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Critical Imagination for Transformative Agency: Pedagogies for Science Teacher Education

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ABSTRACT

This paper theorizes transformative agency and its potential to promote justice-oriented science teacher education. We argue that science education often acts as a disimagination machine, constraining possibilities for envisioning and enacting transformative change. To contest this reality, we draw on critical perspectives in science education, specifically Paulo Freire's and Simone Weil's philosophies to theorize transformative agency as encompassing three dimensions: a) reading the world to identify injustices, b) imagining untested feasibilities, and c) writing the world anew. In doing so, we act upon the belief that inherited practices of science education that negate collective joy must be challenged. We expand current conceptualizations of transformative agency by proposing critical imagination as one of its core components, enabling the envisioning of possibilities for change. We propose three pedagogical approaches for cultivating critical imagination: a) facilitating practices that move beyond the self to recognize multiple human and nonhuman others; b) adopting a planet-centred orientation to education transcending human-centered approaches; and c) troubling dominant spatial and temporal scales of thinking. We argue for the need to develop liberatory pedagogies that bring critical scientific questions to justice issues while nurturing critical imagination. This entails conceiving agency as more than responsive classroom practices but rather as achieving justice-oriented commitments, agendas and visions that center the world and its necessities.

"To exist, humanly, is to name the world, to change it. Once named, the world in its turn reappears to the namers as a problem and requires of them a new naming"

(Freire 1970, p. 88)

"Let me disappear in order that those things which I see may become, owing to the fact that they will then no longer be things which I see, things of perfect beauty"

(Weil 1956, p. 383).

1 | Introduction

Researchers in different parts of the world have argued for the need to reimagine science education (Torres-Olave et al. 2023;

Wallace et al. 2022) and science disciplines (Nobles et al. 2022) in ways that challenge enduring social inequalities and promote equity and justice (Tolbert et al. 2023a; Morales-Doyle 2017). More specifically, researchers have argued for the need for science education to navigate the complexities of such reimagination, paying attention to the multiple realities we live in (Bang and Marin 2015; Kayumova and Dou 2022), as well as the different power structures that affect us from intersected systems of oppression (Avraamidou 2020; Tolbert et al. 2022). Such calls have justice horizons for the field for the transformation of power dynamics, relationships, and historical exclusions that need to be considered, recognizing root causes and acting upon them.

As Freire (1970) argued, any process of naming the world, such as the process of science education, will also entail naming its

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inequalities, which becomes a problem to solve and, therefore, requires new namings through new ways of being and doing science education. Such new namings require "to tap into imagination…to become able to break with what is supposedly fixed and finished, objectively and independently real" (Greene 1995, p.19).

However, despite efforts to promote justice-oriented science education, many structures perpetuating injustices, such as curriculum and teacher education, remain fixed and untouched (Settlage and Williams 2022). Moreover, science education often acts as a disimagination machine (Giroux 2021), constraining the possibilities for envisioning and enacting transformative change. As research shows, limited attention has been paid to exploring the structural constraints that teachers may face in their future school contexts (Tolbert et al. 2023b) together with the pedagogies that may facilitate envisioning these constraints and their justice-oriented transformations (Nag Chowdhuri and Archer 2023).

While several studies illustrate what justice-oriented science teaching looks like and the associated curricular materials (e.g., Bell and Rhinehart 2021; Bernal-Munera 2023; Hennessy et al. 2023; Tolbert et al. 2022), only few researchers, and those are situated in specific contexts, have examined the pedagogies through which teachers, especially preservice teachers, come to embrace social justice goals (e.g., Luehmann et al. 2024; Chen and Moore-Mensah 2022; Morales-Doyle 2024). What this means is that preservice science teachers miss opportunities to discuss agentic ways of navigating and challenging such injustices and contest hegemonic visions of science education.

Luehmann et al. (2024) argued for a more explicit integration of dialogues about justice-oriented science education and initial teacher education to support beginning teachers' justice-oriented pedagogies. This dialogue should move away from linear perspectives that constrain preservice teachers to a singular, rigid notion of justice-oriented pedagogies. Such limited viewpoints fail to account for the intricate and diverse ways in which injustices manifest across different contexts.

At a more conceptual level, there exists a lack of theorization in terms of what we mean by justice-oriented science education and its relation with the pedagogical strategies necessary for it (Luehmann et al. 2024; Morales-Doyle 2017, 2024), particularly in the context of initial teacher education (Kitchen and Taylor 2020) - and teacher education more broadly - and the sense of agency required for such task (Miller-Rushing and Hufnagel 2022). To advance such efforts, we need to develop *pedagogies* that allow us to see the possibilities and learn the necessary concepts and tools for achieving justice-oriented science education (Au 2021). This is precisely what we aim to do in this paper through first (re)conceptualizing *transformative agency* and then proposing three pedagogical approaches that encompass such conceptualizing.

Adopting a justice-oriented science education perspective means to develop a sense of agency as educators, bringing science questions to justice issues (Morales-Doyle 2023) through an imagination "that makes different possibilities visible" (Bazzul and Tolbert 2019, p.307). As argued by Chen and

Mensah (2022), this implies guiding our "knowledge, decisions, advocacy, and enactment of practices to challenge school [and educational institutions more broadly] norms and structures and to promote diversity and equity" (p.387). Therefore, cultivating such agency and associated practices is imperative in initial teacher education (Avraamidou 2016).

Towards this aim, researchers have focused on developing agentic teachers' practices, such as how to make science more relevant to students' lives (Schenkel and Calabrese Barton 2020) and how to develop political clarity in preservice teachers through embracing their agency (Morales-Doyle et al. 2020; Tolbert et al. 2023a). In this body of research, agency is conceptualized as something to catalyze the transformation of structures of oppression rather than maintaining and reproducing the world *as it is*.

We aim to further contribute to this study by proposing *critical imagination* as a core component of transformative agency for justice-oriented science education. To do that, we engage with the following questions:

1. How can transformative agency be conceptualized for promoting justice aims?

2. How can we cultivate transformative agency through critical imagination in science teacher education?

2 | (Re)Conceptualizing Agency

We understand justice-oriented science education as encouraging relationships with science to "design worlds in which all life forms can flourish" (Kayumova and Dou 2022, p.1113). This would mean envisioning science in a world where it will be easier to love (Freire 1994) through collective joy and attentive practices (Weil 1946). For Weil (1946), collective joy represents a state where "no corner is left for saying *I*" (p. 31), understanding the self in connection to others. At the heart of the account of re-imagining and designing worlds lies the construct of agency. We define agency as the "power to reflect upon one's circumstances and decide what to do in them or about them" (Archer, 2007, p.153). In the context of teacher education, we are concerned with how teachers can become agents of such change through transformative agency. Hence, transformative agency becomes a way of reading the world to imagine, and write new ones (Morales-Doyle et al. 2020; Torres-Olave 2022). This transformative process simultaneously shapes our personhood (Stetsenko 2020) while expanding science education through new justice-oriented pedagogies prioritizing collective rather than merely individual flourishing.

