Critical Pedagogies in STEM Education: Ideas and experiences from Brazil and the UK

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Critical Pedagogies in STEM Education:
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<table>
<thead>
<tr>
<th>Page</th>
<th>Title</th>
<th>Authors</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>Bridging Brazil and the United Kingdom for Sustainable Education</td>
<td>ALESSANDRA MOURA</td>
</tr>
<tr>
<td>6</td>
<td>Presentation</td>
<td>ARTHUR GALAMBA, HAIRA GANDOLFI</td>
</tr>
<tr>
<td>8</td>
<td>What is Critical Pedagogy?</td>
<td>ARTHUR GALAMBA, HAIRA GANDOLFI</td>
</tr>
<tr>
<td>16</td>
<td>The Convergence of Science Education and Decolonial Thinking</td>
<td>BRUNO ANDRADE PINTO MONTEIRO</td>
</tr>
<tr>
<td>34</td>
<td>Paulo Freire and Decolonial perspectives: encounters in science education</td>
<td>HAIRA GANDOLFI</td>
</tr>
<tr>
<td>54</td>
<td>Acting in the “cracks” of curricular normativity through the History of Science in Science Education</td>
<td>CRISTIANO B. MOURA</td>
</tr>
<tr>
<td>74</td>
<td>Trajectories of black women scientists in the exact sciences: a study on representativeness in scientific contexts from Investiga Menina!</td>
<td>ANNA M. CANAVARRO BENITE, CLARISSA ALVES CARNEIRO BERNARDES, TRAJECTO, GUSTAVO AUGUSTO ASSIS FAUSTINO, REGINA NOBRE VARGAS, MORGANA ABRANCHES BASTOS, THATIANNY ALVES DE LIMA SILVA</td>
</tr>
<tr>
<td>92</td>
<td>The Equity Compass and the Science Capital Teaching Approach: Teacher tools to support critical pedagogy</td>
<td>SPELA GODEC, MEGHNA NAG CHOWDHURI</td>
</tr>
<tr>
<td>112</td>
<td>How do 16-17 year old school students engage with scientific research?</td>
<td>RALPH LEVINSON, STEPHEN PRICE, PAUL DAVIES, HAIRA GANDOLFI, KOSTAS KORFIATIS, OLGA MARKOULIDES, RUTH WHEELDON</td>
</tr>
<tr>
<td>128</td>
<td>Socio-scientific issues in science education – contributions of a community of practices for the development of critical approaches to emergent socioenvironmental themes</td>
<td>EDGAR MIRANDA, RITA VILANOVA, VANEssa DE SOUZA ROSADO DRAGO</td>
</tr>
<tr>
<td>150</td>
<td>Building educational resources for the curricular approach to socio-scientific issues: an experience of collaboration between university and basic education school</td>
<td>ISABEL MARTINS, MARCOS CORREA, MARCELO BORGES ROCHA, BRUNA KARL, MARCIA GARCIA, YASMIN LANATTE</td>
</tr>
</tbody>
</table>
The British Council works all over the world collaborating with international projects that promote more quality and equity in basic education. In addition to contributing to sustainable human development, our work is intended to contribute to peace and prosperity among people. This publication is in line with our aspirations.

During the years 2020 and 2021, teachers around the world migrated their continuing education activities to the online environment, given the limitations to face-to-face activities imposed by the COVID-19 pandemic. Educators around the world needed to review their practices not only to create remote and hybrid teaching models, but also to review the prioritization of the skills needed for their students to navigate the new times.

Scientific literacy and critical thinking were some of the skills that gained greater importance for students to understand the information related to the global health crisis that was circulating at the time. These skills are necessary for students to complete basic education with a worldview consistent with the reality. They are foundations of education for sustainable human development.

Ways to develop these and other fundamental competences at school are addressed in the publication Critical Pedagogies
in STEM Education created by specialists from Brazil and the United Kingdom. The book is an offshoot of the webinar “Challenges to Implement Critical Pedagogies in STEM Education”, held in June 2021, as part of the activities of the STEM Education Hub, an initiative of the British Council and King’s College London. It was yet another contribution to the ongoing training of teachers in Brazil in a delicate period for basic education in the country. Many more are published at www.stemeducationhub.co.uk.

Throughout the book chapters, despite each country and each educational system having its peculiarity, all co-authors find value in the differences and similarities of their approaches. This work is the result of connections and building trust between experts who are, above all, educators, and also people willing to learn continuously.

Paulo Freire has said that there is no neutral education. Every educational action entail educators’ choices. Therefore, we hope that the reading of the chapters in this book will inspire the development of a science and technology education that is stimulating, engaging and sustainable. As well as the peaceful and collaborative worldview that is championed by our organization.
This new publication of the STEM Education Hub is yet another collaborative activity between researchers from Brazil and the UK in Science, Technology, Engineering and Mathematics (STEM) Education. The STEM Education Hub is a project run in collaboration between the British Council and King's College London. And in the collaborative and multicultural spirit of the STEM Education Hub, we are delighted that this book was co-edited by two Brazilian STEM educators from King’s College London and the University of Cambridge.

The focus of this book on critical pedagogy is timely. The international community of STEM educators has been making substantial theoretical and practical development on inclusive pedagogies. Gender inclusion, decolonisation and racism in STEM teaching and professional settings are some of the concerns that researchers in this book have. As a community of STEM educators, we endeavour to teach STEM subjects without losing sight of building a fairer and more just world. Understanding what the critical issues in STEM education are
is only the first step for the necessary transformation towards those aims. We must close the gap between research practice, academic debate and classroom practice. And this book aims to contribute to close that gap, hoping that teachers will read, share and discuss it with colleagues and develop ways to implement critical pedagogies in their lessons.

We are very much grateful to the British Council for the strategic, administrative and financial support to publish this book. And immensely grateful to the authors of the chapters: Bruno Monteiro, Haira Gandolfi, Cristiano Moura, Anna Benite, Clarissa Trajecto, Gustavo Faustino, Regina Vargas, Morgana Bastos, Thatianny Silva, Spela Godec, Meghna Chowdhuri, Ralph Levinson, Stephen Price, Paul Davies, Kostas Korfiatis, Olga Makoulides, Ruth Wheeldon, Edgar Miranda, Rita Vilanova, Vanessa Drago, Isabel Martins, Marcos Correa, Marcelo Rocha, Bruna Karl, Marcia Garcia and Yasmin Lanatte.

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WHAT IS CRITICAL PEDAGOGY?

ARTHUR GALAMBA
HAIRA GANDOLFI

The aim of this book is to support school science teachers in understanding what critical pedagogy is and to give insights into how it can be implemented, in diverse ways, in their science lessons. It presents a collection of international studies by Brazil and UK-based science educators, with a range of perspectives on the links between critical pedagogies and Science Education. We hope it will inspire and motivate teachers to reflect on and then transform the way they teach science. The majority of the studies and proposals found in this book were first presented and discussed in a seminar1 organised by the STEM Education Hub – a project created through a partnership between the British Council and King’s College London/UK, which aims to bring together the Science, Technology, Engineering and Maths (STEM) education communities from Brazil and the UK. The authors of the chapters in this book are educators from those two countries who have been researching what can be broadly termed as ‘science education for social justice’. Since teachers and students in Brazil and the UK have contrasting socio-economic and political challenges, including diverse socio-historical trajectories, the issues addressed in the studies presented here – and the way the authors engage with them – reflect a fascinating variety of forms in which critical pedagogies can be conceptualised and enacted within this landscape of ‘science education for social justice’.

1. The seminar is available to watch at www.stemeducationhub.co.uk.
The meaning of the term ‘critical pedagogy’ as we use it today stems, to a large extent, from the work of the Brazilian educator Paulo Freire (1970; 1994; 1998; 2005) and several other Freirean scholars, such as Henry Giroux, Peter McLaren, Peter Leonard and Ira Schor. Critical pedagogies, in their diverse contemporary forms, want to make visible issues of knowledge and power, culture, ethnicity, gender, class and sexual orientation within and surrounding educational experiences of students, teachers, families and wider communities. As Peter McLaren (1999) has claimed, alongside many other thinkers such as Michael Apple and Michel Foucault, education can be one of the most important vehicles for social and economic transformations. It is a view defended by Paulo Freire in his work both as an educator and as a scholar of education, and central to the development of his seminal ideas around ‘critical pedagogy’. It is, then, not difficult to understand why Freire was exiled during the rule of a fascist dictatorship in Brazil between the 1960s and 1982, with his thoughts on critical pedagogies still considered subversive today by many: he envisioned critical pedagogy as a way of practicing education for empowerment towards social change and transformation, for challenging unequal realities.

Defining in a few words the meaning of critical pedagogy is a challenging task, as it contains several conceptual and methodological aspects encapsulated together. McLaren (1999) sought to explain it saying:
Critical pedagogy is a way of thinking about, negotiating, and transforming the relationship among classroom teaching, the production of knowledge, the institutional structures of the school, and the social and material relations of the wider community, society, and nation-state (…) [It attempts to] eliminate inequalities on the basis of social class, it has also sparked a wide array of anti-sexist, anti-racist, and anti-homophobic classroom-based curricula and policy initiatives (p. 51).

Among this complexity of ‘critical pedagogy’ ideas, there are a couple of elements that we wish to address in the introduction to this book, which we believe can be useful to teachers who are not very familiar with the area. The first element here has to do with teachers’ comprehension of the aims of schooling and of the structure and content of a particular curriculum. As Freire (1970) has explained, there is no ‘neutral’ education, as education is always ideological and political, frequently serving to maintain the status quo, the privileges and power of the dominant (socioeconomic, cultural, ethnic, etc.) classes. Therefore, the curriculum content, pedagogical methods, school routines and forms of assessments, as we know them, represent just one of many possible ways that they can be set up and used. Great science teachers should take pride in how they teach about photosynthesis, conservation of energy or ionic and covalent bonds, and they also should continue to invest in their subject knowledge and in the quality of their teaching. However, the teaching of scientific concepts, models and laws in isolation is doing little to challenge social injustices faced by our own students and globally. Indeed, it may be just contributing to feed young people and adults devoid of critical thinking and transformational skills into an established, oppressive and unequal society.

Within this scenario, three decades ago, Ira Shor (1992) proposed a broad principle to underpin critical pedagogies that can provide teachers with some guidance about how they can tweak their science lessons to develop students’ critical outlook. He said, “instead of transferring facts and skills from teacher to students, a Freirean class invites students to think critically about subject matter, doctrines, the learning process itself, and their society” (Shor, 1992, p. 24). Therefore, critical teachers, who seek to reduce inequalities and oppression in the
society within which they and their students live, should avoid a reductionist approach to teaching by accepting that a particular school curriculum will determine everything their students should learn (Christensen & Aldridge, 2013). Yet, how can teachers integrate the ideas from critical pedagogies into their day-to-day practice?

This question takes us to another relevant element of critical pedagogy - its methodological aspects. Let us make clear from the outset that there is no single method that can serve as a benchmark for critical pedagogy. Paulo Freire (1994), when engaging with educators from all parts of the world, was very clear that critical pedagogies should not be seen as specific methods, as prescriptive. Instead, they should be seen as a set of educational and ethical positions and diverse associated practices that aim to question the unequal and immutable structures of power in society, structures which constantly impose only certain values and norms on the whole of society. Critical pedagogies question those values and norms because the established structure of power selects some individuals as ‘successful’ and ‘acceptable’, while excluding others from privileged positions.

In his work as an educator, Freire was widely known for his criticism of traditional ‘teaching methods’, such as what he called ‘banking education’, a teaching method that could be seen as equivalent to rote learning. He metaphorically compared the depositing of money in banks to teachers depositing knowledge into students’ minds (Freire, 1970). As Freire explained it, ‘banking education’ does not teach students to question the world, but to accept it as a given, as an immutable social world in which we have our pre-determined place and to which we must accommodate ourselves. Typically, in the heavily teacher-centred teaching approaches that he criticised as part of this banking model of education, the teachers are the only ones who can speak, because they are the only ones who know. The students must remain in silence to learn uncritically the knowledge and skills needed to perform their expected roles in society (for example, to enter a specific job market). Such pedagogical approaches subjugate the students, disregard the realities they belong to, and communicate to them that they must learn to accommodate themselves into the world as it is. Therefore, this kind of
educational practice, with its content, methods of teaching, school routines, and ways of assessment, will subliminally communicate to students the behaviours and values they should conform to and bear with them in their lives.

Critical pedagogies, on the other hand, advocate dialogue between teachers and students. We should note, therefore, that ‘active’ pedagogical approaches – such as pedagogies underpinned by social constructivism, which advocate interactivity between students, through dialogue and hands-on activities – can be found within critical pedagogies. However, such student-centred approaches alone do not make learning critical. To be critical, teaching approaches must find ways to develop students’ understandings that power relationships undergird the social world and that unbalanced power relationships will give rise to oppression and inequalities (Aronowitz, 1992). Furthermore, critical pedagogies differ from traditional pedagogies in that they do not simply seek to expand students’ utilitarian and practical skills, but are mainly concerned with developing students’ conceptual tools to read the social world and to better understand how their realities relate to the social structure (Macrine, 2012). Shor (1992), for instance, asserts that a critical teacher should be a problem-poser and encourage students to raise questions and also question answers.

The collaborative strategies that teachers and students can use to develop critical skills that challenge inequality and social injustices can, then, vary considerably. In part, this is because critical pedagogies are necessarily "situated"; they are shaped by local/regional/national contingencies. As such, they should address the needs and realities of those particular students attending a certain lesson, in order to promote reflection and discussions around solutions to social issues that directly affect their lives (Macrine, 2012). Hence, the pertinent issues will change depending on context, place and time. A few decades ago, Freire asked, “why are there no rubbish heaps in the heart of the rich areas of the city?” (Freire, 1998, p. 36). As societies evolve, questions and priorities change. Today, teachers and students could still be asking the same question Freire asked before or could be posing other questions that link to different kinds of injustices. For example, they might ask, “why science
is mostly done by white male scientists, whilst discriminate females and ethnic minority groups?”, “why neoliberalism is still prevailing if it is enlarging the gap between the well-off and the poor?”, “how has the privatization of education been used to perpetuate inequality?”, “why LGBTQ+ people don’t have the same rights that cisgender, heterosexual people do?”, or “how could we change our habits of consumption to help fighting climate change and environmental disasters?”, amongst several other questions linked to different kinds of injustices.

In bringing these wider ideas and questions to the specific case of science education, with its potential role in challenging injustices, the authors in this book engage with critical questions and reflections that we hope will help the reader to rethink the way we, science educators, teach science. In Chapter 1, Bruno Monteiro provides a brief historical review of seminal works on issues related to racism, colonialism and power in education. He establishes important links between Freire’s work on critical pedagogy, the field of decolonial thinking and practice in education, with specific consideration of how colonial thinking is still pervasive in science education and scientific practice in Brazil. In Chapter 2, Haira Gandolfi expands on Monteiro’s work to outline how Paulo Freire’s work can be read as deeply linked with decolonisation endeavours in science education. She introduces us to a UK-based study involving a secondary science teacher with a focus on the development of critical consciousness and decolonial curricula. In Chapter 3, Cristiano Moura highlights that the History of Science can be used in science lessons to educate about the development of ideas in science. He advocates for a History of Science that discusses the social and political aspects in the production of knowledge and its implications for today’s science education. In Chapter 4, Anna Benite and colleagues point out that science still is dominated by white males and explain how the research project Investiga Menina!, carried out in Brazil, addresses issues of representativity in exact sciences. They argue that educators should invest in the dissemination of the work carried out by Black female scientists as a way of raising awareness and challenging race and gender-based prejudice.

In Chapter 5, Spela Godec and Meghna Nag Chowdhuri introduce us to the concept of ‘science capital’, explaining
how it can provide teachers with a helpful theoretical framework to understand why some students do not feel related to science. They include ideas on what strategies teachers can adopt to achieve more equitable, socially just-informed, teaching practices inspired by Freirean critical pedagogy. In Chapter 6, Ralph Levinson and colleagues present a research study that explores how students from the UK engaged with contemporary research problems, questioning the banking model of education in science. They assert that teachers should create discursive spaces, so that students can use scientific knowledge to open up new ways of explaining the world. One of the interesting findings of this research is that students from ethnic minorities felt very attracted to the openness, speculation and new ways of thinking required by genuine science inquiry. In Chapter 7, Edgar Miranda and colleagues present a study that was conducted within a community of practice composed of teachers, researchers and students, which sought to address social scientific issues in science education. They address the environmental crime and disaster of Brumadinho in Brazil, presenting examples of teaching practices. They also contend that building communities of practice is an effective approach for developing critical pedagogies associated with social scientific issues. In Chapter 8, Isabel Martins and colleagues also focus on socio scientific issues. They present a free and open online environment on which teachers can find explanatory texts and other educational resources such as games, videos and scientific dissemination actions. Aligned with the spirit as the STEM Education Hub, they bridge the work of researchers, teacher trainers and school teachers, seeking to promoting university-school articulations of basic education.

We wish you an enjoyable reading and that the chapters of this book will inspire teachers to transform the way they teach science.
REFERENCES


THE CONVERGENCE OF SCIENCE EDUCATION AND DECOLONIAL THINKING

BRUNO ANDRADE PINTO MONTEIRO
begin this chapter by inviting my interlocutor to reflect on some contributions of colonial thinking in the field of Science Teaching and to get to know examples of Brazilian works that dialogue with constitutive elements of this emerging epistemological movement that has been subsidising new reflection, research and critical pedagogies. To start off with, we've dug up a well-known Nigerian proverb that directly encourages us to reflect on the predominance of the points of view in certain historical narratives, and the interests and positions of power of those subjects or groups that tell them. The proverb in question is an invitation to rethink the possibilities of other possible repertoires, especially those that are forgotten in the weaving of the stories that are accepted as true by society. The wisdom of African folklore imprinted in this beautiful proverb claims the right to a voice and recognition of their cultures. This great metaphor, in the context of the debate on colonality/decoloniality, leads us to thinking of the real lions, groups of human beings who appear as defeated, subaltern, exterminated and catechised in the stories told by their colonisers, or rather, of the human hunters who invaded the territory of Abya Yala and other Southerners around the world, from the 16th century onwards. To broaden this provocation even further, I would like to cite the talk by Nigerian writer Chimamanda Ngozi Adichie at TED-TALKS which went viral on social network and Youtube. In this lecture, the writer draws attention to the issue of the “danger of the single story”. In other words, the existence of historical narratives that are told and that reinforce certain points of view from the social standing of the stories’ winners. The famous writer exemplifies this issue by quoting one of her books entitled: “half a yellow sun”. In this work, Chimamanda tried to portray the history of Nigeria’s civil war which took place at the end of the 1960s, from the point of view of popular characters and the drama they experienced in their daily lives in the aftermath of the war. From the perspective of the characters, issues such as Eurocentrism, colonialism, precariousness, poverty, religious and political conflicts were addressed in the course of the literary plot. 

