowledge constructed in this process to interpret and analyze the initially presented situations or others related to the main theme. This produces a learning cycle that connects academic knowledge with real-life situations experienced by the students.

Santos and Mortimer (2002) reinforce the importance of developing decision-making capacity as a key element in citizenship education. Achieving this requires more than simply adding science and technology concepts to the curriculum or teaching stages that simulate decision-making processes; it requires fostering a commitment to responsible social action, which entails shaping attitudes and values. In STS education, although there is no rigid prescription, recurring methodological strategies can be identified aimed at developing educational activities that emphasize decision-making, especially in social issues where science and technology serve as important parameters. According to Santos and Mortimer (2002), this curricular proposal aims to provide students with tools that enable them to act, make decisions, and understand what is at stake in expert discourses —an essential condition for the full exercise of citizenship. The STS approach, therefore, helps to overcome the hegemonic model present in broad social sectors, characterized by the predominance of technocratic decisions. Furthermore, it aims to dismantle the salvationist or redemptive view often associated with science and technology. Common strategies in this approach include using socio-scientific issues, engaging in debates about the nature of science, critically analyzing media content, and practicing argumentation exercises, as highlighted in Gonzalez's (2023) review.

Thus, the centrality of social practice in HCP requires articulating the question "how do we teach?" with "who do we teach?" as the concrete student is taken as the reference, differentiating them from the empirical student. While the latter is understood in their immediate and abstract individuality, with sensations, desires, and aspirations that do not necessarily correspond to their real interests, the concrete student is "the individual who synthesizes within themselves the social relations inherent to the society in which they live and in which their education process takes place" (Saviani, 2012, p. 42, apud Pasqualini, 2020, pp. 13–14). Therefore, Pasqualini (2020, p. 14) emphasizes the need to move beyond the empirical student toward the concrete student. The author argues that mediating between content and recipients (concrete students) requires taking the following aspect into account: the "incorporation by students (as individuals) of the conceptual nexuses (general) synthesized in the conceptual systems of science, art, and philosophy takes place within a material and symbolic context, conditioned by specific material and symbolic circumstances" (ibid.). Within this horizon, using content related to agribusiness, for example, while relevant to all Brazilian students, will have greater significance for those living in regions directly affected by this form of agro-industrial activity.

Given the central role of social practice in HCP and the emphasis on contextualization in STS education, curricular content must be developed in connection with the dominant productive processes of contemporary society. For

HCP, core content refers to that related to the process of transmission-assimilation of systematized knowledge. For STS education, it is essential to link scientific reference content to its contexts of production, circulation, and appropriation. Starting from the premise that content and form are intertwined, in the field of science education, didactic strategies are closely related to the processes of producing reference scientific knowledge, giving central importance to practices such as experimentation and investigation, fieldwork, visits to science museums and science communication spaces, reading and writing scientific text genres, hypothesis construction, argumentation, and explanatory syntheses through graphs and other symbolic systems, among others. Moreover, the way the teacher constructs the didactic process will depend on at least three aspects: (1) mastery of knowledge about the content, its production, and social uses; (2) the material conditions under which the specific social practice is developed; (3) the nature of the content to be taught (for example, cytology cannot be effectively addressed through naked-eye observation of an ecosystem during fieldwork).

Methodological choices are not the result of mechanically following the sequence of steps outlined by HCP, beginning by analyzing social practice, followed by problematization, instrumentalization, catharsis, and, ultimately, a return to social practice as the endpoint. In fact, these moments are intertwined (Saviani, 2019). However, for pedagogical work to be developed coherently with this perspective, it is important to emphasize the need for a study movement focused on the theoretical foundations of HCP and PLACTS, including their epistemological, ontological, pedagogical, and political premises, as well as a continuous process of reflexivity regarding the relationship between the content to be taught and the processes that sustain social inequalities.

CONCLUSIONS

In this essay, while recognizing the limitations inherent to any text, we presented a discussion on the role of science education in promoting citizenship education within the context of environmental crisis, the rise of scientific denialism, and the spread of obscurantism. For this purpose, we advocated the relationship between health, environment, and citizenship as a way to contextualize content and articulate it between PLACTS and HCP teaching approaches, as theoretical-practical frameworks for developing pedagogical work. This epistemological and ontological exercise has enabled us to revisit the questions “who do we teach?”, “what do we teach?”, and “how do we teach?”. Based on the discussions presented throughout this essay, we draw the following conclusions: Schools are primarily recognized as fundamental spaces for socialization, where the political citizenship of individuals is constructed. Furthermore, they function as places of access to a body of knowledge that often originates from social practices restricted to specific groups. Thus, schools are one of the main spaces for the political creation of citizenship, understood as a dynamic and transformative process rather than merely a legal condition. This understanding is directly connected to the challenges posed by scientific denialism and environmental collapse (Marques, 2023), emphasizing the importance of experiences in diverse socialization spaces. Exposure to these contexts is essential for the education of critical individuals capable of political action. Those without

access to a broad range of experiences are left with a limited repertoire for understanding and transforming reality.

When contextualized through the relationship between health, environment, and citizenship, using a democratic and emancipatory approach grounded in real situations, the content to be taught is much more likely to become an instrument for action in social practice. This does not imply adhering to a superficial utilitarianism of content, but rather advocating a process of appropriation and continuous reflective revision of both reality and content, in a dynamic articulation of theory and practice. Thus, there is no fixed methodology with rigid stages or a prescribed list of content to be followed by teachers in basic education or by teacher trainers. What we propose is a pedagogical practice guided by ethical and political principles, sensitive to the material conditions of life that affect us all. Moreover, it should be structured based on technical and scientific knowledge that must be appropriated by historically marginalized groups.

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