The need for turning our attention to justice-oriented education lies within the history of science itself. A historical examination of science (education) points to various intersected structures of oppression that negate collective joy (e.g., racism, sexism, homophobia, xenophobia, extractivism), which science has helped to legitimate by taking scientific knowledge to validate them (Bang and Marin 2015; Morales-Doyle 2018; Nobles et al. 2022), for example, through curricular materials (Kim 2021; Lodge and Reiss 2021; Tannock 2020). Concurrently, we can find

stories of critical hope (Frausto Aceves and Morales-Doyle 2022; Tolbert et al. 2022; Torres-Olave 2022) through the acts of different people that account for the possibilities for science education to advance towards epistemic, social, and environmental justice. We build on this study and we argue that educators have a moral duty to work towards social justice by embracing liberatory pedagogies (Suárez and Beatty 2022). Doing so it entails identifying and naming inequalities while cultivating ways of thinking for "disrupting, displacing, inverting inherited concepts and practices" (Alexander 2005, p.7) that perpetuate them. Aiming to further contribute towards the conceptualization of liberatory pedagogies in science education, we first explore the construct of agency in general terms and how it has been explored in science education research. Following that, we propose a conceptualization of transformative agency and its main components. Drawing on critical perspectives in science education and Freirean and Weilean philosophy, we define the core characteristics of imagination as a core dimension of transformative agency. Finally, we provide recommendations for science teacher education pedagogies through attention practices that go beyond the self, towards planet-centered education, and that trouble hegemonic scales of thinking. Ultimately, through this paper, we aim to initiate a conversation around the urgency of developing such pedagogies that have critical imagination at their core and which bring what Morales-Doyle (2024) calls *critical science questions to social justice issues*.

2.1 | The Construct of Agency: Traditions and Imagining Anew

Agency has been a broad and contested term that has been related to several concepts such as motivation, self-invention, willpower, purposiveness, intentionality, freedom, hegemony, liberty, power, resistance, and creativity, (e.g., Eteläpelto et al. 2013; Stetsenko 2019). It has been conceptualized across different traditions of inquiry, including psychology (e.g., Bandura 2001), sociology (e.g., Archer 2000), and critical education studies (e.g., Giroux 1983).

Either as a capacity (Bandura 2001; Biesta and Tedder 2007) or as a power within humans (Archer 2000; Giroux 1983), agency has to do with our ability to make change within the world. It is through our agency that we have the possibility of imagining the world anew and acting upon it. As such, exploring agency and grasping it empirically has been part of our interest as a social justice issue to be able to find what limits it, what could be its catalysers (Torres-Olave 2022), and how could be facilitated *pedagogically* in teacher education.

Biesta and Tedder's (2007) definition of agency accounts for how learning is manifested in how individuals "critically shape their responses to problematic situations" (2007, p.138). In their conceptualization, they argue that agency is the "capacity to shape our responsiveness to the situations we encounter in our lives" (2007, p.146) rather than an individual attribute. They highlight how we make decisions based on our previous experiences as the *iterative dimension* of agency with a *projective* one to inform our learning for future actions. Similarly, other authors point to the capacity

we have to stand back (Davies 2005) or to push back (Buchanan 2015) in certain situations or events and that this can also take the form of resistance (Sannino 2010). Across different traditions, as stated by Emirbayer and Mische (1998), agency has been treated with different analytical dimensions, which can be better understood by three constitutive elements: *iteration* (how past experiences inform today's decisions), *projectivity* (its projection towards futures), and *practical evaluation* (what concrete practices and decisions we engaged with).

However, from a critical and transformative view of agency, Stetsenko (2019) argued that these views, despite being "useful" to study agency empirically, tend to result in a reductionist view of the human experience as based on "responses" to something. As she stated, "people never merely react, nor respond, to what exists but agentively act in co-creating both the world and themselves beyond "the givenness" of the present" (Stetsenko 2019, p.2). Similarly, and opposing individualistic notions of agency (such as those that are purely psychological, e.g., Bandura (2001), with a focus on self-efficacy), Archer (2003) stated that by placing agency solely within the individual, the role that structures play is not fully considered. Thus, from a critical positioning, considering agency as solely the ability of an individual to make a change, or the opposite, as only the ability of collectives, or as only people reacting to structural issues are each reductionist and therefore limited and insufficient. As Morales-Doyle (2018) argued, our struggles and actions do not happen in a vacuum and isolation. As such, dialectically, our actions, and therefore, our agency serve transformative or reproductive purposes. Such a vacuum is not only spatial; it also has temporality, because our struggles do not come only from the present (Bang and Marin 2015). This calls for approaches to agency that consider iterative and projective dimensions beyond only *our* past experiences or *our* envisioning of the future, beyond *the self* and, as a consequence, beyond what Stetsenko (2020) highlights as essential: beyond the givenness of the present. The past needs to be brought to the present more explicitly, and any justice-oriented work cannot be reduced to the present of the justice-oriented agent. Knowing the historical aspects of present justice issues is key to transformative agency since it can raise awareness of our hegemonic worldviews, our ways of telling the history and whose voices are heard and whose are not in those narratives (Morales-Doyle 2024; Moura 2021).

Building on these theoretical underpinnings, we argue for a conceptualization of agency as a process through which we make ourselves while we also make the world, in dialectical dynamics with structures, with temporal and relational dimensions. From a critical position, we are agentically transforming the inequalities we recognize in society by acting and imagining anew. Such imagining needs to consider past wrongs in the name of science (and the interplay between science and larger projects of society) and build its reparations while thinking scientifically about the present and designing futures for collective joy and flourishing. Hence, a conceptualization of transformative agency needs to move "away from assumptions of passivity, accommodation, quietism and adaptation to the status quo" (Stetsenko 2020, p.32).

Ultimately, a more critical conceptualization of agency needs to recognize its dialectical and temporal dimensions - how we make ourselves through making the world, building on the past to transform and enact the present while imagining just futures. Such a view moves beyond adaptation, grounding agency in individual and collective struggle and transformative possibility.

2.2 | Teacher's Agency in Science Education Research: Towards a More Expansive Understanding

Teacher agency has generally been used to refer to the ways in which teachers can be agents of change (Moore 2008), has been usually conceptualized as a dimension of teacher identity (Avraamidou 2014), referring to how teachers represent themselves through their views, orientations, attitudes, knowledge, and beliefs about science teaching, the ways in which they act within specific contexts, and how they are recognized by others (Avraamidou 2020).

In the context of teacher education, Rivera-Maulucci et al. (2015) argued that there is a need for a more nuanced understanding of how various structures enable or constrain teacher agency to transform practices and enhance student learning. Consequently, more studies have emerged examining links between teacher agency and students' educational opportunities. Much of this study addresses either how teachers respond by supporting or resisting educational and curricular reforms (e.g., Fu and Clarke 2019; Guerrero and Torres-Olave 2021; Ryder et al. 2018; Wallace and Priestley 2017; Wei and Chen 2019) and agency towards justice-oriented education through the teaching of science (e.g., Moore 2008; Rivera-Maulucci et al. 2015; Varelas et al. 2018).