“Until the lions have their own historians, the history of the hunt will always glorify the hunter.”

Nigerian Proverb
Another very important work that should be widely disseminated, especially in Latin American countries, is Eduardo Galeano’s book “The open veins of Latin America”, since it presents an essential overview of the African diaspora, the colonial invasion, genocide of indigenous populations and how the expansion of the countries that make up Latin America took place under the impact of European and North American imperialism during the colonisation of these territories. In addition, the work discusses and presents how the productive and economic cycles, trade, and political and social relations were founded under the aegis of a perverse idea of discovery. Galeano’s book, censored at various times in history in countries such as Brazil, Uruguay, Chile and Argentina in their authoritarian regimes, makes counterpoint with the official narratives on the theme of the colonisation of the Americas and its ramifications. This “other story” is told by Galeano from a neglected point of view, including in educational literature where the stories told by the “hunters” predominate, as highlighted in the proverb in question and which, in practice, represents the great European and Latin American chroniclers and historians who recorded our history from the perspective of their contractors, who were usually priests, emperors and other political and military leaders.

In the illustrative work of Uruguayan Joaquín Torres García (América del Sur, ilustración del año 1946), an engraving published in the 1940s and widely known in Latin America, we’re able to recover another provocation that invites us to reflect on the historical processes of this territory. The artist presents an inverted map of Latin America, i.e., with the Southern tip of the continent facing upwards and the Northern tip at the bottom, provoking reflection on what we consider to be our North and our South. In the words of the artist:

“I have been saying School of the South because, in reality, our north is the south. There should be no north, for us, except in opposition to our South. So now we turn the map upside down, and then we already have a fair idea of our position, and not how they want it in the rest of the world. The tip of America, as of now, extends itself, points insistently towards the South, our North”. (GARCÍA, J.T.; 1941)
A reinterpretation of Torres García’s engraving was produced in the illustration by researcher and artist Daniel Renaud and can be found in the book organised by Monteiro & Dutra et al (2019), entitled Decolonialities in Science education.

Daniel Renaud, Caminho de Tuya’ī. (Monteiro & Dutra et al, 2019)

Through this image, Daniel Renaud translates the representation of the decolonial turn symbolised by the possibilities of contact between Western and indigenous cultures and quilombolas, among other traditional communities. This representation reveals the intent of promoting reflections that our reference should not only be the north and that our way of seeing the world should therefore be oriented from our south, or in other terms, from our ancestral essence. This understanding goes beyond the concept of a geographical south, i.e. it is aligned with the idea of a “global south”. (Santos and Meneses, 2010), which in fact corresponds to the territory of the oppressed where diverse forms of oppression and the disregard for human life materialise, and can be located anywhere. In other words, they represent the precarious territories present in all countries, including rich countries, where currently thousands of refugees and immigrants are trying to settle in search of a life with dignity. At the same time, the image is a statement that the countries of Latin America have a lot to learn from the history of the original traditional peoples who have occupied the Americas, or Abya Yala, for millennia.

The reflections made in this introduction aim to promote discomfort and to position us on the basis of contributions from decolonial thought in order to think about issues in the context of Science Education. We start from the idea that we are stuck in a Eurocentric and disciplinary model of conducting educational processes. In this context, we promote the teaching of subjects related to the natural sciences inspired by belief systems that were imposed on us explicitly and subjectively throughout our education. The presence of scientific scholar discourse in science textbooks that silences traditional and
popular knowledge, exclusively reiterating the prestige of Western science, is all too frequent. In the field of academic research in education, even with the growing immersion in critical references, we still live, in general terms, within the canon of a hard, exclusionary scientific practice which is not perturbed by the processes of denial of other forms of knowledge construction.

Decolonial studies emerge in the opposite direction of exclusionary perspectives, establishing important problematisations that aim to question the centralisation of the Eurocentric logic of knowledge production, revealing a multiplicity of epistemologies and cultures. A new lens that seeks to see, recognise and value the universe of what Paulo Freire called in his Pedagogy of the Oppressed, "the ragged of the world". From the lines below, we would therefore like to present some information about decolonial thinking, to provoke reflections on the field of Science Education and to present some examples in facing contemporary educational challenges, especially regarding cultural, environmental, ethical and political issues.

**DECOLONIAL THINKING**

In light of this introduction, I will focus my discussions on two very important articles in the context of reflections on decolonial thinking. The aim here is to give an introductory overview that aims to present a little about the origins of decolonial thinking and some concepts that can help to understand the role of science education from another perspective. Luciana Balestrin’s paper published in 2013, entitled *Latin America and the decolonial turn*, presents at the outset, the contribution of the post-colonialist movement, consisting of a set of debates and studies that were established throughout the 20th century and that somehow culminated in the 1980s in a more concentrated debate and precursor of what is understood today as decolonial thought. These post-colonialism studies then brought a reflection on the processes of independence, liberation and emancipation of the societies exploited by imperialism and neo-colonialism, especially in the Asian, African and American continents. The author also points out that from the 1980s onwards, literary and cultural studies became evident in some American and English universities and, in this context, the need to seek an alternative to the historical concept of what we understand as ‘modernity’, classified by Enrique Dussel (2000) as a mythical project, was advocated.
In this context, the term ‘colonial’ emerges and refers to situations of diverse oppression defined by gender, racial and ethnic boundaries, identifying an antagonistic relationship between subjects that configure the social places of colonised and coloniser. Post-colonialism throughout the 20th century was strengthened as a field of study by the influence of several important thinkers and works that configured new theoretical categories. One of these, the “colonial difference”, is discussed by Walter Mignolo (2012) and consists of the idea that in the colonised territories, tension evolved from the fact that the presence of the colonisers (invading peoples) prevented the colonised (subaltern peoples) from being themselves. In other words, it is a social relationship that is not constituted from the mutual recognition of full identities, but from the impossibility for the cultures, customs and traditions of the colonised peoples to express themselves in the emerging social scenario.

Another important fact in Balestrin’s text (2013) refers to the differentiation between the terms that express the processes of colonisation, colonialism and coloniality. According to this author, colonisation refers to the process of invasion of a foreign territory; colonialism refers to the structuring of a political configuration previously established in a metropolis and implemented in a foreign territory; and coloniality is the process that subjectively endures even after the independence of the colonised territories. In other words, even after the socio-political disconnection with the metropolis, there are psychopolitical effects that remain and that are implicit in people’s subjectivities, as if they were an inertia that resists recognising its own potentialities in detriment of the absorption and cultivation of a *modus operandi* that was implanted in the course of the domination process.

In addition to these theoretical and philosophical aspects, the work of Balestrin (2013) highlights the emergence of several study groups that sought to expand and conduct research and reflections that consolidated what we are calling in this paper ‘decolonial thinking’. The Subaltern Studies Group (SSG, 1979); The Latin American Subaltern Studies Group (1993), and The Modernity/Coloniality Group (MC, 1998). A highlight for the group known as MC, is philosopher Walter Mignolo’s protagonism in its constitution
and the consolidation of the arguments that established the need to transcend and decolonise the Western forms of knowledge construction. Walter Mignolo denounced epistemological imperialism prevailing in the human sciences and projected these studies beyond Eurocentric lenses in order to make room for the theoretical and philosophical contributions that Latin American thinkers themselves produced about their conditions of oppression. This movement has become known in the humanities and social sciences as the decolonial turn. The driving force of this group sought to establish a continuous reflection of the Latin American cultural and political reality including subalternised knowledge that had been discarded in the colonisation process. In summary, the decolonial turn proposed by the Modernity/Coloniality group proposed a rupture where several authors, both from the centre and the peripheries of the production of the geopolitics of knowledge, should question the predominance of a Eurocentric interpretation of the world, contained in the theoretical framework of the social sciences (Balestrin, 2013).

In this way, the key concept that can help us think more directly about the problems of the field of Science Education, a field related to the natural and exact sciences and marked by the influences of a universal and logical positivist science, is the concept of **coloniality of power** (Quijano, 2000). This concept unfolds into the **coloniality of being** (Mignolo, 2012; Maldonado Torres, 2007) and the **coloniality of knowledge** (Maldonado Torres, 2007), based on re-significations and contributions from other authors. From these concepts or theoretical categories, it is possible to perceive the effects of coloniality in the colonised territories which are expressed, according to Balestrin (2003), in the patterns of control of economy, authority, nature and natural resources, gender and sexuality, subjectivity and knowledge. In addition to these issues, Quijano (2000) defends race and racism as central concepts to analyse the colonial project in all its aspects. From these categories, it became possible to understand how this process served as a parameter for classification and segregation of people, establishing in invaded territories, lives that were valuable or not and, likewise, valued and discarded knowledge. Another fundamental concept that became the basis of decolonial studies was the concept of **cosmogonic coloniality** (Walsh, 2009). This elaboration by Walsh demonstrated the disconnection between the factors of spirituality and nature
that occurred during the colonisation of the Americas, insofar as the knowledge and representations of nature and spirituality constructed by the traditional and enslaved peoples, were disregarded by the colonial enterprise in light of an ideal of rationality. We can say that the colonially of power established a pattern of power from the racialisation of the world and the creation of a subordinate identity that established dichotomies between civilisation and barbarism, development and underdevelopment, progress and retardation, rational and mystical or holistic, western and non-western, human and non-human, citizen and sub-citizen.

From the work of Ramón Grosfoguel (2016), we observe a set of questions originated by this author, based on the work of Santos and Meneses (2010), which provide us with a series of important aspects to understand the scientific and cultural production of so-called modern societies. Both works, sought to understand and deepen analyses of contemporary epistemic mechanisms and structures that were grounded in the intellectual production of men who were active in five main countries: Germany, France, England, United States and Italy. Among the questions raised by Grosfoguel (2016), we list the following:

“How was it possible that the men of these five countries achieved such epistemic privilege to the point that their knowledge is today considered superior to that of the rest of the world?”

“Why is it that what we know today as social, historical, philosophical, economic or critical theory is based on the socio-historical experience and worldview of men from these five countries?”

“How is it that in the 21st century, with so much epistemic diversity existing in the world, we are anchored in such provincial epistemic structures camouflaged as universal?”

(GROSFOGUÉL, 2016)
These questions, besides helping us to understand the scientific production of so-called modern societies, have helped us to see the effects of coloniality present in the production processes of westernised and universal knowledge. From these questions it is clear that the colonial project and modernity have produced a philosophical and scientific framework that disregarded and subalternated diverse ways of understanding the world, customs and epistemologies of most of humanity. It is worth noting that the disciplines linked to this segment of scientific production carry with them the epistemological marks of the field of knowledge that gave rise to them, which in our case, are the disciplines linked to the natural and exact sciences. I reiterate that most conceptions of what is understood by scientific knowledge were built on the basis of a single perspective, from European and American contributions. This reality is evidence of a political project in which science played a part, and which from the outset assumed objectives that consolidated the supremacy of its values and way of life, leading to the exclusion of many other ways of seeing the world. The prominent place achieved by science in school would be a consequence of its recognition, especially in the last century, where incalculable advances have occurred that have translated into technologies that, opportunely, solved several dilemmas of humanity.

In any case, it is important to stress that in countries like Brazil, the colonial influence of the scientific and educational structuring model led to pedagogical practices inspired by prescribed models imported from other countries. This fact demonstrates a practice of knowledge assimilation, a structuring of school devices, and the very methodologies of research and science teaching that are based on models that denounce the coloniality of power and knowledge in the history of the organisation and structuring of Education in Brazil.

In the researches we have followed, we have seen the application of these concepts in several theoretical and methodological perspectives and, in this way, their potentialities in the interpretation of several processes related to science education become clear. In this sense, we can ask: how can science
education benefit from this epistemological legacy of decolonial thinking? We will answer this question by presenting some examples of Brazilian works that, in some way, are based on or inspired by problems present in the contributions of decolonial thought, and we will rehearse some problematisations in order to launch ideas that promote critical pedagogies in science education.

SCIENCE EDUCATION FROM THE PERSPECTIVE OF DECOLONIAL THINKING

To exemplify some relations between concepts coming from decolonial thinking in science education, we present the book entitled *Cordial Contents: humanised chemistry for a school with no gags*, organised by Queiroz and Oliveira (2017) and published by Livraria da Física. The title of the work provokes certain organised movements in Brazilian civil society that seek to introduce a policy of repression in schools, ensuring that teachers work in favour of religious and ultra-conservative values. This book presents various experiments of science education that confront the effects of the coloniality of power and its various forms. One of the chapters deals with the chemistry of chilli peppers, also associated with the ways of Exu, a deity of Afro-Brazilian religiosity. In this way, when thinking about how this work touches on the issue of coloniality, we can conclude that it opens space in the formal chemistry curriculum for engagement with contexts of Afro-Brazilian religiosity in local culture, since the study of the substances present in chillis is of great importance for certain cultural rituals in Brazilian communities.

Another chapter deals with the issue of women babassu coconut breakers, and besides dealing with the chemical properties of the substances and processes of essential oil extraction, it calls into question the leadership role of women in certain non-patriarchal communities and how their heavy artisanal work is responsible for the subsistence of a huge region. A chapter on the chemistry of inorganic functions stems from a problem related to precarious work in the mining companies of Minas Gerais State, i.e. from the oppression imposed on the workers, while also addressing chemistry content related to obtaining various inorganic compounds through mining, as well as the
nomenclatures of these compounds and the types of chemical reactions involved in various processes, from extraction to the industrial production of salts, oxides, acids and hydroxides. From this interrelation between the contents of chemistry and the precarious work conditions, a possibility of science education critical of a social problem, is developed.

The book also presents other examples that relate to the effects of coloniality. The chapter entitled Gender, Science and Theatre, questions the predominance of men in science and demands the right of women to be scientists with fair recognition of their work. From a play staged by students in a school about the biography and dilemmas faced by Marie Curie, several concepts about radioactivity are presented in the plot of the play. The situation of waste pickers linked to the issue of racial discrimination in Brazil, to the extent that most of the people involved in this type of work are black men and women, is the theme of another work that debates environmental racism while addressing the chemistry of waste and its transformation processes. The chemistry of sex hormones, associated with debates on gender and the dilemma of trans people is another important work that raises several questions in the classroom regarding the predominant heteronormativity in our societies. This case is an essential example that touches on the issue of the coloniality of being, since only the male and female genders are considered normal in most social contexts.

Thus, even if these works do not directly address or use the concept of coloniality, they are experiences of Brazilian teachers engaged in critical pedagogies of the current social system. It is possible then to see that here we have the emergence of a critical Brazilian pedagogy that produces a new look on science education based on the recognition of processes of cultural subalternisation, i.e., a new look that tries to articulate, in the scope of educational practices, diverse contributions and ways of seeing the world, to scientific knowledge.

In the work by Pinheiro and Rosa (2018), entitled Decolonising knowledge: law 10639/2003 in science education, the authors directly present experiences of science education with a view to the problems related to the effects of coloniality, especially those related to
the struggle of black people in Brazil. We highlight the didactic experiences that discuss racism and skin colour through studies on the properties of melanin, the studies on the properties of the hair fibre of the black population as a bridge to problematise cultural issues related to standards of beauty and approaches on the use of psychotropic substances by incarcerated black women. In addition to presenting various pedagogical experiences in science teaching, the book discusses

“historically scientific production and therefore the Teaching of Science were thought up from the myths created by European coloniality which established standards of civility, progress and humanity while building a particular history universalised by them”. In the middle of this process, there was also the “construction” of a modern monocultural and epistemicidal science, which denied other civilising matrices and the millenary scientific-technological knowledge of ancestral peoples, such as the African peoples, the first to inhabit the world” (Pinheiro and Rosa, 2018).
The book *Educação Ambiental Desde El Sur*, organised by Meneses and Sánchez et al (2018), is a collection of texts that present experiences grounded in the concept of critical environmental education. The authors clearly present their understanding of the critical strand of environmental education, placing it in the terrain of struggles for common goods and in the search for the construction of a decolonial thought, with emphasis on Latin American roots. His discussions bring important contributions aimed at the construction and strengthening of critical environmental education, permeated by a view that values alterity, and is not subordinated to the colonial tradition of research and education. Among the experiences presented, we highlight the chapters dealing with the following themes: critical and decolonial environmental education: reflections from Latin American decolonial thinking; gender, race and sexuality: a study of environmental education in Latin America and the Caribbean from the perspective of critical environmental education; intercultural dialogues with the Guarani Mbyá indigenous community. The epistemological shift proposed by the work as a whole is an exercise to think up new practices of environmental education in line with experiences and cosmovisions of other cultures, especially traditional communities in Latin America.

Finally, we present the work *Decolonialities in Science Education*, organised by Monteiro and Dutra et al (2019). The material is based on the dialogue between four research groups in science education, with the aim of materialising theoretical and practical reflections on the potential relationships between the territory of science education and decolonial studies. Objectively, the initiative sought to provoke reflection on the epistemological bases of this field and on new possibilities of confronting contemporary and future challenges, especially cultural, ethical and political issues that naturally involve the processes of knowledge construction. The work presents a collection of 19 manuscripts, with the participation of authors from Brazil, Argentina, Mozambique and Bolivia, among others. In this context, it encourages debates on new research methodologies and educational programmes aimed at valuing identities, cultures, traditional knowledge, human
rights and the environment in line with an anti-colonial struggle agenda that opposes the mechanisms of domination and reproduction of social inequalities undertaken by hegemonic social structures, their discourses and policies. In this work, we find important experiences that discuss issues related to the natural sciences curriculum, environmental cinema, human rights, territories of environmental sacrifice, structural racism, popular knowledge in chemistry education, nutrition and cultural resistance of black populations, feminism in science education, among others.

**FINAL CONSIDERATIONS**

From our studies and interlocutions with other research groups, we have been reflecting on the effects of the coloniality of power, being and knowledge and also on the various epistemological questions, which somehow interfere in themes that circulate in the field of science education. These reflections and ongoing investigations in various Brazilian research groups have shown that traditionally, our research and educational practices are restricted to Eurocentric epistemological models, for the time being, depoliticised, disciplinary, uncritical and stuck in universalised methodologies of Science Education. In this work we highlight several authors and works that reflect the decolonial mindset from the influence of the Modernity/Coloniality Group in the Latin American scenario. However, we highlight that our studies and reflections seek to expand the theoretical scope of analysis towards several Brazilian thinkers such as Lélio Gonzalez, Paulo Freire, Abdias do Nascimento, Milton Santos, Carolina Maria de Jesus, and Conceição Evaristo, among others. In the context of other Southerners, we seek theoretical support in works by Rita Segato, Frantz Fanon, Angela Davis, Boaventura de Sousa Santos, and Judith Butler, among others.

Understanding how the process of coloniality took place and seeking alternatives to deconstruct it is the first step on a long road to transform educational practices related to the teaching of natural and exact sciences. Practices that are rooted in modernity and need to be questioned about their intensions of objectivity and neutrality. In science textbooks, we need to confront the various predominant visual representations of white, male, universal bodies. In astronomy classes, for example,
we need to recognise ways of representing the sky and constellations from other cosmogonies, i.e., to recognise that there are cultures and mythologies that have constructed different explanations, i.e., those of how certain peoples emerged, and their relationship with nature, of climate cycles and seasons, of planting, harvesting and hunting periods, as well as explanations of the origin of the universe, moral, ethical and religious questions. For example, the westernised constellations of Orion, Taurus, Pleiades and the Three Marys are in the same region of the sky where the Guarani people, an ethnic group that occupies a large part of what is now South America, see the Tuya’i or Old Man, a mythological character who signals the arrival of summer at the same time that he reminds his people every year of certain moral and ethical lessons.

In chemistry classes, we need to reveal the polluting substances in a certain lake while simultaneously showing who will have the misfortune of drinking the contaminated water and who will have the benefit of the clean water. We will find that the misfortune will mostly fall on certain racialised populations considered likely to be targets of these environmental injustices. We will be able to address the molecular structures, properties and effects of substances present in psychoactive drugs, problematising the social groups that sustain drug trafficking and the groups that suffer from turf wars. We can also include debates on cases of malnutrition of indigenous populations or increased consumption of heavy metals and pesticides present in food, and at the same time study the geometries of molecules in 3D simulators. Similarly, in biology classes, we will need to show that there are no genetic differences that justify the politically-structural enterprise of racism. We will explain how vaccines work in the human body and discuss why poor countries are always at the end of the queue. We will demonstrate that the peoples of the Amazon have never separated nature from human beings and that they have never considered destroying the forest to establish monocultures, gold mines and cattle farming. We will argue in favour of a systemic interpretation of this set of ecosystems, which works as a living being, demonstrating the influence of Amazonian respiration in the atmosphere and on the incidence of rainfall that guarantees agricultural
production through the distribution of water over thousands of kilometres in that region. We will discuss the advances of technologies in approaches linked to the science education movement known as Science, Technology, Engineering and Mathematics (STEM) and ask what will be done with millions of workers who will have their professions extinguished by artificial intelligence. We will discuss the environmental costs of technological equipment that use a range of electronic components made from various minerals sourced from illegal mining areas where people work in sub-human conditions. We will problematise the precarious situation of access to health care in the world and discuss the budgets allocated to war and space research. In this context, we will do the math and compare the costs of the companies that aim to provide space tourism to serve small groups of millionaires that do not stop accumulating the biggest part of planet's capital, while the FAO (Food and Agriculture Organisation of the United Nations) reports that 800 million people around the world are hungry. We will study alternative forms of energy, advocating the electrification of the world's automobile fleet in order to put an end to the burning of fossil fuels, while showing and demanding solutions from the authorities to a new environmental problem related to the disposal of a plethora of batteries.

Faced with these challenges, we understand, based on Paulo Freire, that educating is a political act in any situation, regardless of the area of discipline in which pedagogical practice takes place. This critical stance is intended to overcome inequality, social exclusion and to free people and their social groups from pre-determined conditioning by colonialist and capitalist logic. From this perspective, we advocate investment in critical pedagogies for science teaching committed to the humanisation of underprivileged groups through inclusive educational processes. May this path lead us to an emancipatory practice in order to promote social justice through the recognition and rescue of diverse knowledge succumbed to relations of domination. In this way, we start from the “epistemologies of the south” of Santos and Meneses (2010), establishing problematisations that aim to overcome barriers in the construction of scientific and educational practices concerned with the challenge of building another possibility of humanity.
REFERENCES


Abstract: In this chapter I will explore the relevance of Paulo Freire's influential work on Critical Pedagogy to those interested in engaging with recent debates around decolonisation of education. More specifically, I will reflect on how Freire’s notion of critical consciousness can underpin a decolonial approach to school science that supports students’ explicit engagement with the links between scientific development and social, economic and political spheres. To illustrate this decolonial approach to school science based on Freire’s ideas, I will also briefly present a collaborative project undertaken with a science teacher at a state secondary school in London/UK for one year, exploring our journey of decolonising this teacher’s science lessons and the possibilities that can emerge from taking this approach to school science from within the National Curriculum in England.

PAULO FREIRE, CRITICAL PEDAGOGIES AND DECOLONISING THE SCIENCE CURRICULUM

Recently, and especially after the Black Lives Matter movement, we have seen the rise of calls for the legacies of colonial projects to education to be addressed by educators and policymakers. This kind of work, which involves first unveiling and then attempting to undo social, cultural and historical impacts of colonial endeavours on different communities, is known as decolonisation (Manathunga, 2018). And, as further elaborated by previous chapters in this book, approaches to decolonising education often aim to better understand the legacies of colonial projects to how education is done, including to what kinds of knowledges are deemed worthy of being taught and to how those knowledges are actually portrayed by educational practices. They also often aim to support, by better understanding links between colonisation and education, teachers’ and students’ engagement with diverse representations, complex histories and anti-racist practices within their school experiences (Manathunga, 2018).
But while these calls for decolonising education might seem like a recent phenomenon in some Global North countries like the UK, reflections about the legacies of colonial projects to education have been part of educational thought and practices since at least the first half of the 20th century, especially in formerly colonised Global South countries (e.g., Brazil and South Africa) and in Global North communities involved in anti-segregation movements (e.g., USA). And, among influential decolonial endeavours in the Global South, we find the work of Paulo Freire in Brazil around ‘Critical Pedagogy’, the central topic of this book.

In his seminal book *Pedagogy of the Oppressed* (published in 1968), where he started to outline his view of *Critical Pedagogy*, Freire criticised what he called the *banking model of education*, in which learning and knowledge are seen as a simple process of memorisation of a selection of specific facts/content – or of depositing facts onto students –, without involving any level of critical thinking about those facts:

“[In the banking model of education] the more students work at storing the deposits entrusted to them, the less they develop the critical consciousness which would result in their intervention in the world as transformers of that world. The more completely they accept the passive role imposed on them, the more they tend to simply adapt to the world as it is and to the fragmented view of reality deposited in them.” (Freire, 1972, p. 71-72; my emphasis).

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1. ‘Global North’ and ‘Global South’ are often used to refer to groups of countries along distinct socio-economic and political characteristics instead of purely geographical locations. While the former refers to countries often considered to be socio-economically ‘more developed’, like USA, Canada, Australia, Japan and those in the European continent, the latter generally refers to Latin American, South Asian and African countries.
As outlined in Freire’s quote above, this kind of banking model of education that involves students passively receiving fragmented factual knowledge about the world cannot support them in becoming transformers of that world, exactly because they will only have a fragmented view of that world. In other words, according to Freire, if we want our societies – including ourselves and our students – to be capable of overcoming social, economic, political, gender and racial inequalities, we need education to go beyond simply memorising facts about a certain content prescribed in our curricula and schemes of work. What we need is to go beyond that to promote students’ development of what Freire called critical consciousness. Critical consciousness is the central tenet of his view of education based on Critical Pedagogy: it involves an in-depth understanding of how the world (really) works, including the norms, values and socio-political interests at play behind the knowledge being taught and learned through educational experiences.

What Freire argued then is that we should not necessarily ignore or deny a certain kind of content or fact, but we need also to develop an understanding of how this knowledge has been produced, including its historical trajectory until how we know it today, and the norms, values and interests involved in this process of knowledge production – that is, a less fragmented view of that knowledge, as alluded to in his quote above. Freire’s proposal of a type of education based on the development of critical consciousness should then help us and our students to better grasp the complexities of historical and current social challenges, which in turn would help us to more critically address those social challenges as “transformers of the world”. But, what would Freire’s notion of critical consciousness mean for us science educators?

As science teachers, it is not difficult to identify, in our own practices, what Freire criticised in the quote above around memorising facts. In a lot of countries, such as the UK and Brazil, this approach sometimes takes central stage in science curricula, textbooks and examination procedures, as exemplified by memory-based teaching strategies around the periodic table, naming of compounds and species, etc. (Erduran & Dagher, 2014). In this kind of approach to science education, scientific knowledge is often taught as something given, “a gift bestowed” upon us, a set of facts that comes from nowhere and is dissociated from any process, history, norms, values and interests. And although these views of scientific development have been recently challenged by researchers in the field...
of Science and Technology Studies, the “social” nature of scientific development is still largely absent from most school science across the world (Erduran & Dagher, 2014; Gandolfi, 2021a).

Teaching scientific knowledge devoid of any engagement with norms, values and social aspects of scientific development is then what Freire calls above a “fragmented view of reality”: students taking part in this type of science lessons are only engaging with a partial, fragmented understanding of how scientific development happens. They are only learning, for instance, about the facts around metal extraction in a Chemistry lesson – such as chemical reactions involved in this kind of process, properties of certain metals – but not about the links between large scale exploitation of minerals by mining industries, financial systems, and labour exploitation, land rights and environmental crisis within communities where mining happens across the world.

My argument throughout this chapter, and as further illustrated in the following sections, is that Freire's notion of critical consciousness asks school science practices to explicitly recognise links between this field of knowledge and social, economic and political spheres, in opposition to teaching science as devoid of any process, history, norms, values and interests – that is, as only a set of, for instance, chemical reactions, physical and chemical properties, and naming procedures.

In addition, I believe that looking at science and science education based on Freire's seminal notion of critical consciousness opens the door for us, science educators, to also engage with the recent calls for decolonising education mentioned at the start of this chapter. With most educational endeavours in this area currently happening in the fields of social sciences and humanities (Gandolfi, 2021b), such as school English and History, here I propose that approaching science education based on Freire's notion of critical consciousness can also help us all better understand and address colonial legacies to education from within school science, especially around how different kinds of knowledges, practices and members of scientific endeavours are portrayed by school science. But what are the links between Freire's ideas and contemporary practices and proposals around decolonising education?

As I mentioned earlier, Freire's work has been an important landmark to those
working in decolonising education in recent decades, with some considering his ideas to be central to how decolonisation can be addressed within the field of education (Akkari & Mesquida, 2008; Darder, 2015). This is because he was interested in a kind of education that does not simply describe the world to students in a fragmented way, but that actually helps them to critically understand the complexities of that world through the development of critical consciousness about historical, sociocultural, economic and political aspects around the knowledge they learn. Freire’s ideas are then intrinsically linked and central to decolonisation of education since, like Freire, this area also aims to challenge narrow views on what kinds of knowledges (content, facts, ideas, practices, etc.) are deemed worthy of being taught through:

- Recognising that complex socio-historical processes impact the production of the knowledge we teach and who is part of those knowledge communities (e.g., scientists) (Gandolfi, 2021a).
- Understanding this knowledge production as intertwined with social, political and moral legacies and practices (Sousa Santos, 2018).
- Fostering a reflexive understanding and deconstruction of socio-historical legacies resulting from colonialisms and other unequal relationships to the production and teaching of different kinds of knowledge.
- Addressing the insularity of narratives about knowledge production, people and their communities emanating from Europe (or the Global North).
Therefore, in the specific case of school science, a decolonial perspective inspired by Freire’s work would look at the development of scientific and technological knowledge as directly connected to the widely diverse socio-cultural and historical roots of science. It would recognise, for instance, that “science was itself built upon a global repertoire of wisdom, information, and living and material specimens collected from various corners of the colonial world” (Roy, 2018). It would also understand that what we often call ‘modern science’ – the one usually found in most science curricula – is a result of several exchanges, appropriations and collaborations (forced or not) between different communities, and of the circulation of diverse types of knowledges and material resources, all promoted by historical and geopolitical contexts, such as trade routes and colonial projects (Gandolfi, 2021b). This decolonial way of looking at scientific development then involves exactly the development of critical consciousness about scientific development and the scientific world proposed by Freire: an approach to science that recognises the complex links between this field of knowledge and social, economic and political spheres throughout our histories and within our contemporary societies.

This perspective on school science, however, does not aim to simply uncover these socio-historical processes within the teaching of science but, and more importantly, to make visible the often unequal relationships established between different communities as part of scientific and technological endeavours, such as in the case of extraction of natural resources (e.g., mining) in oppressed and marginalised communities. Let’s think, for instance, about the environmental crisis currently happening at a global scale: can we ask our students to critically engage with this topic in our science lessons if, for example, they are not aware – critically conscious – of how unsafe and exploitative cobalt those mines in Africa owned by Global North companies are, having been simultaneously feeding technology behind so many modern products, such as mobile phones, and the destruction of key natural habitats and ways of living in Global South communities? Understanding the links between scientific development and social, economic, and political aspects, including its use in the exploitation of people and resources, is then key to
helping our students’ engagement with complex social challenges deeply linked with scientific development; and hopefully, in the words of Freire, to also placing them in a better-informed position to be transformers of the world in the face of these challenges.

But how can that be actually done in school science? To explore this question, in the next sections I will present a school-based experience at a state secondary school in London that aimed at decolonising the science curriculum through Freire’s notion of critical consciousness.

**A CLASSROOM-BASED EXPERIENCE: CRITICAL PEDAGOGIES FOR DECOLONISING THE SCIENCE CURRICULUM**

In this section, I will briefly introduce my collaborative project with one secondary science teacher in England, which aimed at exploring the use of Freire’s notion of critical consciousness to bring decolonial ideas to the science curriculum. The participant teacher and I spent one year working together on sets of lessons around different science topics that are already found in the science curriculum in England: Medicines, Magnetism, Evolution and Earth’s resources.

This work happened at a large multicultural state school in the London area with one year 8 classroom (26 students aged 12-13). Ian, their science teacher and my collaborator in this project, is White British and had been teaching Science for around 10 years at the time. He decided to participate in this project due to his interest in broadening (“being more creative”, in his own words) his school’s science curriculum and, more specifically, in reflecting the multicultural nature of his school within his work with science topics. Ian did not have any formal training in decolonial studies, but he had come across Paulo Freire’s ideas before in his initial teacher education course; he was especially interested in how this project could help him not only broaden his approach to his school’s science curriculum, but also challenge his tendency of adopting the *banking model of education*, as outlined in the previous section, in his day-to-day teaching practice.

As mentioned above, throughout one year Ian and I worked collaboratively on bringing decolonial ideas with the help of
Freire’s notion of critical consciousness to four topics in his regular science curriculum: Medicines, Magnetism, Evolution and Earth’s resources. To fit this experience into the school’s expectations, the teaching of each topic lasted 5 hours and students were still expected to sit a centralised exam at the end of the year alongside all other year 8 groups who were not participating in this project. This work was carried out through an iterative approach of planning, implementing and evaluating: together we developed a complete set of plans for a topic during weekly planning meetings; Ian then taught that set of lessons; and afterwards we met again to reflect on how those lessons went before starting the development of the next set of lessons for a different topic.

We created a set of lessons for each topic based on a storyline (or narrative) approach, where a science topic is taught through developing a narrative around relevant scientific development stages and milestones around that topic. That is, we organised the sequence of a particular topic from the science curriculum through a connected socio-historical narrative about scientific development running across all lessons, which also allowed Ian and his students to revisit and re-explore relevant ideas as they advanced on their work on that topic. Within our specific Freirean lens, these socio-historical narratives were used to flesh out the links between science and social, economic and political spheres and, within our specific decolonial lens, they were also based on looking at scientific development through processes of exchanges, collaborations and exploitations of natural resources and people. These storylines are briefly summarised below:
#1 MEDICINES: accounts about the uses of natural resources in the history of medicines and medical knowledge, including the importance of natural resources to medicines development; local knowledge/expertise/practices about natural resources and their medicinal uses, and how frequent contacts between different groups foster exchanges and exploitation of these resources and expertise.

#2 MAGNETISM: history of the relationship between science and technology in the form of the compass. Building on the Medicines topic, this topic was grounded on how knowledge and uses of magnetic materials were exchanged and expanded by the interactions between diverse communities, and how this enabled even more expansion and contact between communities through technological innovations (e.g., compass).

#3 EVOLUTION: historical sociocultural narratives around the processes of species change, collection of evidence and development of explanations for these processes; links between naturalist travels, natural resources, extinction, and the theory of Evolution. This topic connected ideas previously explored in the Medicines topic on natural resources and naturalist travels with Natural Selection, theory of Evolution and biodiversity.

#4 EARTH'S RESOURCES: accounts on metal usage/exploitation in different societies and on the links between these natural resources, environment, and chemical knowledge. This topic linked to the previous topics by exploring the impact of naturalist travels and colonization/imperialist endeavours (e.g., metallurgy in the colonial Americas) on development of chemical and technological knowledge about metals, extraction techniques, and on environmental issues.
A set of lessons for each of these four topics was then planned through a socio-historical storyline that brought together the original content from the school’s regular year 8 science curriculum and reflections on the links between scientific development and different communities, power and socio-political landscapes. Thus, our decolonial perspective based on critical consciousness did not replace the original content of the science curriculum but was actually integrated throughout it. In the words of Freire (1972, p. 52-53), we were not seeking to “deny the facts” or replace the teaching of content, but to “see them [the content] differently” by exploring often underexplored aspects within historical and contemporary scientific development, such as issues of land and local knowledge exploitation and links to socio-political and financial aspects.

In addition, a Freire-inspired decolonial endeavour cannot be done by thinking about these science topics as separate sets of scientific knowledge; or as separate bodies of knowledge. That is, if we aim to challenge a fragmented view of science, as based on Freire, science topics need to be approached through an integrated strategy that allows us to also see the bigger picture of scientific development. So, despite the four topics above being often linked to different science subjects in the English curriculum (Biology, Chemistry and Physics), Ian and I approached our planning of those lessons in a way that promoted connections between them, as alluded to in the #1-4 list above. Since our four topics were based on a similar socio-historical narrative around processes of exchanges, collaborations and exploitations, we were able to plan for ideas to be explicitly revisited in future lessons, establishing connections between different areas and topics of scientific development, akin to a spiral approach to curricular practices. An example of how this looked in practice will be presented across the next sections.