Apart from a few exceptions (e.g., Morales-Doyle et al. 2020; Tolbert et al. 2023b), most of the research on science teachers' agency focuses on professional development contexts or descriptive analyses tied to student learning outcomes (Miller–Rushing and Hufnagel 2022). By explicitly focusing analysis of agency enactment towards the end goal of improving student learning, this body of research risks positioning teachers mainly as technicians with the sole purpose of serving as data points or vessels to students' educational experiences rather than essential actors in thinking about science education, its possibilities and structural challenges (Au 2021; Torres-Olave 2022). Along that line, Guerrero and Torres-Olave's (2021) critical discourse analysis reveals how curriculum materials can hinder teachers' agency by not positioning them as central actors shaping and transforming education through their personal and collective aims. Research in science teacher education risk falls into the same if other dimensions of agency are not explored. Similarly, Biesta (2015) argues that educational research generally has a tendency to what he calls the *learnification of education*, instead of focusing on questions about what, why, and how we teach.

In that vein, studies in science education literature, have a tendency to explore the practical and/or relational dimension of agency and few studies examine its projective or temporal dimension associated with the whys, hows, and whats of science education. One such exception is Olitsky (2021) work to find out how teachers' "internal conversations" (Archer 2000) in the context of national reform in underserved schools may help them increase their sense of commitment through reflexive time. As Olitsky (2021) reflects, having moments for internal conversations to think about their practices and school realities while also a mentor to talk about their decisions may be helpful with teacher retention because they see there is a support system understanding that pedagogical decisions need time and space. In that way, even though not directly, Olitsky (2021) work expands relationality also to the projective dimension of agency and the need to problematising the time scales we think education with.

Exploring projective dimensions of teachers' agency may help to reveal their visions, hopes, and challenges that extend beyond practical teaching experiences to broader educational issues. This includes understanding what constrains their agency as well as how they make sense of their roles to find possibilities for expanding their agency (Torres-Olave 2022) or what Quiroz-Martinez and Rushton (2024) call "pockets of possibility". In that way, agency provides a valuable lens for examining the complexities of becoming a science teacher, particularly concerning political, structural, societal, and institutional factors (Williams and Tolbert 2021). As such, research on teachers' agency, when rooted in goals related to social justice, can explore these socio-political realities. This perspective captures how teachers seek spaces of agency in broader terms, considering not only their immediate classroom work but also the potential impact on and of the teaching profession and science education's role in advancing justice.

As argued by Tolbert et al. (2023b), there is usually a disjuncture for preservice teachers between the world of the university and school, which requires science teachers to develop structural awareness of the different challenges they may encounter across schools in early stages of initial teacher education. Different challenges that have been well documented by critical researchers in science education, such as structural racism and heteronormativity reproduced in science textbooks (e.g., Kim 2021; Lodge and Reiss 2021), exploitative notions of scientific innovation that justify the displacement of communities (e.g., Tarvainen 2022), the over-obsession with science for individual achievements (e.g. Hennessy et al. 2023), and the presence of fossil-fuel industries developing science curriculum (e.g., Tannock 2020), as some examples. Those realities can clash with teachers' values and feel their sense of agency diminished when facing them, however talking about them while exploring spaces of possibility can help with finding opportunities for agency as well as to understand the scope of their work (Torres-Olave and Dillon 2022; Williams and Tolbert 2021).

However, when such structural awareness receives limited attention, it can cause what Tolbert and colleagues (2023b) call "praxis shock" by not cultivating a sense of agency that incorporates other scales of thinking and engagement beyond students' learning outcomes. A sense of agency that needs to incorporate reflecting on the need of others to face those challenges, the possibilities to problematize the very essence of science and society relations and make that praxis shock a limit

situation to enact our agency rather than to paralyze us. Tolbert and colleagues (2023b) highlight the need for engagement with other educational actors to think science education and its challenges, which implies the cultivation of relationality as a practice that is part of teachers' agency entangled with a projective dimension. Elsewhere (Torres-Olave and Dillon 2022), we reflect on how these relational practices are essential in science teacher education to understand others they will be working with, the nature of schools, and the environments in which students learn. Besides, developing a sense of relationality can also illuminate ways for interdisciplinary work within schools as well as collaboration with other actors beyond institutions that are crucial to think science education.

Bang and Marin (2015) provide an example of this relationality. In the context of out-of-school science activities with families, they facilitated what they call *moments of talk*. In these moments of talk, students and their families encounter nonhuman actors like trees and deer to explore interlinked stories with the land they co-inhabit while learning science. Exploring these possibilities of the nonhuman world, teachers could reflect on the multiple other actors that are present (and absent) in science education. All those actors bring with them knowledges, questionings, and challenges that teachers need to navigate. As Tolbert et al. (2023b) argue, teachers would benefit from learning to create alliances with others who are not just teachers but also policymakers, families, local communities, nonhuman actors, and scientists. These opportunities can be brought up to teacher education.

Bang and Marin's (2015) example also brings another layer of agency. They argue that science education shapes nature-culture relations and time dynamics, which science teachers may reproduce (or contest). They mention that "science education is a key site in which nature-culture relations are defined, enacted, brought to life, expanded, narrowed, and legislated" (Bang and Marin 2015, p.531). These hierarchical dynamics connect to time-space relations serving problematic notions of progress that have erased marginalized groups to dominate the land in the name of rapid scientific progress (Tarvainen 2022). Those are realities teachers also need to face because they may be their own realities and because they maintain harmful discourses of science.

Hegemonic time dynamics are also present in educational institutions when we want to see students learning progress (Saul 2020) or schools' cultures change in small and standardized frames of delimited time (Galioto and Moyano Davila 2023), usually for what is understood as default identities, i.e. ways of being a science person (Kayumova and Dou 2022). In that line, Kayumova and Dou (2022) reflect on how science education strongly focuses on standardized outcomes that do not account for the plural ways teachers and students *are* and *do* science (Hennessy et al. 2023), which are also delimited by time dynamics. Standardizations that are also reproduced in science teacher education.

Any change takes time (Tolbert et al. 2023b). A time that is not unique nor singular (Kayumova and Dou 2022), and preservice teachers (and teachers in general) would benefit from learning about how to think outside of dominant time scales if seeking

the transformation of oppressive structures (Torres-Olave 2024). Alternative temporalities need to be considered, which relates directly to Bang and Marin's (2015) attempts to surface relationality and temporality as intertwined rather than as separate dimensions of transformative agency. Such a way of thinking agency in more expansive ways extends to multiple identities and nonhuman actors. An example of that can also be seen in Bonelli and Dorador's (2021) study on micro disaster in northern Chile. They reflect on how linear notions of time linked to science and progress have resulted in exploiting salt-pans to extract lithium for green mobility. Such extraction has caused not only the displacement of communities but also the destruction of environments for nonhuman actors in the name of scientific progress. In their work, they reflect on how we should expand our imagination with planet-centered ways of feeling, thinking, and doing science. In that way, Bonelli and Dorador (2021) mobilize a scientific way of imagining that considers other relations and other temporal rhythms that can inform how we understand transformative agency in the context of science teacher education.

Most of these absences in studying science teacher agency can have their root in a lack of conceptual operationalisation of *forms* of agency and a need for more attention to the politics of initial teacher education and its pedagogies. As Arnold and Clarke (2014) concluded over a decade ago, the construct of teacher agency is under-theorized in science teacher education, a similar finding made in the recent review by Miller-Rushing and Hufnagel (2022). A lack of operationalisation of teachers' agency misses the opportunity to explore and realize what any notion of agency means for science teacher education (Kitchen and Taylor 2020) and to explore and problematize its essence (Settlage and Williams 2022). In that light, Morales et al. (2020) argue that it is not only the task of teachers but also of teacher educators, and therefore, of initial teacher education as a system, to interrogate the representations of science in society and challenge its oppressive norms for socio-political transformation. Otherwise, the very practices of initial teacher education may hinder preservice teachers' transformative agency. Moreover, without sound theories to inform and interrogate practice, teacher education risks reducing intellectual work to technical skills and missing opportunities to foster structural critiques teachers may encounter, such as the "praxis shock" mentioned by Tolbert and colleagues (2023b). Such lack of theorization can also mean leaving science education *as it is* without contesting inherited concepts and ways of thinking the world that are exploitative (Bang and Marin 2015; Bonelli and Dorador 2021; Tarvainen, 2024) and that keep reproducing the present inequalities of science education mentioned earlier.

Therefore, advancing research and practice on teacher transformative agency requires focused efforts on theoretical development, not just gap-filling. We need more expansive conceptualizations of teacher agency that can shape research programs and pedagogical visions. In particular, notions of transformative agency directed towards dismantling injustices need further exploration in connection with teacher education as a site of power where liberatory pedagogies can and *must* be cultivated (Suárez and Beatty 2022; Torres-Olave 2022) if we are committed to justice-oriented work. This entails conceiving agency as more than just responsive classroom practices, but

rather as achieving commitments, agendas, strategies and visions as educators (Chen and Mensah 2022), transforming systemic inequities while uncovering the limitations of such work and the necessary skills and pedagogies to face such challenges (Morales-Doyle 2018).

In what follows, we synthesize existing knowledge for the purpose of advancing a conceptualization of teacher agency, especially transformative orientations. Towards this end, we bring Freirean pedagogy in dialogue with critical studies in science education as well as educational philosophy to develop a notion of transformative agency. Later, we offer three pedagogical orientations towards its cultivation in teacher education that draw on the arguments made in previous sections.

3 | Transformative Agency: Reading, Imagining, and Writing the World

A few researchers in science education have engaged with the construct of critical or transformative agency. For example, in the context of science teachers' initial education, Morales-Doyle et al. (2020) wanted to learn how preservice teachers develop a socio-political understanding of their future work and the structures they will navigate. By doing so, they describe "structures as social, cultural, physical, symbolic, discourse, and political schemas that define and govern social systems, and agency as the capacity to engage with these schemas and mobilize resources, which are sources of power within domains" (p.2)—proposing a way of capturing this through a Freirean lens. A Freirean lens where agency can be understood as a way of *existing humanly* which involves reading the injustices of the world to act upon them and their contestation (Freire 1970, 1998). For Morales-Doyle et al. (2020), *reading the world* involves identifying, describing, and explaining an issue while acting upon the world; *writing the world* involves power over something and determining *when*, *where*, and *how* to act upon it, a process that is both individual and collective. These categories are rich and account for teachers' work not only as actions but also as ideas and a reflexive process that happens before, during, or after those actions. This also aligns with the reflexivity modes that Archer (2000) proposes for capturing agency, such as *internal conversations* which need a *communicative dimension* with others, as well as with Freire (1970) idea that reading and writing the world are dialectic processes where we make the world while at the same time making ourselves in dialogue with others. In that way, Morales-Doyle et al. (2020) notion goes beyond an understanding of teachers' agency as what they consider more just, but also, how those considerations are reflected in collective spaces such as the context of initial teacher education.

Sannino (2020) proposes another notion of transformative agency from another research agenda. Drawing on cultural, historical activity theory (CHAT), Sannino (2020) offers the need to understand the processes that *trigger* transformative agency. Knowing these processes makes it possible to generate pedagogical instruments to support them. Using the Vygotskyan term of double stimulation, she argues that agency is enacted under two stimulus circumstances. First, we encounter a "problematic situation" (first stimulus) that, when we try to cope with it, triggers a second stimulus "to rely on them [i.e. previous situations] when instances of the problematic situation reoccur" (p.10). In this way, agency is an *iterative* process of learning to cope with these problematic situations and then transforming them while considering temporal dimensions *projected* onto past experiences and present actions.

Together, these notions of transformative agency account for ideas beyond *concrete* action and how to inform such actions, moving beyond the reduction of agency to only practical implications or responses to something, as argued by Stetsenko (2019). However, a dimension has not been further explored, which, as stated earlier, has to do with moving *beyond the self*. By moving beyond the self, we do not rely *only* on *our* past or present experiences of the world we have at hand to inform our practices and envisionings. Moving beyond the self needs to incorporate other scales of thinking that also consider the history of the disciplines we learn with and the current circumstances of the world that we do not necessarily experience directly. We might not have been directly involved with the dropping of the nuclear bomb during World War II, but since then, there have been several regulations on the production and use of nuclear energy for instance. The same goes for pesticides, particular the DDT: banned in the 1970s due to their nocive effects on humans, non-humans, and environments, it still raises debates not only on the DDT itself—which is still banned from most countries—but on the use of similar products whose effects we are unsure about. Similarly, when teachers resist or contest educational policies that affect their profession, they may not see a concrete quick change; however, that does not mean they will stop contesting them.

In Figure 1. (a) there is our interpretation of Morales-Doyle et al. (2020) conceptualization of reading and writing the world. In Figure 1. (b), our way of expanding such vision by adding temporal and relational scales of thinking in two axes, a way to illustrate how to move beyond the self.