Lastly, it is also important to remember that the planning of these topics, with their overarching narratives, resources and tasks, was grounded on making the trajectories of knowledges and practices in science visible to Ian’s students in order to support their development of critical consciousness about scientific development. However, as argued by Freire, such endeavour cannot be achieved if one is still operating within a banking
model of education that simply privileges memorisation of facts/content and places the teacher as the one “depositing” the correct knowledge onto students. Interestingly, an important element of Freire’s Critical Pedagogy that is often employed to counter this banking model and promote the development of critical consciousness are dialogic strategies, where students are encouraged to question knowledge, ideas, stories, etc. that they come across in their educational experiences. As a result, our lessons were not only grounded on the decolonial socio-historical narratives outlined above, but also on a dialogic pedagogy that promoted students’ active participation and contributions to the topics being explored. Ian then taught these lessons through a mix of his own input with support to several small-group and whole-group work and discussions, always attempting to elicit his students’ own views, questions and contributions to the topic being explored.

In the next sections, I will briefly present two examples – one from the Medicines topic and another from the Earth’s resources topic – to illustrate the key strategies outlined above that we employed in this project to try and bring decolonial ideas to school science based on Freire’s notion of critical consciousness:

BRIEF EXAMPLE (I): MEDICINES

As outlined in the previous section, the Medicines topic (#1) was planned to highlight the importance of natural resources to the development of medicines, stages involved in such process and, under our chosen socio-historical storyline, how frequent contacts between different cultures and communities enabled exchanges, collaborations, adaptation and forced exploitation of different knowledges and practices around medicines and their development. For instance, this set of lessons involved students doing their own research (task 2 – homework, in Figure 1 below) on practices and knowledge about natural resources and medicines in Native American, African, Arabic and Asian communities, such as: bark from mahogany trees to fight malaria in Ghana;
Indian snakeroot for high blood pressure; etc. In the next lesson this was then followed by a subsequent small-group and then whole-group conversation about how such knowledge and practices were shared and/or exploited through maritime and land route travels (such as the Silk Road and the Great Navigations), commerce, forced migration (diasporas, slavery), colonisation, anthropological and naturalist travels, as summarised in Figure 1.

As seen in the last slide of Figure 1, grounded on students’ own homework (task 2), Ian explored important decolonial ideas around medicines development and local knowledges, power and socio-political landscapes with the help of key questions posed during their work through the topic. Here, Freire’s challenge to the banking model of education outlined earlier in this chapter comes to the forefront in order to facilitate Ian’s decolonial work on the Medicines topic: instead of approaching...
examples of local knowledges and practices around medicines brought in by his students as part of task 2 as simply a set of facts, he prompted conversations in the spirit of Freire’s dialogic practice to support a wider engagement with the complexities and nuances of scientific development. The following snapshot of a discussion that happened in Ian’s classroom as part of their conversation about task 2 illustrates that:

**Ian:** Right, do we think this is a good thing? [using knowledge about natural resources to produce conventional medicines] Hands up if you think it’s a good thing that we share this information [the whole class put their hands up]. Ok, hands down. Are there any bad sides to it?

**Student B:** I was gonna say, because we talked about raids, and raids happen, they can barge into the country and take things, so like most of the remedies are gone. So that’s another way it can spread, through raids. Or they can sell it for money, so they give it to different countries.

**Student C:** Also, like some people, you know, they cut the trees down and they don’t plant new trees and stuff. So they will cut it off and then leave it like that. So for the cure for malaria now it’s difficult to find the tree.

**Ian:** Ok, so you’re talking specifically about the mahogany tree, which has been over-farmed. Is that what you mean?

**Student C:** Yeah!

Thus, when discussing this task, students seem to have engaged in a critical conversation about examples they had previously researched. Looking at the classroom exchange above, it is worth also noticing the explicit conversation they had about a key aspect often found in most colonial projects: exploitation of natural resources and peoples. More importantly, we can see how students started a process of challenging a simplistic view that any kind of collaboration or exchange to forward scientific development is necessarily positive, in turn engaging with notions of ownership of natural resources, native peoples’ struggles against violent exploitation and socio-environmental impacts of scientific developments. The decolonial socio-historical storyline adopted to organise this set of lessons grounded
on Freire’s notion of critical consciousness seems to have brought a more nuanced conversation about scientific development to the forefront of these lessons, challenging a fragmented view of science and allowing for a more in-depth exploration of how the (scientific) world works.

**BRIEF EXAMPLE (II): EARTH’S RESOURCES**

As outlined earlier, in the topic of Earth’s resources we set out to explore the history of mineral exploitation, grounded on a socio-historical storyline based on the impact of naturalist travels on the development of chemical and technological knowledge and practices around metals and extraction techniques. This set of lessons involved, for instance, a task where students had to explore (in pairs) a group of cards with examples of different metals, their properties, and historical and contemporary exploitation, such as: knowledges and practice among indigenous communities in the American continent around metallurgy, including their exploitation by European colonisers during the sixteenth, seventeenth and eighteenth centuries; techniques of metal manufacturing in Africa, Asia and Middle-East and their expansion to Europe; etc. They were then prompted to discuss, as a whole-group conversation, the set of questions outlined in Figure 2 below.

**FIGURE 2. SAMPLE SEQUENCE OF SLIDES USED THE EARTH’S RESOURCES TOPIC**

Metals in History
- Take a look at your mind and discuss it (in pairs).
- Think about the following aspects about the idea in your mind:
  - The metal being used
  - How this metal was used
  - Where this community got the metal from

WHERE in the world?
- If all metals cannot be found in all places around the world, how do you think people learned about their existence in those different places?
- What do you think they did when they found out about the existence of those different types of metals in other places?

Metals in History
- How were the metals obtained by the communities in your mind? That is, where did steel and gold come from?
- Do you think all metals can be found in all places around the world?
As with the previous example from the Medicines topic, Figure 2 illustrates how Ian promoted more nuanced – or “less fragmented” – discussions about scientific and technological development with the help of explicit discussions with his students. The following extract from this part of the lesson further exemplifies how Ian supported his students to engage with more nuanced critical thinking by first responding to their initial answers and then prompting them to make further connections and expand their ideas.

**Ian:** If you couldn’t find all these metals on your doorstep, how do you think they found out about their existence in different places?

**Student G:** Through trading?

**Ian:** Trading, yes. What big trading happened that you guys have heard about here before?

**Student H:** Ah yeah, with Medicines, there was the Silk Route.

**Student I:** Yes, with the compass as well.

**Student J:** You can navigate around the world and visit different parts.

**Ian:** Great! That’s how the Spanish got into South America. And what metal can be found in abundance in South America here in the map?

**Student K:** Silver.

**Ian:** Why do you think it took people a while to find these materials? I mean, how come even today there are still some metals that we’ve only recently started to use them properly?

**Student L:** Some natural barriers?

**Student M:** Other people who live in the places.

**Ian:** And what is their part here?

**Student H:** They might know more about the metal and you can use them to help getting the metal from nature.

**Student I:** Where to find it and how to get it from nature.

**Ian:** Great! We call that ‘extraction’.
Beyond Ian’s use of a dialogic strategy to foster his students’ critical thinking about exploitation of metals, the classroom discussion above also illustrates how this approach inspired by Freire helped him to specifically bring important decolonial ideas around scientific and technological developments, global exchanges and exploitation of local knowledges and practices into this Earth’s resources topic. In addition, their mention of the lessons about medicines and the compass (which was part of the Magnetism topic) also highlights how the integrated strategy, which aimed at establishing explicit links between different science topics across the curriculum, seems to have indeed allowed students to revisit and expand their ideas initially explored in previous examples and topics. This can be seen as another positive outcome from our approach to decolonising the science curriculum that not only sought to promote in-depth critical thinking about scientific development, but that also attempted to challenge seeing science topics as separate sets of scientific knowledge, trying instead to help students see the bigger picture of science. Or, in Freire’s words, develop a less fragmented view of scientific endeavours.

Overall, what we managed to see throughout this attempt to decolonise the science curriculum based on Freire’s notion of critical consciousness was a consistent exploration by Ian and his students across different science topics of how scientific development happens in all its complexities and contradictions. In addition, this experience seems to have also widened students’ more nuanced understanding of the contributions of different people and communities to knowledge development in science, in close alignment with one of the key aims of decolonising education endeavours outlined earlier in this chapter: addressing insularity of narratives about knowledge production, people and their communities emanating from Europe (or the Global North). In the words of some participant students:

“In normal other lessons we don’t learn about scientists and with these lessons, as you learn about the development, you learn about the scientists, how they work and how things changed.”
“I think people forget, like, it’s not just one person, it’s a lot of people in different places working on many ideas.”

“I like it because we didn’t really know about that; before it was only ‘that guy from Europe’, but we never thought about other people working on science, like people from Africa or China.”

As a result, this project seems to have not only challenged a fragmented view of how science works but it has also, through this process, expanded these students’ views of who can actually participate and contribute to scientific development and the role of wider society within it.

**CLOSING COMMENTS**

As I argued throughout this chapter, Paulo Freire’s notion of critical consciousness has the potential to help us challenge an incomplete – or fragmented – approach to school science that only privileges memorising scientific facts, supporting instead students’ engagement with more nuanced understanding of the links between scientific development and social, economic and political spheres. The experience at a state secondary school in London briefly described in this chapter showed us some insights into these possibilities, including the relevance of integrated socio-historical storylines about scientific development and of explicit dialogic practices to fostering students’ critical consciousness about the scientific world and its relationship with socio-political arenas. In addition, this experience seems to have been of great value to Ian, the science teacher involved in this project, especially in relation to his both of his original aims when accepting to take part in this project – that is, broadening his curriculum and adopting more dialogic and less banking model practices in his teaching:
“[I learned] loads of new content. I learned that students can interact differently with that content, through the questioning, and that I don’t need to rely so much on hammering the principles on them. The students actually can learn through the stories and discussions. I also learned that students are interested in scientists and their work. I read a lot about science around the world, but I didn’t know how that could come to this curriculum, which is completely Western-based.” (Ian)

As alluded to by Ian above and by his students in the previous section, the adoption of Freire’s notion of critical consciousness to ground this project has also supported a more decolonial approach to teaching and learning about scientific development throughout this project. As I have been arguing throughout this chapter, Freire’s ideas are seminal to those interested in decolonising education both in the Global South, where he developed his Critical Pedagogy, and in the Global North, where the project described here happened. As such, contemporary calls (e.g., Gandolfi, 2021b; Roy, 2018; Erduran & Dagher, 2014) for more critical, holistic and decolonial engagement with science and scientific development within education can certainly benefit from the seminal decolonial ideas put forward by Freire decades ago.

Among areas and ideas related to science education to which I believe this kind of decolonial approach based on Freire can contribute, there are several directly connected to wider social issues currently faced by our societies across the world, such as: environmental crisis, including issues of environmental injustice; health challenges, including inequalities in access to healthcare, as exemplified by vaccine distribution during the COVID-19 pandemic; etc. Thus, in a world of increasingly challenging social issues, reflecting on Freire’s ideas and their links to decolonial endeavours might help us science educators better understand the role science and school science needs to play in such challenges scenarios.
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ACTING IN THE “CRACKS” OF CURRICULAR NORMATIVITY THROUGH THE HISTORY OF SCIENCE IN SCIENCE EDUCATION

CRISTIANO B. MOURA
Abstract: For some decades, the History of Science has been advocated as a very fruitful way to teach about science, seeking to focus on aspects of the construction of scientific knowledge and not just its final products. However, recent studies have pointed to the potential of exploring science not only from the point of view of its epistemology but also considering the social and political relations reflected in the sciences and which science itself often helps to (re)produce/build. In this chapter, I start from the observation that by adopting the historical perspective in teaching and learning, curriculum documents focus mainly on the use of the History of Science to explore the epistemology of science, falling short of discussing social and political aspects of knowledge production, crucial today in science education. To overcome this problem, I suggest that the use of History of Science in science teaching can act in the cracks of the prescribed curriculum, provided that one explores deeper connections between the historical events and the students’ perspectives in the classroom. As examples, I present two historical case studies – about atomic models and about the synthesis of ether –, one theoretical and the other implemented in a secondary classroom in Brazil, analysing relevant aspects of both studies to propose more general considerations from a historical perspective for science education.

INTRODUCTION

The History of Science (HOS) has for a long time been regarded as a fruitful way to teach science and, especially, about science; i.e., exploring aspects of scientific work by scientists and other science workers. Following the long-advocated path (McComas, 2008; Allchin, 2011) that teaching science needs to include aspects of the production of scientific knowledge, HOS emerges as an approach that, through the study of historical cases, illustrates with authentic examples how such production takes place. It presents science as a human enterprise, involving the collective work of several scientists and
non-scientists, and subject to debates, consensus and dissent formation, to the agency of the material environment, among other aspects. This tradition of a historical approach in Science Education is therefore strongly linked to a central focus on exploring the epistemological side of science, considering that epistemology is the branch of philosophy that deals with the construction of scientific knowledge. Of course, other branches of philosophy, sociology and anthropology of science also end up influencing the use of historical approaches in science teaching – hence this field of study is actually commonly referred to as HPSS (History, Philosophy, Sociology of Science) in Education.

Although there is a long tradition in the use of HPSS in Education (Jenkins, 1990; Porto, 2010), a more recent movement has brought to light several contemporary discussions about the production of scientific knowledge from a historical perspective: if it is true that all knowledge we deal with at school has historicity, not all aspects of these stories have been brought to light, as I will clarify later. Gandolfi (2021), for example, shows movements both within the area of science education that challenge the notion of a neutral curriculum, i.e., of a neutral and objective organiser of established knowledge, and within the History of Science and Science and Technology Studies fields. Regarding the latter two, recent literature in these fields has recognised that scientific development has been intrinsically linked to processes of exchange, appropriation and collaboration with diverse local communities, within a broader geopolitical and historical context (Nyhart, 2016). Unveiling such stories then means recognising that the construction of scientific knowledge was linked to this context of subordination of knowledge from other cultures and the hyper-exploitation of natural resources in different communities around the world (Santos & Meneses, 2010). Such events left marks on the very rationality that permeates scientific knowledge, with consequences such as the imbalance of human-nature relationships.

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1. Based on Santos (2010), when we talk about subordination, we refer to the hierarchization of knowledge, relegating certain knowledge to a level of lesser importance without clear criteria for such hierarchy, or even valuing specific parameters that are values of a specific culture rather than universal criteria.
If we seek that people can historicise themselves, i.e., that they can participate as subjects of history, as defended by Paulo Freire (1987), it is essential to explore the stories we tell in the classroom from a point of view that allows us to understand our historical place within the scheme of things. Exploring the type of question that I defend above, therefore allows us to understand to what extent we are represented (as inhabitants of the Global South) in the History of Science and what the consequences of this are, not only for us, but for the planet and its sustainability. Considering the recent challenges related to imbalances in the human-nature relationship, this is a fundamental theme for contemporary Science Education.

Recognising such literature in the area of History of Science and Science and Technology Studies, and recent efforts such as that of Gandolfi (2021), to switch such discussions to school education, the question that arises is in what ways can we explore them in science education at school?

This chapter seeks to explore this issue, and I will therefore divide it into two parts. In the first part, I develop an argument based on the field of curriculum studies that the discussions sought when retelling the history of science in school education are of the nature that such an effort will be more fruitful if it occurs in the “cracks” of normative curricula, resisting the tendency to standardise such proposals. As per my argument, this would be in line with critical perspectives for education. In the second part, I present two cases from the History of Chemistry focussing on the discipline of high school chemistry, where these “curriculum’s margins” could be explored to produce discussions on the production of scientific knowledge that not only problematise the ways in which such knowledge is and was produced, but also the social contradictions within scientific processes themselves.

**BETWEEN DECOLONIALITIES, CRITICAL PEDAGOGIES AND SCIENCE EDUCATION: WORKING IN THE CURRICULUM “CRACKS”**

Decolonial studies, within the realm of history and social theory, have emphasised in their criticism the process of colonisation of several continents by Europeans, which occurred essentially between the 15th and 17th centuries with the so-called Great Navigations, and then with the operation
of the British Empire and other European empires in the Americas, Asia and Africa. These works have argued that colonisation was a process that meant more than simply the occupation of territories previously inhabited by indigenous traditional peoples of the Americas, Africa, Oceania and Asia. It is argued that the historical process of colonisation continued as a phenomenon called coloniality, which generates thought patterns that are linked to a structure of domination and exploitation that guarantees the perpetuation of the same centres of power. This coloniality of being and power classifies and hierarchises subjects, ways of life and knowledge production, attributing greater value to European knowledge, its subjects and ways of life and relegating subjects, knowledge and ways of life that do not resemble European values and knowledge. Theories from the decolonial field therefore advocate the reinscription of knowledge, subjects and ways of life from the so-called Global South to the knowledge “game” (Santos & Meneses, 2010), whether in academic-school experience or in the social and institutional perception and imagination. This has the following consequences: the struggle for the recognition of knowledge that has been historically subordinated, and its rehabilitation as valid and possible in the knowledge domain; the fight against social classification that results in racism and male chauvinism; and the struggle against the imposition of a unique, capitalist way of life, which has had the effect of depleting the Earth’s resources and its other human and non-human inhabitants.

In terms of translating these studies into curricular practices at school level, Gandolfi (2021) – and her chapter in this book – gives us an example using the historiographical strand known as the Global History of Science. From this perspective, the relationship between scientific and technological development and the social and geopolitical contexts in which they occurred is explored from a “big picture” approach, in which they seek to combine micro-historical (more detailed) and macro-historical studies. Moura, Alsop, Camel and Guerra (2023), also highlighting a concern with the contexts of coloniality that still persist in our society.

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2. As an example, the work “Epistemologies of the South” organised by Boaventura de Sousa Santos and Maria Paula Meneses, whose introductory chapter is cited here.
today, argue backing a path that favours micro-historical studies. According to the authors, such curricular changes in which ways of knowing, being and living could effectively be placed side by side with historically subordinated experiences is a long-term project. However, colonial patterns are manifested not only on a macro level, but on a micro-power level, which is why challenging racism and patriarchy through narratives that privilege a more micro view, through the Cultural History of Science, would be a strategy that would also play against the patterns of coloniality that plague society, including racism, sexism and the non-recognition of the work of various social actors who were involved in the construction of science. In this chapter, I align myself more with the second proposal, although I recognise that both are not mutually exclusive and can even be investigated and addressed in the classroom as complementary strategies.