Moving beyond the self brings explicit attention to the relational/contextual and temporal/projective dimensions of agency that Tolbert et al. (2023b) and Bang and Marin (2015) bring to life. These dimensions require us to look at others not only as those immediate others in our lives and spaces but further than that. As such, people's first stimuli do not necessarily come from *our* present but from the multiple interconnected matrix of oppressions that delimit forms of life in the past, in other presents, and in the futures we want to build looking at both spaces of struggle and possibility. To these spaces, Freire calls "limit situations" (Freire 1970, p.99) not in the sense of ultimately *limiting* but for making visible *what else* is possible beyond that limit. A limit situation can act as "the frontier between being and being more" (Freire 1970, p.102) which is what a Freirean' perspective of transformative agency brings with it: a possibility and language to think and speak differently. Thus, the limit situation depends on our position across different places, and how we include or exclude others in temporal and contextual ways; therefore, it is a process of autonomy "recognizing the self in relation to others" (Tolbert et al. 2023a). In the study conducted by Tolbert et al. (2023b), they portray a particular example of this limit situation when preservice teachers encounter school contexts and a disjuncture
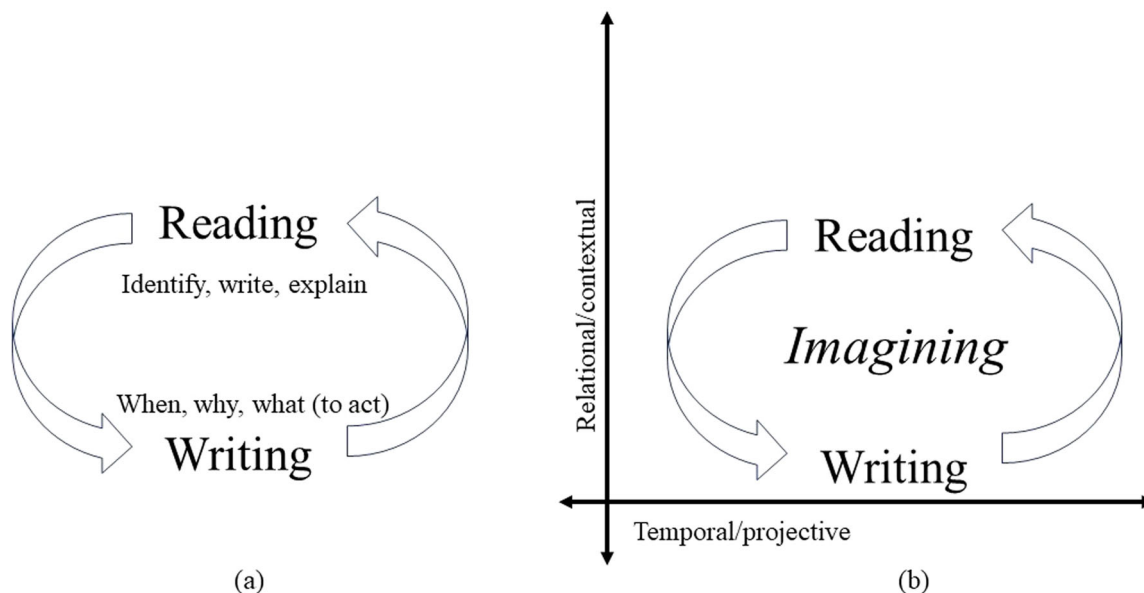
FIGURE 1 | Transformative agency: (a) our understanding of Morales-Doyle et al.'s (2020). concept of transformative agency, and in (b) our concept of transformative agency.

between "the two worlds" of university and school. For Tolbert et al. (2023b), this disjuncture can be a generative space rather than a shock that immobilizes actions and discourages pre-service teachers from teaching. But for that disjuncture to become generative, there needs to be spaces for the cultivation and critical engagement with those disjunctures in initial teacher education. Such engagement will mean bringing concrete problems of limit situations to collective discussion and analysis, and seeing *what else is possible* when encountering such a limit, or in Sannino's language, what previous or known situations may help to cope with the situation.

In Freirean terms, the reinterpretation of Sannino's second stimulus can be expanded not only to previous situations but also to what he calls *untested feasibility*. Such untested feasibility requires our imagination in our search for being more, our "permanent process of searching" (Freire 1998, p.21) *for thinking anew* even about situations we may never encounter. An imagination that involves an authorial process of the world and ourselves (Freire 1972) as designers of thriving worlds (Kayumova and Dou 2022) for collective joy (Weil 1946). As a consequence, in the making of ourselves we are also designing our disciplines, its practices, values, and limits, and therefore, there is possibility for their reenvisioning. Similarly, in those collective discussions of those recognized limit situations, we can also realize what are the root causes of such a limit as well as our *scope* for action in individual, collective, and temporal terms. In that way, we can explore what Tolbert et al. (2022) highlight as necessary: Who or what else do we need to solve this situation? We may also ask: What are the scales of this problem? What can we encounter on the other side of the limit? Who is affected by it? What does the history of our discipline, both science and education, say about this type of change? What practice do we need to leave behind and transform?

In attempting to respond to those questions, we can realize that transformative agency has multiple dimensions that imply a *relational* and *temporal* imagination to grasp the world's complexities and those untested feasibilities we may collectively imagine as the other side of the limit. Such imagination needs to be cultivated *pedagogically* in science teacher education in ways that interrogate science in society and the different scopes teachers have to act on those situations.

3.1 | Critical Imagination as a Core Dimension of Transformative Agency

Cultivating transformative agency through its multiple dimensions offers a more comprehensive and possibility-oriented approach than focusing solely on practical aspects. By embracing this complexity, science educators and researchers can develop a critical imagination that expands and reveals new possibilities, allowing us to collectively create "visions of what should be and might be in our societies" (Greene 1995, p. 5). Such visions contest fixed notions of science education, challenging and transforming its limit situations and redefining what it means to be and do science education.

As Greene (1995) argues, "[i]magining things being otherwise may be a first step toward acting on the belief that they can be changed" (p. 22). Two important concepts for this cultivation of imagination are *untested feasibility* by Paulo Freire and *attention as acts of love* by Simone Weil. The realization of those *visions of what might be*, the *untested feasibilities*, could be facilitated through pedagogical approaches of how to move between *imagining* and *acting* critically.

As mentioned previously, Emirbayer and Mische (1998) propose one of the dimensions of agency is its *temporality*, which Biesta and Tedder (2007) have called the *projective dimension*. This projective dimension can be related to Freire's concept of *untested feasibility*. For Freire, untested feasibilities are based on the assumption that human existence and the struggle to improve it must be guided by the conviction that building worlds where it will be easier to love is possible (Freire 1994).

Love, in Weil's (1946) notion, is an act of paying *attention* to the world's necessities. A love that is *ontological* because it connects *the subject* and *the present world* (Freire 1994; Weil 1946) while envisioning just futures. Enacting love for a better tomorrow involves developing "critical consciousness" (Freire 1970) or what Morales-Doyle et al. (2020) and Tolbert et al. (2022) called "political consciousness" and "structural awareness" respectively. In that way, transformative agency is not only tied to someone else's learning outcome, or finding a space in the middle of a constrained situation that affects us individually. Critical consciousness is directly linked to transformative agency because it involves a process of *knowing* that is individual, collective and *authorial*, involving identity development and worldmaking (Stetsenko 2020). Transformative agency has to do with our historical and ethical being as teachers and as political and intellectual beings, and therefore, it is a process of *creation* and not merely *reactions*. As Freire points out: "to teach, one needs more than knowing...but I must also know in favor of what, in favor of whom, in favor of what dream I am teaching...as a consequence of thinking in favor of whom, in favor of what dream I am teaching, I will have to think against whom, against what dream I am teaching." (Shor and Freire 1987, p.46) As such, the *untested feasibilities* that transformative agency can make possible are closely related to *what*, *how*, and *for what* we learn and teach science. Towards this aim, we need to be *attentive* to the world and its necessities to capture them as reading the world.

This unveiling of thinking in favor of *whom* and *what* we teach is not solely the work of schoolteachers, but also of teacher educators, how they understand their role in shaping future teachers' sense of agency and what pedagogies they engage with at the university (e.g. Rodriguez et al. 2024). It has to do with educators more generally unveiling tacit issues that constrain their opportunities for self-reflection, such as accountability policies and neoliberal values that are embedded in science education (Weinstein et al. 2023) or any other dimension of their work that goes beyond purely teaching methods. This complexity points to the value of distinct pedagogical strategies for developing transformative agency in future teachers. These strategies encompass teachers' broader professional responsibilities, including critically examining historical, local, and global science-society relations, developing personal and collective visions, and navigating the multifaceted challenges of working across diverse educational realities. It also has to do with understanding social justice beyond what happens within the school realm but also the university, the communities we serve and belong to, with other dimensions of teachers' experiences, such as their personal and collective visions as well as struggles. For that to happen, we need *untested feasibilities* which require our *critical imagination* to think science education beyond its strong insulated compartments (Torres-Olave and Dillon 2022)

In Pedagogy of Hope, Freire (1994) explains that the possibility to act otherwise is born mainly from a search to be more, a search to become *more fully human,* and the capacity to problematize our reality to identify spaces for counternarratives, spaces for acting differently, driven by love. Freire argues that we can imagine the *untested feasibility*, by problematising our reality and its limit situations. In his words: "It is precisely a reading of the world that enables its subject or agent to decipher, more and more critically, the limit situation or situations beyond which they find only untested feasibility" (Freire 1994, p. 96). Limit situations for teachers could be, for instance, the enduring hierarchies and monolithic representations in science education (Kayumova and Dou 2022) and the multiple forms of oppression we named before that act delimiting our imagination (Giroux 2021). It may be the case that we are not facing some of those limit situations directly; however, that does not mean we should not care about them. That is precisely what moving *beyond the self* means as an act of love (Tolbert et al. 2023a).

For example, when studying diverse topics of chemistry in a school in Chicago, Morales-Doyle (2017) reports on how students were able to connect those topics with issues of environmental racism and the impact of pollution on communities near a school in the US. Those impacts were not necessarily impacting the daily life of some of those students, but they were encouraged to think beyond themselves and engage with the community. Similarly, Bonelli and Dorador's (2021) transdisciplinary collaboration in the context of microdisasters in northern Chile emphasizes the need to transcend the confines of "experiential human time" (p. 14) when thinking on issues of environmental justice. While some present-day injustices can be traced back to the past, it is equally important to recognize that our current actions will impact future generations, even in geological (deep) time. Besides, some local solutions can have an impact on other geographies in the present if we delimit our thinking only to *our own* reality. This understanding is particularly valuable when encouraging preservice teachers to reflect on the challenges posed by environmental and socioscientific issues for global communities. These challenges include not only the climate emergency, which affects different populations worldwide in varying ways, but also long-standing local problems such as mining. Such problems often benefit countries and populations in the Global North while causing harm to people and environments in Global South contexts, highlighting the complex interplay between local actions and global consequences.

Therefore, we need to advance in cultivating an imagination that is critical, that is relational, and that is temporal. Such imagination cannot be cultivated in isolation, it requires collective imaginaries which we as teacher educators need to bring to initial teacher education to discuss, interrogate, and reflect as Freire invites to: in favor or what, whom, and for what those imaginaries are built. This would mean pedagogically linking a reading (identifying, describing, understanding), imagining (what else is possible), and writing the world (how, when, and where we can act) rather than understanding them as unrelated, discrete categories.

Such skills could cultivate a *critical imagination* in both future teachers and ourselves as teacher educators and researchers. This type of imagination allows us to think about how science challenges or reproduces the injustices of our world (Bonelli and Dorador 2021) and what kind of questions we could ask about justice issues we may encounter (Morales-Doyle 2024). An imagination that expands *which others* we are thinking with or without, and that expands our temporal and spatial scales to think beyond ourselves.

In sum, critically imagining the world can be conceptualized as a core dimension of transformative agency, which is both relational (who or what else do we need?) and temporal (what is the temporal scale of the transformation? what are the implications of this action at a different temporality?). Such a projection, however, cannot only look at the future and cannot be reduced to imaginative practices for the world in which we are. It needs to be grasped *beyond the self* in both relational and temporal ways. It is an imagination to act otherwise and, therefore, is critical in ways that make room for other ways of being and doing, and it is also expansive towards the *untested feasibility*, the *not yet* of our experience.

Thus, we now turn to an exploration of three pedagogical questionings that can help in cultivating critical imagination especially for the context of teacher education but that could also be of use for other actors committed to social justice in broader terms.

4 | Pedagogies to Cultivate Critical Imagination: Attention to the World and Its Necessities

In what follows, we argue about the importance of providing preservice science teachers with opportunities, particularly through pedagogies, to read, imagine, and write new worlds that contest inherited concepts and practices affecting our collective living. These pedagogies are driven by an imagination that emphasizes collective joy as love for the world through our present actions. Such imagination seeks untested feasibilities beyond monolithic and fixed representations of being and doing science education, with attention to the world at its core. In this section, we first explain what we mean by attention relying on Weil's (1946) philosophy. We then present three pedagogical approaches that invite teacher educators to engage in interrogating various limit situations they may encounter in dialogue with preservice teachers, aiming to cultivate critical imagination.

When we understand *reading the world* as one of the dimensions of transformative agency (Morales-Doyle et al. 2020) we need to then open spaces for such a reading that are not only abstract spaces but actual moments of encounter that situate such reading. One particular practice we need to start engaging with is what Weil (1946) has called *attention as an act of love* that nurtures our critical imagination. An attention that is directed towards what the world *is* today, its complexities and necessities. Such readings can teach us about the multiple ways people and nonhuman actors are affected by inequalities. It is an attention to recognize what is there, i.e. reading the world, its presences and also absences.

Weil (1946) argues that attention is a form of love because it does not seek immediate answers but is an attention to *recognize* and acknowledge *the existence* of what we encounter. In such a way, attention has a critical ontological value to navigate multiplicity and plural ways of being and doing (Kayumova and Dou 2022) and the different injustices that affect communities as well as the ways people struggle against them. In our field, those others can be the historically marginalized communities in science education or the very representation of others within curricular texts. Such others can also be other disciplines with which we do not tend to dialogue. It is inevitable to think of "STEM" programs, which emphasizes and push us to think of possible dialogues with *certain* disciplines instead of others. Even with fixes like its integration with arts, becoming STEAM, a pedagogy of attention here can help in thinking of hidden political agendas behind this and other jargon (Weinstein et al. 2016) that delimit who is the other we are recognizing and dialoguing with. A practice of attention can allow us to make possibilities visible through interrogations to such realities and expand our opportunities for actions rather than delimiting them.

In what follows, we propose three pedagogical approaches for such interrogations: a) facilitating practices that move beyond the self to recognize multiple human and nonhuman others; b) adopting a planet-centred orientation to education transcending human-centered approaches; and, c) troubling dominant spatial and temporal scales of thinking.

4.1 | Attention Beyond the Self: Recognizing Multiple Human and Nonhuman Others

In this section, we elaborate on the value of facilitating practices that move beyond the self to recognize multiple human and nonhuman others. Such a*ttention practices* involve transcending not only the individual self but also institutional and disciplinary boundaries, encouraging us to engage with diverse actors and disciplines in reimagining the world anew.

To mobilize this kind of attention, pedagogical approaches should allow us to ask: How do we consider others? What part do those others take in our decisions? Which others are absent in the spaces we have been paying attention to? How may those others help us to cope with the realities we encounter or advance justice oriented science education? How might including those voices reshape our understanding of the problem and imaginative possibilities for addressing it?