But where does the school curriculum fit in all of this? According to Silva (2015), critical curriculum pedagogies emerge as a phase of questioning a more technical perspective that was strongly present in the beginnings of what became known as curriculum theory. The first curricular perspectives took the status quo as a desirable reference for the construction of society and, based on that, focused on the best or most optimal ways of organising and developing curricula. Issues such as assessment were presented from the perspective of verifying the achievement of previously established objectives, which, in turn, gave no importance to any questioning of the current social order or the transformation of realities. This begins to change from multiple movements in different countries, such as the curriculum reconceptualisation movement in the US, especially represented by Pinar; the theses of Bourdieu and Passeron, Althusser and others in France; the new sociology of Education, with names like Young and Bernstein; and in Brazil, the fundamental work of Paulo Freire (Silva, 2015). Although there are differences between the theoretical nuances that each work employs (and also the scope of their works, some more limited to the field of education and others more broadly encompassing social theory), Silva (2015) points to the convergence between such theories in terms of bringing to the field of curriculum a stance that tries to disrupt the status quo, one that questions the...
assumptions of social and educational arrangements. With that, such pedagogies are oriented towards the transformation of social reality. According to Freire (1992), it is essential to understand that the future is not determined and that we can therefore dream of transforming the present and the future. To that end, Freire (1987) invites us to get involved with transformative action, permeated by praxis and that therefore cannot be carried out without knowing the origin of the injustices witnessed in society and, more markedly, in the countries and contexts of the Global South.

More than how to design an adequate curriculum, questions related to how curricula help to (re)produce various social aspects that prevent a more just and egalitarian society come into play. That is, if the curriculum is not just a list of content, what other aspects of school and schooling are linked to social structures? Is the way desks are arranged in a classroom curriculum? What about the allocation of speaking turns? The objects of a classroom, the amount of weekly hours allocated to each subject, the considered traditional/canonical content of the subjects, the setup (aside from the content) of the activities, among many other aspects, enter into discussion about curricula and how these different aspects build (and sometimes rebuild) those social injustices that we see in society more broadly.

As I have already pointed out, there are undoubtedly important differences between these diverse curriculum theories. Like Silva (2015), however, I choose to see the so-called critical pedagogies from the viewpoint of this convergence that aims to build other realities. We know, from the initial discussion in this section, that the curriculum is permeated by disputes and configurations that link it very strongly to social order. Whenever we talk about curricular innovations, therefore, some immediate concerns of ours, teachers in the school sector, arise: but what about external assessments like ENEM (the National High School Exam in Brazil) or Vestibular (university entrance examinations in Brazil)? But what about the extensive canonical content required by my senior leadership? What about the students’ own demands, concerned both with external assessments and often with issues related to their grades? As a high school teacher, my research has been based on finding paths that affect the day-to-day classroom more than point to
changes in curriculum policies in a broad sense, even though these dimensions are not completely separate. I have therefore argued that the potential in the use of historical cases in the basic day-to-day classroom lies in the fact that it is a way of differently performing knowledge that has already been curricularised.

To borrow an analogy from the Culture Historian of Rio de Janeiro, Luiz Antonio Simas, I believe in “crevice cultures”, which, according to the author, are those that “dribble the normative and canonical standard and insinuate unusual responses to survive in an environment where they would normally not be welcome” (Simas, 2019, p. 22). In other words, in line with Moura et al. (2023), I understand that our task in proposing historical approaches is less about thinking up ways to make these histories part of the curriculum prescribed to a large number of students, stabilising subjectivity, and more about ways of making them available to participate in the “cracks” (or “crevices”) of the standardised curriculum. This does not mean that knowledge and discussion involving the history of science should be marginalised. Its importance for science education in the contemporary world has been already exhaustively demonstrated in literature in the area (McComas, 2008; Alchin, 2011). However, what I want to postulate is that the multiplicity of existing classrooms and their very own dynamics prevent defining, in advance, what kind of path in historical approaches should be taken for any given content and group of students.

Still echoing Simas’s idea, it is not because it is a classroom in a Brazilian school that the history of chemistry in the colonial period will resonate with the identities of the students present there. Investing in the “crack” means, in this context, investing in a historical context that allows itself to be on the lookout. We prepare possible paths which will only be materialised when meeting with the classroom. In this sense, it seems to me that the story closer to the case study, to micro-history, has more effective room for manoeuvre in the classroom. A historical event designed to address the issue of gender in science, for example, can present other facets when it lands in a classroom. That is, from the same historical event, the theme of race, science funding policies, scientific careers, or more philosophical questions of knowledge may emerge, even if they were not designed for a particular
classroom (e.g. an example of these discussions is present in Cardinot, Moura & Guerra, 2022).

When dealing with the imponderable in the classroom, the use of history of science in science education has the power to avoid curricular regulation. Thinking along the lines defended here, the history of science always remains semi-framed within curriculum standardisation: it seeks to refer to canonical contents of the curriculum and is endorsed by research in the area, but due to the nature of the discussions it proposes, it goes beyond such contents and the research endorsement – it discusses topics that will not be covered in the external assessments, but which can help to reflect on the status quo, on society in all its complexity. To keep the reference to Simas (2019): history of science, thought in the perspective proposed here, is the ‘surdo de terceira’ of Science Education; it is here to surprise the consolidated standards and not create new ones. Only then, perhaps, are we approaching some kind of social transformation, as dreamed of by critical pedagogies.


In this section, I present two historical case studies to exemplify the perspective on the use of history of science in teaching that is advocated in this chapter. Both are more in line with high school, where the themes of atomic models and organic chemistry are studied in Brazil. The theme of atomic models in particular, is also present in primary education, so what I discuss here can be adapted to other grades.

Consistent with what was initially advocated in this chapter, the purpose of bringing two examples here is not that readers can simply take and use them in other contexts. I think of them more as inspirations to motivate similar implementation of HOS in the classroom. In the first case, the appropriation of

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3. According to Simas (2019), the ‘surdo de terceira’ is the third of the three drums played by samba schools that improvises in the beat set by the first and second drums, and whose function is to keep time for the band’s percussion section.
the historiographical perspective of the Cultural History of Science is not the main aspect. I bring an example like this, however, because it represents a case in which the implementation took place in a real classroom. In the second case, there is already a clearer appropriation of this perspective. There has not yet been an experience in the classroom with this historical case study, though, so ideas are offered only as potential paths for its implementation.

Both cases are presented in their general context, as a summary or general outline of the historical event and the purpose of the choices made in their development. Next, the main aspects related to scientific knowledge and development mapped in each narrative are highlighted. Finally, in the first case, some observations from the classroom experience are presented and, in the second, some notes on possibilities for the class are outlined. It is worth remembering that, due to space limitations and the character of this text, the historical events are not described in their entirety, which can be found in the sources cited in each case.

ATOMIC MODELS AT THE TURN OF THE 20TH CENTURY

HISTORICAL CONTEXT

Research on atomic models is full of controversies, ups and downs, and a much more bumpy path than it might seem at first glance. In addition to characters already known and present in textbooks, such as Ernest Rutherford and J. J. Thomson, there are still others such as Jean Perrin, Hamtaro Nagaoka and John William Nicholson who contributed to the development of atomic theories of this time, in some cases with decisive contributions to the history of science, but which do not appear in textbooks. The historical event outlined in Moura (2014) is intended to remove the contributions of these other researchers from invisibility, producing a more complex narrative about the production of atomic models at the turn of the 20th century.

The purpose when researching and outlining this specific event was to deconstruct an excessively linear and fragmented perspective of the development of atomic models, which contributed to an idealised vision of the scientific endeavour. In addition, although without a deeper approach, the idea of bringing characters seldom mentioned in

4. This section is based on Moura (2014). More detailed information about the historical event described can be found in this reference.
this story (despite all of them being men who developed their work in Europe) was to contribute to a vision of science as a collective enterprise, where the models “of Bohr”, “of Thomson”, were not just “of Bohr” or “of Thomson”, but products of disputes in that historical context that led to new understandings and definitions of the atom.

In Thomson’s case, for example, students are invited to deconstruct a view that he was solely responsible for the perspective of an atom that had electrons, since this kind of research was shared among many contemporaries. Furthermore, a linear narrative that Thomson’s atomic model would have preceded planetary models for the atom is also challenged. In a closer contextual look, we are able to notice that some proposals of planetary models for the atom already existed before or contemporaneously with Thomson (as is the case of Jean Perrin’s and Nagaoka’s models), which suggests an environment of dispute instead of evolution of concepts. The instrumental aspects related to each model are also developed from their relationship with technical knowledge and material culture. Thus, the models are put into dialogue with the experimental evidence of their time. Some laboratories, such as the Cavendish laboratory, became important centres for the production of knowledge about the atom and ended up justifying the movement of people in that context, as in the case of Japanese, Hamtaro Nagaoka and New Zealander, Ernest Rutherford, himself.

Still on the topic of location, it is interesting to note that much of the research with atomic models at the time took place in England first, and afterwards began to take place in other countries (such as Germany and the USA), with Europe still as the main production centre of such knowledge. This type of discussion, which at first seems to be more about epistemological aspects of science, can be connected to discussions that are crucial today when talking about scientific development (and its connection with sovereignty) in countries of the Global South. What are the science production centres today, or rather, what is the geopolitical configuration of science, and what are the consequences for science and for peripheral countries? What strategies were historically created by non-European countries to participate in the scientific
circuit in other times and how are today's strategies, such as the Science without Borders programme in Brazil, similar to these historical strategies?

Another aspect explored was the connections between changes in mindset expressed in the broader culture (the visual arts, for example) and the change in mindset represented by the new atomic models developed in this context, which still pertain to a debate related to the controversy between a discrete or continuous world. This type of relationship, however, ends up escaping a type of historical approach closer to the Cultural History of Science, insofar as it does not focus on more “micro” aspects of the historical case, as we will see below.

A SYNTHESIS OF THE DIDACTIC ASPECTS HIGHLIGHTED IN THE EVENT

In terms of pedagogical aspects, historical research and reflection on the teaching context (in this case, regular secondary education) initially raised three major aspects as potential discussion points: the relationship between scientific development and the cultural context; science as a collective enterprise and not of isolated great geniuses; and the role of models in the sciences. The activities were carried out with two high school classes of 35 and 32 students respectively, in a state school in Rio de Janeiro. Activities were carried out to make posters and slides, and, in line with the perspectives of critical pedagogies, dialogue was prioritised and valued throughout the intervention. The details of the analysis of the activities and of the dialogues (Moura, 2014) show that such strategies were able to give rise to interesting discussions about social and political aspects of scientific development.

Looking back at this event, it is possible to note many other aspects that could have been (or could be, in the case of future interventions inspired by what was done) explored, if we aligned ourselves with progressive demands for science education, as is the case of the critical pedagogies. Aspects of Japan’s scientific training policy that shaped Nagaoka’s trip to Europe for a post-doctoral degree, the central role of the Cavendish Laboratory at that time and the consequences for the dynamics of knowledge production, such as the constitution of research groups and collaborations, among others, as well as discussions about how such geopolitical formatting creates and
reinforces global hierarchies of knowledge production could be further explored and paralleled to contemporary discussions on these themes. This would have the potential to reinforce the understanding of power asymmetries on a global scale, which are the subject of much of decolonial literature, as well as part of the programme of critical pedagogies: to provide our understanding as socio-historical (individual and collective) subjects (Freire, 1987).

**THE CLASSROOM AND NEW PATHS: A CRITICAL VIEW**

By taking this event to the classroom in 2014, my initial intention was to explore the three major aspects previously raised in historical research about the event, according to the previous section. For this, I alternated between more panoramic approaches to the story and moments of greater detailing with a deeper dive into the details of the historical event (Moura, 2014). It should be noted, however, that other aspects emerged from the lesson. While I approached the students with several scientists who participated in the construction of the atomic models, one student raised a concern about the participation of women at that time, which I had not initially foreseen for this event. In the prescribed curriculum that I myself had produced, little space was given to students to express their views genuinely, that is, without necessarily being related to the three topics I had established in advance to be addressed in that event.

This case, and others, led me to reinterpret the possibilities of the historical approach in the classroom. Contextualisation could not, then, be a straitjacket that limits students to discussing certain topics rather than others, however significant, politicised, and progressive they may be. There must be a degree of manoeuvre in planning that allows for greater openness, even if the contours of the historical event itself impose some contingencies derived from the very nature of the event or available data. This led me and my research group to a search for new possibilities for HOS in teaching, which resulted in the research on a second historical event, which I report below.
THE SYNTHESIS OF ETHYL ETHER IN THE 19TH CENTURY

HISTORICAL CONTEXT

Organic chemistry is known (at least in Brazil, where it is part of the curricular tradition of the final year of secondary education) as a subdiscipline of chemistry that is almost directly associated by students with the task of naming complex substances and enormous carbon chains. Generally, little or no historical context is explored about this subdiscipline of chemistry – its contextualisation is usually drawn from relations with contemporary contexts, notably environmental ones. Seeking to contrast this vision of a science that comes “out of nowhere”, comes the prospect of working with an event involving organic chemistry. Furthermore, when it comes to organic chemistry, the possibility of the chemistry of natural products (and its history) comes to mind, where connections with the colonial period and the colonisation process more obviously come into play. However, we wanted to explore the fact that even in the case of primarily European contexts, one could “open” a historical event to speak of contexts of oppression. This would still mean having a decolonial look, since, as affirmed by Santos and Meneses (2010), the “South” does not only speak of countries that were subjected to colonial exploitation, but of classes and social groups within the geographic North that were subjected to colonial and capitalist domination. I therefore maintain that where there is an attempt to reverse the losses arising from these relations of exploitation, there will be a progressive perspective for scientific education.

In line with the precepts of the Cultural History of Science, we chose a well-defined event (in terms of time and theme) to delve deeper into the intricacies of such a story. This event was the synthesis of ethyl ether. The proposal was designed for the last year of Brazilian high school, where we, in general, deal with organic chemistry, specifically the chemistry of alcohols. As argued in Moura (2019), ethyl ether was an important solvent and anaesthetic, known for these properties more widely in Western Europe from the 18th century onwards. In addition, because of the state of torpor caused if inhaled, the substance has been used recreationally.

The historical path that we explore begins, more specifically, with the theory of ether formation produced by Antoine Fourcroy and Louis-Nicolas Vauquelin, in 1797, and goes through the proposition...
of Jean-Baptiste Dumas and Félix-Polydore Boullay in 1827, exploring the different comings and goings. In tracing this path, the objective was to construct a narrative that: 1) would provide some historical context about organic chemistry, generally absent from classrooms; and 2) translate some aspects of the complexity of scientific work, pointing to asymmetries of existing power in history. Among the various aspects explored in this event (which can be consulted in Moura, 2019), three will be highlighted here to emphasise the main point of what we seek when dealing with the history of organic chemistry through this case: in this or in other historical contexts, not always is it necessary to turn to the history of the colonies to wage a battle against oppressive contexts.

First, we seek to explore the connections of nascent organic chemistry with material sciences and other applied sciences closely linked to industry (and potential discussions on capitalism and consumption, among others) such as pharmacy. Secondly, when looking at the validation aspects of the reactions and theories about ether, we find a plot that clearly involves central groups that have their results quickly validated by the chemical community of the time and marginal groups in Europe that are slow to achieve the validation of their ideas and experiments, marking an asymmetry even within European contexts, and opening the possibility of discussing similar asymmetries in the global context (in the case of Brazil’s relationship with other countries around the globe, for example). As seen in the section on atomic models, and according to the initial discussion, sexism and racism should be seen as parts of colonial imagination that endure over time. With that in mind, in this event we invest in aspects of racism as well as sexism involved in the ether investigations.

As detailed more widely in Moura (2019), there are reports of many anaesthetic tests, such as using ether, in Black people who had their bodies mutilated “experimentally” to see if ethyl ether actually worked as an anaesthetic. In particular, we found a published scientific article that reports one of the first uses of ethyl ether in a Black person, against their will, a fact that was reported and published without any embarrassment in a scientific journal of the time. In the case of women, only considering European sources, there does not seem to have been participation...
of any female scientists, which is explained by the dynamics of knowledge production at the time. However, the existence of informal academic meeting spaces (salons), led by women, often helps to answer the question “where were the women?” at that time, reinforcing that social dynamics seemed to reserve a specific space outside (but at the same time related, since the salons were also spaces of scientific “production”) of science production for these women. More than stating where women should (or not) be, with this event we seek to critically explore the places historically occupied by women in relation to science and propose that other places are provided there are new configurations in the production of scientific knowledge.

A SYNTHESIS OF THE DIDACTIC ASPECTS HIGHLIGHTED IN THE EVENT

The didactic aspects that emerge from the historical research carried out – and here I emphasise that this historical case study was not implemented in the classroom – are multiple and multifaceted. In the first case, there were specific topics that we sought to explore in the classroom, and in the second, the aspects that emerged were more diverse, among which we can list: the connections between science and culture through the importance of ether as a solvent and anaesthetic and its recreational use; the dynamics of change in science, from exploring the transition between plant and animal chemistry and carbon chemistry; science validation mechanisms, the role of scientific societies and power relations between research groups; the role of language and material culture in chemistry; the identity of chemistry and its relationship with pharmacy; and, more specifically important and connected with the discussions that we seek to promote in this book, the subordination of black people and women in the contexts, respectively, of the use of ether as anaesthetic/recreational, and in the social environments where science was carried out. Evidently these are just some didactic aspects of this event, which do not exhaust its possibilities.

POSSIBILITIES FOR CLASSROOMS

Considering a proposal to build a curriculum in the “cracks” of curricular normativity, it would be illogical to point out paths to the classroom without having tried them, in my reading. What I point
out here are more perspectives that I see from the historical research I carried out and thinking about my own classes than guidelines on how to implement this historical case study in the classroom. First of all, I think it is important to note that the existence of several themes that can be brought to the classroom through this event does not imply that all of them need to be effectively addressed. I see this proposition as a great inventory of possibilities for different classrooms, so that the situations in the classroom, together with the teacher, will select the aspects that provoke the most profound discussions about science and societies. However, by way of suggestion, and what seems powerful to me from this event, if we want to emphasise especially the points that connect the discussion on decoloniality and critical pedagogies, the strategies suggested for the first event may also fit for one, privileging the dialogue, positioning and authorial production of students during and beyond classes. Furthermore, I believe that both the event of racism (the experimentation with the anaesthetic properties of ether) and the event of sexism (the dynamics of the salons), as they are described in detail in some cases, can give rise to strategies involving literature and text production. For example: how could we rewrite these sad (and in some cases cruel) events in the history of science in other ways? Scripting exercises, letters to the past and the future could be explored here, as well as other creative activities such as dramatisation, which are already being carried out in association with events of HOS (e.g. Braga & Medina, 2010).