Here we suggest to think of the other not just in terms of human but also nonhuman entities, disciplines, institutions expanding the realm of science education moving towards untested possibilities in those collective imaginaries. With such imaginary, we could ask: As we encounter various actors (human and nonhuman) affected by specific scientific or environmental issues, what alternative futures can we envision that prioritize collective joy and justice? What is constraining such imagining? What stepping-stones would be needed to make those futures a reality?

An example of this practice is found in Bang and Marin's (2015) work through their *moments of talk* where students encounter the world in out of school family walks, and starting from that, they speak science education through the relationships across actors. Another example of such attention is what Geduld et al. (2020) called "transect walks" where preservice teachers in South Africa engage in walks around the schools they will serve so they can understand the conditions in which learning is

happening. Through those walks and using a community participatory action research approach, preservice teachers walk around their communities in the company of a local to explore the socioeconomic characteristics of the school by "observing, asking, listening, looking, and producing educational responses that could assist responses to educational realities (p.16). It is through such practices that Geduld and colleagues are able to create "networks of solidarity" (p.20) between preservice teachers and locals while at the same time open opportunities to reflect on the many contradictions between curriculum, pedagogy, and the school context, potentially addressing rather than avoiding the "praxis shock" (Tolbert et al. 2023b).

Such pedagogical approaches consider peoples, selves, and nonhuman existence in different ways. As an illustration (we will come back to it in following sections), we can consider this example: when going for a walk outside a classroom with a group on a sidewalk, one can consider us, humans, walking in an environment and thinking about pedagogical possibilities in this "scenario" we are reading. We can walk and think about how that place is full of presences and connections and take it as "an opportune moment to visibilize the invisible and learn from them, to be affected by them" (Bonelli and Dorador 2021, p.25), contesting the limits of our imagination with what we cannot see, with what it is *not us*. When thinking of possibilities for prospective teachers to design lessons and activities for their students using this environment to reflect upon a socioscientific issue, how do we engage this projected *other* in our activities? If those others were allowed to talk, what would they say? When projecting and educating decision-making around justice issues involving science, how would it be to imagine those who are absent or who generally are invisible/invisibilized and not considered in those exercises? This movement poses challenges to what is generally done in mapping out controversial themes and spaces, since often our attention is not sufficiently cultivated to make those absences (being them humans or other-than-humans) present in our decision-making and in our affective projections. In this way, we are expanding a reading of the world to make visible those invisible actors as well as imagining the *what is not there* and *what is not us*.

In this way, creating habits of attention will help us to develop sensitivity to the multiplicity of life forms and processes that are at play in the world, including those ways of life that at times seem as invisible. This attention helps to move agency beyond the self because it suspends the *I* and focuses on the *other* in such practices - we would be "mapping" our world asking first for the *other* (including the absent *other*), blurring our notion of immediate experience and *us* as a starting point. As Weil (1956) states, such decentering the self, can allow us to advance with the beauty of reality and its potential to reimagine it towards justice horizons.

4.2 | Attention Beyond Humans and the Confines of Science: Towards a Planet-Centered Science Education

In this practice of attention, we are also shifting the focus and the center of education. Rather than being either teacher or student-centered, we move towards a planet-centered

orientation. In that way, we may start our learning experiences through world problems and realizing our agentic space in that problem. Considering problems we encounter in science education such as climate change, teachers' work conditions, the oppressive use of science and technology to justify the displacement of communities, or reproductive rights, we may ask: What is the scale of the problem, and how does it challenge our imagination to envision solutions that transcend local boundaries? What are the limits of a purely scientific imagination in fully grasping the complexity of this problem, and what other ways of knowing might we need to engage with? How can we imagine new forms of problem-solving that integrate science with other knowledge traditions? What conventional disciplinary norms do we need to challenge?

The complex problems threatening our world today are multi-causal, value-laden, and entangled, rarely solvable by a single discipline or social actor (Metzger and Curren 2017), and therefore, starting with the world rather than with the discipline may have expansive opportunities. While the creation of distinct disciplines has been useful historically, it is insufficient for the challenges we now face. We need new approaches and imaginaries that do not dismiss alternatives for not being "scientific enough" by for example asking, can we imagine ways of integrating diverse rationalities in our problem-solving, even if they challenge the boundaries of what counts as science? Note that we are not suggesting just that problems have to be approached interdisciplinary (considering diverse scientific disciplines), which is already clear from a long call for interdisciplinarity in science education. We argue that some of those problems invite an engagement with other rationalities and routes that are available outside the scientific edifice, such as nonconventional (for Western standards) philosophies and other knowledges that operate in the shadowed areas between the scientific and nonscientific moving beyond singular knowledge systems. For example, elsewhere we have explored how park rangers and other than human actors such as a glacier, can also act as "public science educators" bringing other sensibilities to how we relate with the other than human world (Torres-Olave & Guerrero 2025). Similarly, in Bonelli and Dorador's example (2021) they bring microorganisms' sensibilities and temporalities to decentered humans and bring alone planetary consciousness. As explored by Stengers (2018), engaging with knowledges outside the scientific edifice means bringing back questions that were once set aside for science to "function" as a discipline. Moura et al. (2023) suggest evaluating alternative solutions based on their consequences for collective realities, as determined by the collectives involved. The key is to choose alternatives that sustain collective life on Earth. Asking "a problem for whom?" pushes us to consider non-human actors in our problem formulations and imagined futures (Bang and Marin 2015). How can we cultivate an imagination that transcends human-centric perspectives and envisions just, sustainable futures for all beings? How might we need to transform our very understanding of "problems" and "solutions" to imagine radically different possibilities?

By interrogating our possibilities to work towards justice, we can bring scientific questioning to justice problems (Morales-Doyle 2023) while recognizing the limits of science and of our disciplinary selves, bringing along other ways of thinking,

expanding our sense of agency, and those untested feasibilities we may encounter. At those limits, there is potential for cross-disciplinary and extra-disciplinary dialogues. We can invite preservice teachers to explore how other disciplines and rationalities contribute to addressing an issue. This cultivates relational practices across knowledge communities, as seen in the "transect walks" example where local actors were part of teacher education. A planet-centered education can help future science teachers navigate the different ways they can work with colleagues in problem-posing education, as well as with local communities and actors relevant to such problems. Teacher education, then, becomes a space where they learn how to engage with such diverse others, driven by collective problems, and develop skills to identify these problems. Learning to identify problems that require thinking about science in favor of whom, with and without whom, as Freire asked, equips preservice teachers to read the world critically. From there, they can imagine and write new worlds, enacting the multiple dimensions of transformative agency.

4.3 | Attention Beyond the *Here* and *Now*: Troubling Scales of Thinking

The third dimension of attention practices as part of critical imagination involves considering other scales of thinking. Science and societal injustices are not sudden phenomena but products of historical relationships that must be critically examined to overcome oppressive practices and systems. We are now producing ways of relating that will potentially affect future entities, and in that way we need to think beyond the *here and now* not only in a scale we may be familiar with as Bonelli and Dorador's (2021) example with the *salares* shows.