**FINAL REFLECTIONS**

Based on the considerations in this chapter and the two historical cases that I have proposed, I understand that two aspects are crucial to feed a curriculum based on HOS that is built from the cracks in normativity. The first aspect is to take HOS as something alive which is (re)constructed every time we bring the historical event to the classroom (Cardinot, Moura & Guerra, 2022). It is in the classroom that the contours of what is most relevant to discuss in that environment become evident and it is from this contour that discussions about unsterile sciences will be produced. It is in the materiality of each reality that
science and science teaching flourishes, which is relevant and necessary in that context. This aspect is directly connected with what Freire (1987) says about the need to connect educational activities with the concrete situations that the subjects involved in the learning situation experience, as well as with the principles of critical pedagogies. On the other hand, if students see themselves more connected with situations of injustice related to oppression by gender and race, for example, what value would it have – from the point of view of overcoming the contradictions of the world – to bring students a ready-made event of HOS that only communicates to them about aspects related to experimentation in science? It is possible that in a deeper analysis, there is some purpose, but I propose here that the constant suspicion around the didactic objectives of our actions is part of an alignment with the perspectives of critical pedagogies. In other words, bringing this or that “ready-made” strategy to the classroom, even with a decolonial, critical, or other progressive perspective, may not result in a significant political experience for the subjects – we must always align the compass of our praxis to ensure an authentic student experience.

This first aspect is connected to a second point: to see HOS as a story that can and should reverberate the stories of students. As I have tried to demonstrate, this can be done with a history that addresses hegemonic European science, and not necessarily with approaches from local perspectives to knowledge, although this is an important strategy. This is because students’ identities are not fixed and there are no guarantees that such identities and subjectivities will be mobilised, whether this or that theme is related to non-hegemonic sciences. This, of course, does not mean that experiences with other forms of knowledge are invalid or should be disregarded, but it does mean that even within the hegemonic histories of science, counter-hegemonic paths can be found (Moura et al, 2023) if we look closely with the eyes of a purpose for science teaching aimed at overcoming the contradictions that exist in society, as denounced by critical theories.
REFERENCES


Porto, 2010


TRAJECTORIES OF BLACK WOMEN SCIENTISTS IN THE EXACT SCIENCES: A STUDY ON REPRESENTATIVENESS IN SCIENTIFIC CONTEXTS FROM INVESTIGA MENINA!

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Abstract: The predominant perception of science among high school students in the world is characterised by an idea of solitary activity performed solely by white European cisgender men. Considering that Brazil’s population is made up mostly of women and Black women, it is important that science, and all spaces of power and prestige, truly represent the Brazilian people. Acknowledging such presuppositions, the work currently underway, bearing elements of participatory research, aims to analyse the oral histories of Black female Brazilian scientists and thereby highlight the barriers of race, gender and sexuality that exist in the scientific academic universe. Our results indicate that scientific dissemination plays a fundamental role in combating gender, ethnic and social stereotypes that involve science, in addition to demonstrating the need to disseminate the trajectories and productions of Black female Brazilian researchers as a way of affirming their existence, resistance and permanence in scientific spaces, also presenting young Black women with science that represents them.

Scientific dissemination, also known as popularisation of science for some authors, is the “act of facilitating the understanding of research and works of scientific and/or technological origin by the general population” (França, 2015, p. 12). Such facilitation can be done through illustrations, translations, use of synonyms or even visual resources, as well as through the media (TV, radio, etc.) and alternative media, such as interactive social networks (Facebook, Youtube, etc.). Regardless of the means used, the aim of scientific dissemination production is to encourage the interest and reach of science as well as its understanding by all social strata (França, 2015). There are, however, barriers that make it difficult
for all of society to access science, as scientific knowledge production is far from the people. Social inequality together with illiteracy that permeate the Brazilian social body, make it increasingly difficult for people to access and understand scientific knowledge.

According to the IBGE\(^1\), in 2017, almost 55 million Brazilians had an income of less than R$ 406,00 (£62,40 as of July 2022) per month (IBGE, 2018). Within this percentage, one of the vulnerable groups is people who live in households headed by a single woman with children up to the age of 14 (56.9%). Poverty in Brazil is therefore affecting more children and adolescents up to 14 years of age (43.4%), Black men (34.1%) and Black women (34.8%) (IBGE, 2018). In 2018, among young Brazilians aged between 15 and 17 who had attended or completed high school, 76.5% were white and 64.9% Black (IBGE, 2019). Also according to the IBGE (2019), there are about 11.3 million Brazilians aged 15 and above who cannot read or write and only 8.4 million young people aged between 18 and 24 attending Higher Education.

The combination of these factors corroborate the existence of a high rate of scientific illiteracy in Brazil, characterised as “impossibility of access or difficulty in assimilating available information and knowledge” (Targino & Torres, 2014, p. 5), considering the following aspects that make up the concept of ‘scientific literacy’: “(1) general knowledge about basic and specific concepts of science; (2) knowledge about the essence of scientific activity, (3) knowledge about the social function of Science and Technology (S&T)” (Targino & Torres, 2014, p. 5). In this scenario of scientific literacy, the social function of S&T also involves the understanding of scientific culture, in which a set of values and practices is perpetuated as a type of social productions that sustains humanity, being understood as something universally intrinsic to all human groups. When building this scientific culture, science should then be disseminated throughout society by also

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\(^1\) IBGE – The Brazilian Institute of Geography and Statistics is an entity of the federal public administration linked to the Ministry of Economy, whose mission it is “to provide Brazil with the information necessary for the understanding of its reality and the practice of citizenship through official statistics and geoscientific databases” (IBGE, 2018). Such collected data/information is used in the formulation of public policies and understanding of the Brazilian socioeconomic reality.
considering the current inequalities that permeate education and attempting to prevent this scientific knowledge from becoming synonymous with power and social domination.

According to Paulo Freire (2009), there is a need for education that allows one to discuss their problems and issues; in other words, an education capable of developing the critical and democratic action of people as, without conscientization, the masses will be controlled. And, according to the author, such conscientization is the task of a liberating type of education, which needs to be linked not only to becoming aware of reality, but also to its transformation.

From this Freirean perspective, the project Investiga Menina! was created through a partnership between the Dandara no Cerrado Black Women’s Group and the Ciata Laboratory for Research in Chemical Education and Inclusion Group (LPEQI) at the Chemistry Institute at the Federal University of Goiás's (IQ/UFG). The view of science that predominates among high school students (adolescents between the ages of 15 and 18) in Brazil and in the world is characterised as an activity performed solely by lone white European men (the privileged subject), without the participation of a community involved in the building of scientific knowledge. That said, it is important to emphasise that the lack of knowledge about how scientists think and act prevents students from engaging with the scientific culture. One of the elements defended in the Investiga Menina! project, as well as in this chapter, is therefore related to representation in scientific contexts: science must represent the people who populate Brazil, them being mostly Black (56.1%) and females (51.7%), (IBGE, 2018); that is, the sciences disseminated in the Brazilian territory must emphasise the pluralities of the population it represents, especially of female and Black people.

This project then aimed to demystify the image of the scientist and bring scientific production closer to the people (Vargas, 2018; Bastos, 2020) through pedagogical interventions (PIs) and Intercultural Experiences developed in a school with partner NGOs. During the PIs, the dialogue between the Black body and chemical knowledge was tackled, with the concern of highlighting the knowledge and contributions of the Black population; in this way, some specific topics were dealt with, such as:
i. Hair chemistry; ii. The composition and mechanism of sun protection; and iii. The composition and use of makeup (Vargas, 2018; Bastos, 2020). And during the Intercultural Experiences, spaces for dialogue and exchange were arranged between the community and invited Black Brazilian scientists. During each experience, the scientists conversed and explained their research and their presence in the academic environment, as well as answered some questions from the school community and partner NGOs. In the following sections, we will share more about these initiatives, focusing on gender and sexuality.

GENDER AND SEXUALITY IN FOCUS

Looking at concepts developed in the natural sciences, the human body is “matter formed in exclusive and determined social organisation, constituting the individuality of each being” (Fernandes, 2009, p. 1052). However, ‘subjectivity’ refers to a body-subject capable of talking about itself, presenting itself and representing itself in history (Fernandes, 2009).

According to Cardin and Rocha (2013, p. 2) “human beings express their identity through symbols and discourse”, and it is necessary to understand that such forms of socialisation are not innate, but standardised social constructions that follow behaviours and aesthetic models established by dominant cultures – which is represented here by the privileged subject (Cardin & Rocha, 2013). We are, therefore, not born with attributes referring to genders, since these are elaborated within each culture.

But what exactly is gender? There is a multiplicity of meanings and concepts in relation to gender. According to Scott (1995) “gender is a constitutive element of social relations based on perceived differences between the sexes and gender is a primary way of giving meaning to power relations” (p. 86). The author emphasises that gender is a category of historical analysis, thus assigning value to language, indicating that it is a means of reflecting on other relationships: class, ethnicity and generation, from a historical perspective (present and past). Gender, as a social structure, represents “a character of counterpoint responding to biological interpretations that link sexual difference to hierarchically different social positions.
between women and men” (Santos, 2007, p. 4). Furthermore, this principle transforms biological differences into social inequalities, since certain biological characteristics, such as less physical strength and even less brain weight, were used to characterise the ‘natural’ place of women as being the home, while the ‘natural’ place for men would be the street (Santos, 2007).

In addition to defining social inequalities between men and women, gender – in terms of affective and sexual practices – is accompanied by the rejection of homosexuality, often expressed by homophobia. Heteronormativity is determined as the naturalising practice of behavioural and aesthetic patterns subjectivised by women and men (Cardin & Rocha, 2013). Thus, in the activities developed within the project described in this chapter, emphasis is placed on the importance of understanding the body in all its diversity – race, gender and sexuality, for example. In this way, it will be possible to face the inequalities generated by the different systems of oppression around this area of life.

However, analysing social inequalities and power relations without taking race into account is to reject other existing differences and oppressions. It is necessary to analyse the way in which oppressions, when combined, are capable of transforming into other forms of oppression, since race, class, gender and sexuality cannot be thought of in isolation, as they are inseparable characteristics of beings.

We then agree with Sueli Carneiro (1995) when she states that, at all social levels, Black women are devalued, and since scientific contexts are spaces of social prestige, it is necessary to publicise the Black women who occupy their places in this hegemonic environment. Accepting these assumptions, the project Investiga Menina! had, as part of its activities, to analyse the oral history of a Black Brazilian scientist (more details in the next section), seeking to highlight the barriers related to race, gender and sexuality issues that exist in academic contexts, as well as to indicate the relevance of dissemination as a mechanism that corroborates the democratisation of access to scientific knowledge.
BLACK WOMEN IN EXACT SCIENCES AND SCIENTIFIC DISSEMINATION

Scientific dissemination is an important part of the democratization of knowledge, in addition to presenting the results of a science designed for progress, and also operates in favour of democratic and citizen consolidation and construction. Furthermore, science, considered an inseparable part of human culture, is intrinsically linked to the historical, cultural and social conditions of a society. Here lie essential elements related to the political dimension of scientific dissemination, to the contribution and to responsibilities of scientific and educational systems in proposing and disseminating scientific trajectories and productions that favour engagement and understanding of the population.

S&T can be disseminated through expressive activities such as music and dance, as well as the use of communication vehicles such as television, radio and the Internet. In this perspective, we cite the example of the Dance Your PhD contest, promoted by Science Magazine and the American Association for the Progress of Science\(^2\), with the purpose of combining scientific dissemination with art, and of demystifying the image of the scientist to bring scientific production closer to the people.

The contest was created in 2008 with the aim of challenging researchers to explain their doctoral research through dance, and its main goal is to inform people about research conducted through entertainment, considering the importance of art as a political instrument of struggle and building a bridge between the public and universities/laboratories. In 2017, after competing with 53 scientists of different nationalities, biologist from Pernambuco, Natália Oliveira won the Dance Your PhD contest in the Chemistry and Popular Vote category with 78% of the votes, presenting her work on biosensors capable of identifying biological traces (blood, semen, saliva) in areas cleaned with alcohol, bleach or detergent, thereby assisting in the work of forensic investigators (Oliveira, 2017).

In the media, the victory of the Black female scientist from Pernambuco had great repercussions for the entire population. Jornal Digital Nexo announced Natália Oliveira’s victory in 2017, as seen here in Image 1 (in Portuguese):

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2. To learn more about the Dance Your PhD contest, access: https://revistapesquisa.fapesp.br/en/dancing-for-science/; https://www.science.org/content/article/announcing-winner-year-s-dance-your-phd-contest
Natália Oliveira is an actor, dancer and co-founder of a theatre company. In her doctorate in the area of Biology Applied to Health, she produced research on biosensors for the forensic sciences at the Federal University of Pernambuco – UFPE; a trajectory that goes against the hegemonic positions and naturalised perceptions of what it is to be a scientist – female, Black, and linked to the artistic field.

The video produced by Natália, entitled “Pop, Dip and Spin: The Legendary Biosensor For Forensic Sciences” (Image 2) sought through dance to present her PhD thesis with the purpose of disseminating her research, and more importantly, bringing science closer to people – mainly those who are not represented in these spaces.
By analysing the video made by the scientist, one can understand that through the dance, costumes and performers, singularity and representativeness are brought to the job. The relationship between image and body present in the work refers to the context of the ball culture that combined competition, dance and parades in gay clubs in the 1980s in the United States. Among the categories present in the shows and parades of this dance culture, we can highlight: “vogue”, “executive style”, “transvestite dressed for the first time”, “military style”, “haute couture evening attire” and “realism style” – in the latter, candidates are to dress and look like heterosexual men and women.

In this way, Vogue, in addition to being a category, is also a dance developed by the Harlem dance community itself, consisting of battle simulations where participants had to strike a series of poses, using steps and choreography to demonstrate that they were better than their opponents. With reference to this dance, the Pop, Dip and Spin video of the Black scientist begins
with the scene of a Vogue-style dance battle that ends up triggering a crime.

Jennie Livingston’s documentary Paris is Burning (2005 [1990]) portrays the reality of Harlem dances, as well as dance culture in the 1980s. It is not known where this culture originated, but according to the documentary, it can currently be understood as a community and a network of Black and Latino women, men and transgender people who are lesbian, gay, bisexual, heterosexual and queer. It is therefore necessary to point out that the Pop, Dip and Spin video is “a spokesperson for the visibility of non-normative identities, as it is part of the LGBTI culture, a culture that questions and envisages standards, shared with deviant identities” (Lima & Oliveira, 2017, p. 47).

Heterosexuality is the characteristic most synonymous with the scientist and this is due to its normalisation. Heteronormativity, as a mechanism of oppression, is capable of establishing hierarchies between heterosexuals and homosexuals, with heteronormative people having the primacy of what is valued as superior and positive. This fact shows how the sciences strongly guard expressions of the hegemonic place, since it is a space of power and narrative disputes, and still has a low presence of Black women. In this way, the video made by the Black female scientist Natália Oliveira encourages reflections precisely on what and how identities exist in the scientific environment, in addition to reviewing the naturalisation of compulsory heterosexuality (Lima & Oliveira, 2018) so that the different identities existing in this environment that elude heteronormativity can be represented and reaffirmed.

**METHODOLOGY**

The project described in this chapter has traces of participatory research as it is structured by the notion of popular knowledge production, in which the analysis, understanding and transformation of the reality of the people involved come from them themselves. This research also considered the investigative proposals of Le Boterf (1984), in which: we carried out a partnership between the teachers/educators, including continuous and initial training, with the objective of disseminating the science carried out by Black women; we approached the reality of the people involved; we problematised the low representation of Black scientists and
the existence of discriminatory barriers; and finally, we planned and executed visits of Black scientists invited to carry out an Intercultural Experience with the community.

We highlight that these Intercultural Experiences are characterised by meetings led by the invited scientists in which direct dialogue with the community was developed; at schools, this dialogue was conducted with students and teachers and, at the NGO, it was open to the entire local community. During these meetings, the scientists shared their trajectories, experiences and research, as well as answered questions from the community. In this specific chapter, we will cover the meeting conducted by the scientists Natália Oliveira and Janice Lopes.

It is important to highlight that this work was based on the research conducted by contemporary Black scientists, and that it was built in three phases. At first, scientists Natália Oliveira and Janice Lopes were invited to lead the Intercultural Experience at the partner school in Goiânia for high school students ranging between the ages of 14 and 19. In the second phase, the scientists conducted the Intercultural Experience at the Dandara no Cerrado Black Women’s Group for the participants in the NGO. In the third phase, the footage for the oral history was recorded, in video format, of the Black scientists invited for scientific dissemination on the social media channels of the Investiga Menina project. Since this chapter deals with the third phase of the Intercultural Experience, it is necessary to highlight that after being filmed for dissemination on the project channels, the oral histories were transcribed and analysed according to the Conversation Analysis Technique (Marcuschi, 2003).

THE INTERCULTURAL EXPERIENCE WITH A BLACK FEMALE SCIENTIST

After developing pedagogical interventions (IPs) with chemistry content from the high school curriculum and around themes of Afro-Brazilian

and African culture with the aim of disseminating a more representative science, in 2018 the Investiga Menina! project led Intercultural Experiences introducing contemporary Black scientists to high school students and Black women participating in the partner NGO.

In this chapter we will only deal with this last stage, that is, the one involving the oral history videos. Here we will specifically focus on the contemporary Black female scientist, Natália Oliveira, whose video is available on Investiga Menina! project’s social media channels. Below is an excerpt from the video extract.

**Natália Oliveira organises the Criminal Experts team of the Civil Police of Pernambuco.** Right at the beginning of her speech, Natália reports what led her to choose this profession in the following excerpt: “I decided to pursue my career especially as a criminal expert because I’ve always been interested in genetics and when I discovered that I could use genetics to work with criminal investigations, that’s what caught my attention the most […] You still need to discuss gender and race in the academy. Although today these minorities are becoming more present, there is still a lack of serious debate about who is practicing science in Brazil, and where these people who really practice science in Brazil belong. So, while we keep on thinking about the neutralisation of all people and don’t have firm and explicit representation at university, we will still think that everyone is there in the same environment, everyone is there in the same equitable situation, when in reality, it doesn’t exist. Girls don’t give up […] our passion for science is what motivates us to do things, and to be resistant, because on our way, we will hear several ‘no’s but it is the no that makes us leave our comfort zone […] Follow science careers, it’s not just for a bunch of white boys, the career is for us too.”

Available at: https://m.youtube.com/watch?v=9vO2XRs7fUU, accessed on: 31/10/2021.
criminal investigation, that’s what caught my attention the most.” According to data collected by the Ministry of Justice and Public Security, in 2017 only 27% of the Civil Police’s corporate workforce was made up of women, while in the Military Police, the number drops to 11% across the country (Brasil, 2019).

The inclusion of women in police careers is extremely limited and conducted with little visibility, given that different systems of oppression such as sexism have built and constituted the police as an exclusively male place. In addition, female police officers still suffer moral and sexual harassment from colleagues. Such harassment is manifested not only through jokes that disqualify the work of police officers, but also disrespectful attacks. Unfortunately, these episodes of harassment are rarely reported, as many police officers fear reprisal. As a result of the disqualification of women’s work by police organisations, many women need to prove that they are competent enough to perform the same tasks as men. Oliveira (2015) points out this reality as a female necessity to have to constantly prove that they are competent enough to do the jobs required of them, and even so, many activities can only be conducted under male supervision.

In addition to belonging to the minority of women who make up the permanent conglomerate of the Civil Police in Brazil, Natália is also part of the minority of Black women in the sciences. In the following excerpt: “It is still necessary to discuss gender and race in the academy. Although today these minorities are becoming more present, there is still a serious debate about who is practicing science in Brazil, and where these people who really practice science in Brazil belong”, the scientist highlights the importance of debating who is producing science in Brazil, and clearly points out the need to talk about them.

Rosa (2016) argues about the low representation of Black women in science and also shows that “the Black woman has the particularity of having experiences resulting from the intersection of gender and race, or in other words, of facing a combination of challenges for being a woman and being Black” (p. 4). Data from the 2016 Higher Education Census point to this reality, since, of the total of 53,995 professors in undergraduate courses (specialisation, master’s, and doctorate), only 3% are Black women (Brasil,
In 2017, the National Council for Scientific and Technological Development (CNPq) awarded 93,405 scholarships to undergraduate and graduate students and researchers from educational institutions across the country. When analysing the snapshot of gender and race, the exclusion of Black women is noticeable, as they only amounted to 15% of the scholarship recipients.

Natalia still highlights the importance of representation when she says that “while we keep on thinking about the neutralisation of all people and don’t have firm and explicit representation at university, we will still think that everyone is there in the same environment, that everyone is there in the same equitable situation, when in reality, it doesn’t exist.” This speech by the Black female scientist leads us to remember the composition and meaning of Pop, Dip and Spin: The Legendary Biosensor for Forensic Sciences, because in this work, representation was seen as something structural in its creation. Natália declares herself as a “fat, feminist woman from Pernambuco, who gives voice and visibility to women, the LGBTQIA+ community (...), Blacks and the people from Brazil’s north-eastern region, through an audio-visual production of worldwide reach” (Oliveira & Lima, 2017, p. 45).

The Black population has among the highest rates of violence, unemployment and underutilisation, as well as the highest level of illiteracy and the lowest rate of political representation (IBGE, 2018). In Brazil, in 2017, there were 65,602 homicides, of which 75.5% (49,529.51 homicides) were of Black people (Atlas de Violência, 2019). The high death rates of Black people testify to the genocide of the Black population – a fact that is invisible in Brazil. Likewise, there is concerning data about the LGBTQIA+ community regarding the violence they suffer. In 2017, 193 cases of homicide were registered by Call 100⁵, while the number of complaints reached 1,720. In 2016, the Black population accounted for 49.6% of victims of violence against the LGBTQIA+ population according to Atlas de Violência (2019). As the Black

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⁵ Disque 100 (“Call 100” in English) – Call Human Rights is a service for disseminating information on the rights of vulnerable groups and for reporting human rights violations. Through this service, the Brazilian Federal Government receives, analyses and forwards complaints of violations of the rights of vulnerable groups to the organs responsible for their protection. Complaints could be related to children and adolescents, the elderly, people with disabilities, the LGBTQIA+ population, and the homeless population, among others.
population is demarcated by racial, gender and sexuality-related violence, the representation of Black people, as shown in the video *Pop, Dip and Spin: The Legendary Biosensor for Forensic Sciences*, is essential to affirm and disseminate the multiplicity and resistance of the Black population, as well as from nonconformists of sexual and gender norms.

When this discussion is directed to the ranks occupied in society, it is possible to perceive how affectivity can determine the positions to be taken up. In this sense, it is necessary to analyse which and how such discriminatory factors can act in the construction of the society we live in, so that we can think of one that is more equitable. As reported by Natalia Oliveira in the analysed video: “*Girls don’t give up [...] our passion for science is what motivates us to do things, and be resistant, because on our way, we will hear several ‘no’s, but it is the no that makes us leave our comfort zone [...]***”. In this way, the Black female scientist’s speech not only reflects her struggles and challenges, but also her passions and what motivated her to keep on. Her oral history portrays the possibility of articulating different areas (such as the artistic and scientific fields), breaking away from scientist stereotypes and contributing to convergent representation with the diversity that makes up Brazilian social contexts. The fight against racism and sexism, for example, can be done by bringing together different teaching systems (schools, universities, NGOs) and favouring scientific dissemination.

**CONCLUSION**

Scientific dissemination is an indispensable component of the education of people and for the construction and constitution of a scientific culture that seeks to disseminate the scientific discoveries of national science to the entire population. It is also up to those who decide to use different scientific dissemination devices to challenge gender, ethnic, sexual and social stereotypes that involve the sciences, thus seeking to highlight the researchers who are not represented, thereby disseminating the science produced at national level that is also produced by women, Black and LGBTQIA+ communities.

The analysis of the theoretical framework, as well as the results obtained in this project, demonstrates the need to disseminate Black female Brazilian
researchers and the science produced by them to show the population who is producing science and to encourage Black girls to pursue careers in the areas of S&T. Furthermore, our results demonstrate the importance of scientific dissemination in the deconstruction of the hegemonic science vision. We believe that in this way the scientific fields can be transformed, breaking up hegemonic structures and images, and contributing to the establishment of spaces with equity that represent the plurality of the Brazilian population. Such transformations of scientific fields can impact non-formal and formal education contexts. Teaching can be rethought and restructured, in order to consider contemporary news or stories and productions by Black female scientists as paths to conceptual, procedural and attitudinal approaches. There is, therefore, an indication here of the potentiality of scientific dissemination together with educational work in recovering historical and epistemological aspects of science, as well as its responsibility with social justice.

It is therefore important to emphasise the importance of establishing connections between schools and other institutions, such as universities and social movements, in order to enhance dialogues from other understandings of education, community, engagement, production of scientific knowledge, also aiming at the inclusion of bodies and stories that have been silenced for so long. In this way, the presentation of science articulated with social issues, which is quite different from the sciences presented at other times in their trajectories at school, accompanies the presentation of new ways of being, practicing and presenting science. Works such as Vargas (2018) show this when dealing with hair chemistry, bringing out aspects about ionic bonds and sulphide bridges and the relationship with the appearance of hair, whether it is straight, curly or frizzy. Vargas (2018) also worked with the issue of media and racism, pointing out, for example, the advertisements about hair straightening products and the way in which the beauty standard based on straight-haired white women is propagated.
BIBLIOGRAPHIC REFERENCES


THE EQUITY COMPASS AND THE SCIENCE CAPITAL TEACHING APPROACH: TEACHER TOOLS TO SUPPORT CRITICAL PEDAGOGY

SPELA GODEC
MEGHNA NAG CHOWDHURI
**Abstract:** Science can be understood and practised in different ways. Research shows that school science often celebrates particular ways of ‘doing science’, and while some forms of knowledge, skills and experiences have value within a classroom, others less so. In this chapter, we begin by presenting UK-based research on science participation and discuss the challenges young people experience in engaging with science. We explain the idea of ‘science capital’, which has been helpful to understand the varied participation in science, drawing attention to the issues of inequalities. We then outline two practical tools that can support teachers in developing more equitable teaching practice: the Equity Compass (a reflection tool with eight equity dimensions) and the Science Capital Teaching Approach (a pedagogic approach that focuses on broadening what and who counts as science, and supporting students in making meaningful connections with science and builds science capital). We conclude the chapter by discussing how implementing the two tools can support critical pedagogy.

**INEQUALITIES IN SCIENCE PARTICIPATION – INSIGHTS FROM A LONGITUDINAL STUDY OF ASPIRATIONS IN THE UK**

There is ample evidence that in the UK and many other countries, there are marked patterns in who tends to study and work in science (along with wider science, technology, engineering and mathematics, or STEM, areas) (OECD, 2017; Royal Society, 2020; UNESCO, 2019). Despite decades of initiatives to encourage more diverse participation, participation in these subjects remains dominated by people from more privileged socioeconomic backgrounds. The ASPIRES study¹ (Archer et al., 2020), a longitudinal study with over 40,000 surveys in the UK tracking young people’s aspirations from the age of 10 to 23, has found that contrary to a common belief, the gap in participation is not due to lack of interest or enthusiasm for science.

The study reports that the majority of young people found science interesting and valued science. However, they did not see themselves as ‘being’ or ‘becoming’ a scientist, or pursuing a science career. Young people’s aspirations were patterned by gender, socioeconomic background and ethnicity from a young age – with high achieving, middle class, male students, and those with high levels of the family ‘science capital’ (see below for an explanation) being more likely to aspire to a science career and see science as being ‘for me’ (which is often referred to as a ‘science identity’).

The ASPIRES study found that young people's aspirations are shaped by a number of factors, including: i) dominant representations of science as ‘clever’ and ‘masculine’; ii) educational practices such as science teaching, careers education and educational gatekeeping; and iii) capital-related inequalities such as what resources and support students have available. Based on the early analysis of survey data from the ASPIRES study, Archer et al. (2015) proposed the concept of ‘science capital’ as a way to think about capital-related inequalities that influence young people’s aspirations, which we turn to next.

**WHAT IS SCIENCE CAPITAL AND HOW CAN THIS CONCEPT HELP US UNDERSTAND INEQUALITIES IN SCIENCE/STEM PARTICIPATION?**

Science capital is a combination of science-related resources that a person has, including: i) what you know about science; ii) how you think (e.g., do you value science?); iii) who you know (e.g., does a family member work in science?); and iv) what you do (e.g., do you engage in science-related activities outside school, such as reading books, watching science videos, talking to other people about science?).

Research has found that young people with ‘higher’ science capital tend to be more likely to aspire to science and identify with science. Science capital scores vary by gender, ethnicity and socioeconomic background. In the UK, young people with ‘high’ science capital were significantly more likely to be boys, South Asian and from a more privileged socioeconomic background (Archer et al., 2015).

Explaining in depth the sociological theory that underpins science capital, along with the work of Pierre Bourdieu that originally proposed the concept of ‘capital’ and how it operates alongside ‘habitus’ and ‘field’, is beyond the scope of this chapter. But, below, we offer a short example to
illustrate how some (science) capital can be of limited value if it is not recognised, such as in the context of school science, and what this might mean for the person involved.

Alfie is 12 years old, and he aspires to becoming a DJ or a music producer. He shows little interest in continuing with education post-16 (when education is no longer compulsory). His science teacher regards him as disengaged and Alfie thinks that science is 'not his thing'. He cannot think of anyone who works in a job that uses science and says he never participates in anything science-related himself. Yet, if we think more broadly about science, we can identify a number of science-related resources in Alfie’s life. For instance, Alfie's dad runs a small events company and Alfie often joins him at the weekends. Alfie is responsible for installing the music equipment and ensuring that the circuits are set up correctly and that fuses are not overloaded. Alfie's extensive knowledge and skills, however, go unrecognised in his science lessons. He has had few opportunities to share his knowledge, skills and experience, and those of his family members (his 'science capital') at school. Consequently, he has not made a connection between his practical understanding of technical equipment and science taught at school (dictated by a curriculum). In turn, Alfie does not see his extensive science-related skills as science-related and maintains that science is not for him. (adapted from Godec, King & Archer, 2017 teacher handbook)

The above example illustrates that unless young people's science-related skills and experiences are recognised, such as within school, their value as science capital is limited. This can have implications for how young people relate to science and how much they think science is part of their lives. It is not a supposed ‘lack’ of science that is the problem in Alfie's case, but rather what is recognised and considered important and valuable within a specific setting (in this case, school science).

**CHANGING PRACTICE: THE EQUITY COMPASS AND THE SCIENCE CAPITAL TEACHING APPROACH**

In the rest of the chapter, we focus on two practical, research-based tools that teachers can adopt in their practice to reflect on how equitable their current practice is (using the first tool, the Equity Compass) and tweak their lessons to help engage more young people in equitable ways (using the second tool, the Science Capital Teaching Approach). Both tools
have originally been developed within the science education context, through extensive collaboration with informal STEM learning practitioners (the Equity Compass) and teachers (the Science Capital Teaching Approach). However, the tools are not science-specific but focus first and foremost on supporting equitable teaching and learning in a broader sense. Indeed, these tools have been applied to other contexts beyond science. For the purpose of this chapter, however, we emphasise specifically how the two tools can support science teachers.

The focus of these tools is particularly on supporting young people from minoritised groups and those who have historically been excluded from science. In the context of the UK, this includes young people from lower socioeconomic background, girls – concerning some science/STEM subjects – and some minority ethnic groups, like Black students, who in the UK face particular disadvantages and have a low progression to science despite reporting a strong interest (Archer et al., 2020).

It is important to stress here that the tools are not aimed at simply supporting the STEM pipeline, that is, to increase and diversify numbers of young people entering STEM careers. Rather, the tools are primarily aimed at supporting all young people to actively engage with and use a wide range of diverse science/STEM-related knowledge and skills in their lives, no matter what educational and professional trajectory they follow.

This chapter provides a brief outline of each tool, with an illustrative example for each. We provide links to more in-depth resources in the Reference section (all resources are available online in English and Portuguese).

**REFLECTION: THE EQUITY COMPASS**

The Equity Compass (Figure 1) is a tool that can help teachers to reflect on and develop their teaching, adopting a social justice mind set (YESTEM Project Team, 2021a). The tool highlights that it is important to reflect on not just what you do, but how and why you do it. At the heart of the Equity Compass is a consideration of power – who drives the teaching and learning agenda, who/what is represented and who/what is excluded, and how pedagogy can be developed to best

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2. We use the term ‘minoritised’ rather than ‘minority’ to put the emphasis on the systemic issues and structures that are failing to sufficiently recognise, support and value some people. People can be minoritised within a particular society depending on their race/ethnicity, gender, socioeconomic background, dis/ability, sexuality and other social axes. Who is minoritised might differ between national contexts.
support minoritised students, who less commonly have a voice and power within the mainstream education system.

The tool was originally developed and tested in partnership with informal STEM learning settings in the UK and the US, as part of the Youth Equity and STEM (YESTEM) project\(^3\) based in the UK at the University College London. The Equity Compass has since been used by teachers in primary and secondary schools, to date predominantly in the UK, for teaching science and other subjects, and for considering equity issues beyond the lessons.

3. [https://yestem.org](https://yestem.org)
Of the primary school teachers involved in the Primary Science Capital project, who used the Equity Compass throughout the academic year in 2020-21, 93% said that they felt that their understanding of equity-based teaching and learning had improved. Evidence from research in informal STEM learning also shows that the Equity Compass tool has supported practitioners in developing critical reflective practice, including becoming more self-reflective and intentional in their work (Archer et al., 2022).

Below, we present the four key areas of equity included in the Equity Compass: Challenging the status quo, Working with and valuing minoritised communities, Embedding equity, and Extending equity. We give examples of guiding questions for each of the eight equity dimensions in Table 1, and conclude the section with an illustrative example of how the Equity Compass has supported a teacher with reflecting on making changes in relation to one specific activity – organising a STEM career session for the students.

Four areas of the Equity Compass

Challenging the status quo is about considering the dominant relations and representations that can exclude some young people from meaningfully engaging with STEM. This equity area includes:

- transforming the dominant power relations, such as typical representations of science/STEM and of STEM professionals;
- prioritising the needs, interests and values of minoritised communities, such as ensuring the activities are guided by (minoritised) students and not the dominant players (e.g., the economy, STEM pipeline);
- redistributing resources, such as to ensure that education efforts are not further reinforcing privilege by better serving those who are already better resourced, but support those who may have traditionally had fewer opportunities.

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Working with and valuing minoritised communities includes:

- working ‘with’ students rather than delivering content ‘to’ or ‘for’ them, emphasising the importance of sharing power, and teachers and students meaningfully co-designing learning experiences together;
- taking an asset-based approach that recognises students for who they are rather than who they are not, and values their diverse knowledge, skills and experiences.

Embedding equity stresses the importance of equity needing to be mainstreamed throughout all aspects of practice and throughout the whole school and wider education system. Equity can not be limited to a few selected individuals or initiatives.

Extending equity includes:

- equitable practice being sustained and longer-term;
- ensuring that equitable practice benefits not only the students directly involved, but also for their families, their community and wider society.

The Equity Compass reflective questions

Table 1 presents examples of guiding questions for each of the eight equity dimensions covering the four overarching areas outlined above.
### TABLE 1: EQUITY COMPASS GUIDING QUESTIONS (ADAPTED FROM YESTEM PROJECT TEAM, 2021A)

<table>
<thead>
<tr>
<th>Equity areas</th>
<th>Equity dimensions</th>
<th>Example reflective questions for teachers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Challenging the status quo</td>
<td>Transforming power relations</td>
<td>What attention is given to understanding, challenging and transforming dominant representations of STEM (e.g., that scientists are wealthy white men)? Do students from minoritised communities feel that their classroom/school is a place where injustices in all forms (e.g., racism, sexism, ableism, classism and LGBTQI+ prejudice, and so on) are being addressed and challenged?</td>
</tr>
<tr>
<td></td>
<td>Prioritising minoritised communities</td>
<td>Whose interests, needs and values drive your teaching and the curriculum – those of the ‘dominant’ groups (e.g., STEM industry, STEM pipeline – reflecting a need for more future STEM professionals) or those of students, particularly those from minoritised communities?</td>
</tr>
<tr>
<td></td>
<td>Redistributing resources</td>
<td>How are minoritised students being supported? Are opportunities, e.g., additional activities and school trips, predominantly directed at more privileged students?</td>
</tr>
<tr>
<td>Working with and valuing minoritised communities</td>
<td>Participatory working – with</td>
<td>How participatory is your teaching? What opportunities are available to students to have any say in what and how they are being taught?</td>
</tr>
<tr>
<td></td>
<td>Assets-based approach</td>
<td>How are you valuing minoritised students’ identities, cultural, experiential and home knowledge and experiences – within and beyond STEM?</td>
</tr>
<tr>
<td>Embedding Equity</td>
<td>Equity is mainstreamed</td>
<td>How mainstreamed, intentional and foregrounded are equity issues in your teaching and at your school?</td>
</tr>
<tr>
<td>Extending Equity</td>
<td>Long-term</td>
<td>How are equity initiatives and experiences extended towards being longer term? How does the school track student experience to monitor equity issues and impact?</td>
</tr>
<tr>
<td></td>
<td>Community / Society orientation</td>
<td>To what extent does your teaching support more collective, community-oriented outcomes (e.g., identifying systemic inequalities within the school and the community it serves)?</td>
</tr>
</tbody>
</table>
The Equity Compass tool is designed to be a formative tool to support honest, on-going reflection. It is not about trying to get a ‘perfect score’ or ticking off areas as ‘done’. Developing equitable practice is an on-going process. The Equity Compass can be used to reflect on anything from an individual science lesson to a school-wide programme, and can also be helpful for strategic thinking and development. Working with school leaders in the UK, for instance, we also developed a version of the above questions specifically for school leaders and governors (YESTEM Project Team, 2021b), which would be useful for anyone in a leadership role.