Engaging with history when teaching science is crucial. Certainly, this is not a new conclusion in science education - many researchers have already explored this question decades ago (e.g., Hodson and Dennick 1994; Milne 2011; Klopfer and Aikenhead 2022). Recent work in the History of Science has called attention to the erasure of social actors who played pivotal roles in science (Ideland 2018; Moura 2021) and the unacknowledged contributions of colonized peoples and communities (Morales-Doyle 2024; Moura et al. 2023). For instance, going back to the sidewalk example, we can think, in places that were colonized in the past, about the existences that ceased or were terminated to give room to the project of Modernity (cf. Dussel 1995), that justify displacements and extractivist logics. We can think of where the "resources" to build that particular path made of concrete we are walking on came from, and what the place from where it came looks like now, while we enjoy our Modern lifestyles.

Hence, critical imagination is needed to ask: Whose histories have been erased? Whose voices are heard or silenced? What histories and stories of science are happening today that we may not be paying attention to? It takes a certain degree of (critical) imagination to fill in the gaps of history. We are not suggesting, though, that gap-filling in history is a product of imagination alone rather than serious work by professional historians. Our argument here is that it takes imagination, as exemplified by the generative questions we suggested, to realize the existence of certain gaps in hegemonic histories, and make educative use of that in science education.

We understand that the past is not confined to the lenses of the History of Science. Some authors both in history (Nyhart 2016) and in science education (Moura et al. 2023) have described how the scope of the History of Science as a discipline expanded in recent years through the engagement with new historiographical currents embedding wider understandings of scientific practices—i.e. what counts as/matter for science. However, when exploring the past with the aim of unveiling its injustices, it might be the case that one ends up exploring more even than the expanded history of science we just mentioned. For example, Bernardo et al. (2017), when digging into the history of mining in a Brazilian state to teach chemistry in a high school, ended up exploring the history of labor relations, history of slavery, and other aspects of the history of that place. We contend, then, that more than exploring the history of science, one invested in unveiling injustices in the past might engage with science and history (writ large) and particularly, the history of the teaching profession, its struggles, and historical conquers, to show the importance of what may look a small act.

Attention practices of critical imagination are also crucial for envisioning futures while attending to the present. By reading the world and critically appraising the past, we can imagine possible and desirable futures and the necessary stepping-stones to reach them. This involves imagining how different futures can coexist without exploitation or hierarchy. Freire (1998) argued that our dreams are not the only valid ones; untested feasibilities represent multiple ways of being and doing. Our task is to imagine ways to disrupt monolithic approaches to justice-oriented science pedagogies, recognizing that inequalities manifest in complex and varied ways.

The example of where the resources to build a concrete sidewalk came from and what the conditions are in that place right now can also bring up the spatial dimension of attention. This line of thinking acknowledges that since colonization we live in an interconnected world where resources generally flow in one direction, favoring a very select group of countries in the global North, and damaging environments and life conditions in the remaining areas of the world. This is part of the task that involves reading the world(s) but also takes imagination to be able to see beyond our own horizons and realities, as we learned to do. Also, understanding the global South, not only geographically, but constituted by marginalized communities even in the global North, or social groups that are disfavored in the hierarchies and binaries created (or emphasized) by modernity: men-women, black-white, western-othered among others. In this way, the spatial relations are to be understood not only at local and global scales, but also *across local* scales. It entails asking: where are the groups involved in the chain of relationships implied by this situation/object I am analyzing now? Who are those people, and where are they located? This might even help in thinking possible actions arising from the realization of those relationships. For example, when Tolbert et al. (2023b) reflect on the praxis shock, they suggest a way to deal with this is through alliances with other actors.

Preservice teachers would benefit by knowing what alliances they have at hand, what alliances they would like to work towards and what are the bigger alliances at macro levels they may need for structural challenges. In that way, they can realize the scope of action of those alliances is diverse as the identities and actors engaged in it. In such alliances, they may also ask: how is this problem or "shock" situation connected to larger projects of domination? How may a potential solution affect others in terms of geography and temporally? By imagining such change on larger scales, we may understand that our time scales need to be decentralized from ourselves (i.e., the need to witness the final change) to learn to navigate "shock crises" and moving out of hegemonic temporal scales. Together, these pedagogies also show that if we look beyond the self, it may not be necessary to position *our own selves* in such a future we are building, and therefore, temporal limits can be released to envision justice. These pedagogical questions may help future science teachers to realize that small actions do have meaning on larger scales.

5 | Final Thoughts

We started this paper by asking how transformative agency can be conceptualized and cultivated through critical imagination in science teacher education. We argued that science education often acts as a disimagination machine, constraining possibilities for envisioning and enacting transformative change. We propose critical imagination as a core component of transformative agency, and therefore, transformative agency encompasses reading the world to identify injustices, imagining untested possibilities, and writing new worlds to transform oppressive structures.

Our theoretical contributions lie in advancing a more expansive understanding of transformative agency that moves beyond individual actions or linking teachers' agency only to student learning. We emphasize agency relational and temporal dimensions, highlighting the need to consider the historical roots of present injustices, the far-reaching consequences and possibilities of our actions, and the multiple human and non-human actors implicated in struggles for the multiple forms of justice that act at different temporal and spatial scales. This conceptualization challenges the dominant focus on teachers as technicians, repositioning them as crucial actors in shaping and transforming science education, its whats, hows, and whys. Towards this task, the role of teacher educators is crucial in engaging with dialogues that invite preservice teachers to think and do science education, centering justice for designing plural and just worlds.

Pedagogically, we propose three interconnected approaches for cultivating critical imagination in science teacher education that rely on Simone Weil's notion of attention as acts of love: moving beyond the self, a planet-centered orientation to education, and troubling spatial and temporal scales of thinking. Through a series of pedagogical questions, we invite teacher educators to cultivate habits of relational and temporal imagination, enabling teachers to grasp the world's necessities to envision just futures. By engaging with limit situations, exploring untested feasibilities, and considering the perspectives of diverse actors while decentering the self, preservice teachers can learn to read the world critically, imagine alternative possibilities, understand their agentic spaces, and enact transformative change even at cases where they cannot see themselves experiencing that change. By troubling scales of thinking, teachers can also understand that, for as little as it may look, no justice work is in vain, and it contributes to dismantling larger systems of oppression that may take time and may not be that visible.

As Freire (1970) reminds us, to exist, humanly, is to name the world, to change it. Transformative agency and its core component, critical imagination, are essential for this naming and renaming for reading and writing the world anew. This entails conceiving agency as more than responsive classroom practices but rather as achieving justice-oriented commitments, agendas, and visions. It requires creating spaces for preservice teachers to contest inherited concepts, challenge disimagination machines, constantly seek collective joy, and thrive in a world of pain.

Advancing pedagogies for a critical imagination may offer spaces for educators to enact their transformative agency and build democratic spaces, caring ways of living with others, advancing in solidarity beyond our humanity and geographies. Those acts and pedagogies are happening today; their mapping and essential characteristics in relations and temporality can illuminate new acts that answer how justice-oriented science education could be enacted across contexts. Following Simone Weil's words, "the spirit of justice is nothing other than the supreme and perfect flower of the madness of love" (1956, p.9); we will continue seeking liberatory pedagogies needed to cultivate our critical imagination by enacting attentive love.

Data Availability Statement

The authors have nothing to report.

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