**An illustrative example of the Equity Compass in action**

To illustrate how the Equity Compass has been used by teachers in the UK, we present a short case study, highlighting the specific equity dimensions in bold.

*In the UK, schools often invite professionals to talk to students about their job, with the aim of enthusing students for specific careers. Here, we present a case of a Civil Engineer visiting a school on an annual basis to talk about his work at a local construction company, to inspire students to pursue STEM careers.*

The engineer is an older man who usually wears his construction hat to school visits. He speaks to students about how he became an engineer, what his day looks like and how exciting it is to go into engineering. The presentation is followed by a short hands-on activity where students build bridges using lolly sticks.

The students generally enjoy the sessions and learn new things about engineering. Yet, from an equity perspective, there are aspects that could be developed further to better support all students to engage with engineering, particularly those from minoritised backgrounds who tend to be underrepresented in STEM disciplines.

Using the Equity Compass, the class teacher reflects on how the visits might be reinforcing stereotypical images of engineers (as white men in construction hats). Thinking about ways to **transform power relations**, the teacher discusses with the engineer how he could invite a discussion about the diversity challenges in the sector. The teacher also thinks about how to make the session more **participatory** and more **asset-based**, inviting a conversation about what engineering skills students have already (and valuing a broad range of skills), what students might want to know about becoming an engineer, and if and how they think engineering could help improve their lives or help a cause they care about.
The teacher also reflects on how, generally, many of the STEM engagement opportunities at their school tend to be offered to the students with the highest marks and those perceived by staff as being ‘the most interested’. These students tend to be from more privileged backgrounds. The teacher decides to raise the issue at the next department meeting, with a view to developing a more inclusive approach aimed at redistributing resources, by ensuring that the school pays attention to supporting students from minoritised communities. One way how this could be done is by making sure that additional experiences, such as school trips and meeting STEM professionals, are open to everyone and that everyone is encouraged to attend, with support made available to those who require this.

By raising this issue with his colleagues, the teacher also made a step towards embedding equity at the school – working towards equity issues becoming a shared aim, while also recognising that a school has a long way to go. (Adapted from YESTEM Project Team, 2021a and 2022)

**ACTION: THE SCIENCE CAPITAL TEACHING APPROACH**

Transforming science teaching to meet social justice goals requires a critical reflection of educational practices and processes, as proposed by the use of the Equity Compass above, as well as an active shift in practice. To this second end, our research team has developed a model to support science teachers in changing their practice for equitable science engagement, by making small tweaks to their lessons while also adopting some foundational principles. While student disengagement in science in schools is a result of larger socio-political-economic factors, the approach provides specific ways in which teachers can both recognise the ways in which these impact classroom dynamics and find ways of resisting them.

The Science Capital Teaching Approach is a culmination of collaborative research and practice partnership work that started in 2013 with secondary schools (Godec, King & Archer, 2017), and since developed with primary schools in England between 2019-2021 (Nag Chowdhuri, King & Archer, 2021). The secondary school teachers involved were all science teachers. The primary school teachers, in the subsequent project, taught science as well as other subjects, which allowed us to study how the approach can work across the curriculum and inform a whole school approach to more equitable practice.

The approach is encapsulated in the model shown below (Figure 2). The approach builds on the existing good practice of science teaching and supports teachers to make tweaks based on the key
tenets of the approach. We explain the key tenets (the foundation and three pillars) below, followed by an illustrative example of what the Science Capital Teaching Approach looks like in a classroom. The approach can be used with any curriculum, any lesson plan and can support teachers to change their practice towards more equitable science teaching (and teaching other subjects, too).
Foundation of the Science Capital Teaching Approach: broadening what and who counts

At the heart of the approach is the essential foundation that is based on broadening what and who we value in science teaching and learning. The foundation encourages teachers to challenge traditional representations of science as white, male, hierarchical, elite etc., making science teaching and learning more equitable and participatory.

Thus, teachers reflect on both ‘what’ is being taught as school science (can we widen what sort of scientific knowledge and discourse enter the lesson?); and who gets valued as being ‘good’ or ‘bad’ in science (can we focus on who tends to be labelled as being less scientific?). This foundation supports teachers and schools to think about current practices and, thereafter, expand these practices to support a wider range of scientific behaviours and contributions.

The foundation seeks to value all students and focuses on changing the way we teach science in order to better engage all students, but particularly those from minoritised communities. In the following sections, some of the practical ways of broadening what and who counts are presented.

STARTING WITH THE CHILD

The first way to broaden what and who counts in science lessons is to ‘start with the child’. This foundational activity reinforces the value of child-centred teaching and learning, and helps bring it to the forefront of teachers’ thinking and planning. Teachers intuitively consider their students’ needs, but the pressures of covering content can sometimes hinder child-centred teaching. Focusing on how students experience lesson content and what they might already know about the content, rather than thinking primarily about the content that has to be delivered, can make lessons more meaningful for all involved. Starting with the child also means explicitly recognising the unique contributions that each student can make to a class, and considering how you can value and address this through your teaching. This aspect of the foundation has several similarities with the idea of ‘working with and valuing minoritised communities’ from the Equity Compass (see above).
FOSTERING INCLUSIVE TEACHING AND LEARNING

Different students engage with science lessons in different ways and to different extents. Often, science is taught from the perspective of the most privileged, which can lead to different groups of students (from certain communities) being more likely to feel excluded from science. Teachers already consider how best to make the content relatable to their pupils but we often do this in general terms, which can reflect the identities, experiences and interests of ourselves (the teachers), or the majority group of students. By shifting our perspectives to think about a science lesson through the eyes of those students who we might currently not be reaching, we can identify more tangible ways of adapting the lesson.

SUPPORTING STUDENT VOICE AND AGENCY

The third key element supports students to have a voice in the way lessons are designed and taught. This is not only about listening to the students but enabling their voice to direct the lessons in a way that students are able to learn science that is important to them. Student agency in science involves bringing the science back into their lives and communities, as science moves beyond the classroom. This supports the idea that science is not just a destination (future science careers), but a vehicle that empowers students to be able to live in a democratic world which they can impact using their socio-scientific skills, experiences, knowledge and understanding.

Three pillars of the Science Capital Teaching Approach: techniques to build on the foundation

The three supporting pillars of the Science Capital Teaching Approach are built upon the foundation of broadening what and who counts. These three pillars provide techniques for teachers to enact the approach: personalising and localising; eliciting, valuing, linking and extending; and building science capital. An illustrative example including the elements of the foundation and the pillars is provided later in this section.
PERSONALISING AND LOCALISING

Personalising and localising is about making science content \textit{personally relevant} to the everyday lives of students. The key is to relate the content to examples and experiences from the students’ own lives. This is not just about contextualising science using general real-life examples, but engaging more deeply with students’ lives to understand the knowledge, skills and experience they bring with them. These then become part of the science lessons through personalised and localised science teaching.

ELICITING, VALUING AND LINKING AND EXTENDING

Eliciting, valuing and linking and extending supports students in feeling that their ideas and experiences are valid in the context of science. It helps students feel more able to contribute and participate in the science classroom. In this way, more students feel that science can be for them.

BUILDING SCIENCE CAPITAL

To help support students’ engagement with science, teachers can \textit{build} their students’ science capital by embedding the four areas of science capital (what they know, how they think, what they do, who they know) across and throughout their lessons. This pillar includes both recognising existing resources that students already have and developing new resources and experience that we know from research are important for supporting young people’s identities, aspirations and participation in science (see science capital explanation above).

An illustrative example of the Science Capital Teaching Approach in action

The example below shows how one of the teachers, Mr Williams, used the Science Capital Teaching Approach in his science lessons.
Mr Williams is a Year 3 teacher (teaching students aged 7-8). He finds the social justice orientation of the approach particularly appealing as a lot of the students in his class, while being interested in science, don’t always engage in the lessons. For a science lesson on ‘sounds’, he decided to start with the students’ understanding of sound (Foundation: Starting with the child). Mr Williams asks the students to note down all the sounds they hear on their journey from school to home (Pillar: Personalising and localising, focusing on students’ everyday experiences). This was an experience common among all students and did not depend on the resources or backgrounds of the students.

Mr Williams encouraged the students to share their list and made sure to recognise and appreciate all contributions (Pillar: Eliciting, valuing, linking and extending). He was particularly focused on those students who are less often vocal in class and who tend not to see themselves as being ‘scientific’. The rest of the class listened carefully to each other, as they were also keen and intrigued by the contributions of these students who hardly spoke (Foundation: Fostering inclusive teaching and learning).

The classroom culture shifted slightly when it wasn’t just about getting the ‘right’ answer but creative observations that the students had about sounds in their environment. Students swiftly moved the conversations to what they like or dislike about these sounds. The teacher supported and encouraged this discussion, and surprisingly one of the girls who would often be quiet in class talked about her experience with sound. She often had to use noise-cancelling headphones in class as she found loud sounds and a lot of students talking together irritating. She described how these sounds made her feel, which was an interesting perspective for both the teacher and her peers. Letting the students speak about their experiences and bringing that into science lessons really reshaped the dynamics within the class.

The teacher finished the lesson by asking the students whether they can think of anyone in their extended family who needs to know about sound in their work or hobby (Foundation: Building science capital). The students’ contributions included a range of jobs and activities, within and beyond science, including a childminder (who needs to make sure the space is quiet enough for children to nap), a restaurant manager (who needs to think about the volume and sounds to accommodate guests) and a museum guide (who is often in charge of a session for children with autism and needs to make sure the environment is not overstimulating). This conversation contributed to students’ understanding of transferability of science skills and help them see that many of their family use science skills in their work, even when their jobs might not be typical science jobs. (Adapted from Nag Chowdhuri, King & Archer, 2017)
CONCLUSION: HOW DO THE EQUITY COMPASS AND THE SCIENCE CAPITAL TEACHING APPROACH SUPPORT CRITICAL PEDAGogy?

Freire (1970) said that there was no such thing as neutral education. At their core, both the Equity Compass and the Science Capital Teaching Approach are concerned with issues of power, equity and social justice. These tools acknowledge that continuing with things ‘as they are’ is not neutral but perpetuates inequalities. By challenging the dominant power relations and working with and valuing young people from backgrounds who have been historically excluded from STEM, we see these tools having the potential to address the relations between ‘the oppressor’ and ‘the oppressed’, to use Freire’s (1970) terminology.

We would argue that the tools presented in this chapter also help challenge what Freire (1970) called the ‘banking model of education’, whereby learners are regarded as passive participants in their learning, expected to receive, memorise, and repeat information – while the power and authority mostly stays with the teacher. Freire wrote that “the teacher teaches and the students are taught, the teacher knows everything and students know nothing, the teacher thinks and the students are thought about, the teacher talks and the students listen... the teacher confuses the authority of knowledge with his or her own professional authority” (p. 73).

While science education literature on teaching and learning has recognised several ways of challenging this antiquated view of teaching, by embracing ideas such as inquiry-based learning and context-based learning (Sevian et al., 2018), there still seems to be a lack of focus on issues of power and privilege. For example, context-based science learning has been important to science education, but it often focuses on application, comprehension and utility of science in everyday life rather than foregrounding cultural, personal and political aspects of students and schooling (Sevian et al., 2018). This issue is also compounded as there is scant coverage of social justice theory and pedagogy within much both initial teacher education provision as well as continued professional development within the contemporary school’s landscape in UK (Bagley & Beach, 2015). As a result, practices in science
lessons often continue to reproduce inequalities rather than explicitly challenge them (see Archer et al., 2017 which talks about mascular intellect being valued within science lessons).

Specifically, the Equity Compass’ focus on *Working with and valuing minoritised communities* (*Participatory working* and the *Asset-based approach*) and the Science Capital Teaching Approach’s focus on *Starting with the child* and *Supporting student voice and agency* are examples of how these tools offer ways to creating a shift towards the teacher no longer being the (only) one who teaches, but rather is one who works together with students – and learns from and with them. Further, the Science Capital Teaching Approach’s *Personalising and localising* and *Eliciting, valuing, linking and extending* can support critical pedagogy-informed strategies whereby students explore issues and topics that are meaningful to their lives, while their existing knowledge, skills and experience are being recognised and valued. This focus, we would suggest, can extend to young people themselves being supported to challenging inequalities in their lives, within and beyond the school walls.

In conclusion, the Equity Compass and the Science Capital Teaching Approach are two powerful, research-based tools to help teachers reflect on and develop more equitable teaching practice. By providing achievable and manageable ideas for tweaking science lessons, such as making them more personal and meaningful to students, teachers start to understand, question and resist predominant inequitable ways of science teaching and learning. It is important to note that the issues of power and inequalities are ingrained into our society, and cannot be simply remedied by tweaks to science lessons. However, these tools can be used as a means of developing an equitable mind set and a deep professional commitment to identifying and addressing inequalities – among science teachers, the schools, and the wider society.
REFERENCES


HOW DO 16-17 YEAR OLD SCHOOL STUDENTS ENGAGE WITH SCIENTIFIC RESEARCH?

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Abstract: Our article explores how 16-17 year old school students discuss contemporary scientific research and how they use their current school science knowledge in thinking through open research problems in biomedical science. Contemporary research problems (somewhat simplified) were presented to school groups of six participants who were tasked with discussing possible solutions. More specifically, they were asked to devise testable hypotheses and experiments to account for cell movements that form the embryonic spinal cord. An experienced researcher presented the problem and was available to answer student questions and to prompt them when they became stuck. Our analysis shows that fruitful discussions have the following three features: authoritative scaffolding encouraging elaboration, explanation and use of pupil knowledge; willingness of participants to problematise and revise suggestions; and collective elaboration of ideas sufficient to stimulate new questions. Students drew on knowledge through dialogue which problematised their school knowledge and opened-up its difficulties in application to a research task. We suggest that an openness to new ways of thinking and uncertainty in learning science rather than the STEM 'pipeline' might attract more young people from minority groups into studying science at university and open up new pedagogic possibilities in addressing science research in schools.

INTRODUCTION

Much effort has been devoted to recruiting young people to the ‘Science, Technology, Engineering and Mathematics/STEM pipeline’ (van den Hurk et al., 2019), deemed important for societal benefit. Pipelines convey liquids, usually petrochemicals, from one place to another; which is not the most congenial term to use throughout a time of climate crisis. This curious phrase also conjures up extreme passivity, that it is a good thing of itself to enable young people to be pumped like a liquid towards STEM careers.

Over the years there have been a number of attempts to fill this pipeline with people who are often
excluded from the STEM marketplace, for example Women Into Science and Engineering/WISE, and boosting young Black researchers in STEM (Gewin, 2020). The ASPIRES research (Archer et al., 2015), also part of this book, has demonstrated the influence of social capital and habitus in supporting young people to take up STEM study and careers.

One of the problems of the transition between school science and science in higher education is that a whole new way of thinking and being has to be developed to engage in scientific research. Chinn and Malhotra (2002) have demonstrated many of the differences between science as gleaned from school textbooks and the realities of research, some of which are listed in Table 1. Of course, many science lessons are innovative and challenging so we have included only those aspects of scientific research that school students might find unfamiliar.

<table>
<thead>
<tr>
<th>1</th>
<th>Research questions</th>
<th>Generate or adapt own research questions</th>
<th>Research questions provided</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Variables</td>
<td>Select variables to investigate out of many possibilities</td>
<td>Investigate and report on prescribed variables</td>
</tr>
<tr>
<td>3</td>
<td>Planning measures</td>
<td>Typically incorporate multiple measures of independent, intermediate and dependent variables</td>
<td>Focus on one outcome variable</td>
</tr>
<tr>
<td>4</td>
<td>Transforming observations</td>
<td>Often repeatedly transformed into other data formats</td>
<td>Drawings or straightforward graphs (if transformed)</td>
</tr>
<tr>
<td>5</td>
<td>Indirect reasoning (i)</td>
<td>Observations related to research questions by chains of inference</td>
<td>Observations directly related to research questions</td>
</tr>
</tbody>
</table>

TABLE 1: DIFFERENCES BETWEEN RESEARCH SCIENCE AND SCHOOL SCIENCE (ADAPTED FROM CHINN & MALHOTRA, 2002)
Those who master the ways in which success in science studies is measured, through school examinations, might not be best suited for the uncertain and serendipitous world of research. Conversely, those who have struggled with providing the “right” answer, and hence under-achieved in examinations, might just be the students who can best deal with research problems. Wheeldon et al (2012) found in the context of learning about chemical equilibrium that, when faced with solving a problem where an algorithm could not help, some lower attainers were more successful than their high-achieving peers because they had thought beyond the received wisdoms. Taken together, these works by Chinn & Malhotra (2002) and Wheeldon et al. (2012) suggest that current educational practices might be suboptimal in recruiting talented people to the research endeavour.

While most investigations on students learning authentic science practice has focused on laboratory-based activities, our intention was to study the way students elaborate explanations behind mechanisms, removing the possible distractions of a laboratory environment. Millar and Abrahams (2009) have researched practical work in school and shown that far too often pupils are
following the teacher’s instructions rather than reflecting upon the underlying scientific ideas that inform the practical work. Addressing this problem is central to the aim of our research. Linking the knowledge and ideas to understanding the complex natural world is surely a central educational goal.

The initiative for the research we discuss in this article was a chance opportunity. An enthusiastic biology teacher (Olga Markoulides) had approached Stephen Price (a Bioscience researcher) and asked him to talk about his research to her year 12 (17-18 year old) biology students from a socially diverse and disadvantaged area of London. These students were keen and interested so, subsequently, they and students from other schools were invited to the University College London (UCL), where Stephen Price works. We built into these visits an opportunity for students themselves to develop and formulate their own ideas in contemporary scientific research.

Although there has been little research done with pre-university students discussing mechanisms in scientific developments, there were some indications that this might be a fruitful way for students to gain a nuanced view of scientific research. Epstein (1970) reported that the use of primary research papers in undergraduate biology programmes in the United States stimulated interest in all students. Epstein identified four features for this success: students should be new to research; focus should be on the researcher’s work rather than their scientific content; class sessions should be based on student questioning; and there should be no pressure on students to participate. We thus grounded our empirical research on Epstein’s approach.

Roth & Bowen (1995) also allude to five significant features of open inquiry learning: participants learn through ill-defined problems; they experience uncertainties, ambiguities and “the social nature of scientific work and knowledge” (p.1); learning is based on what they already know; participants take part in shared discourses; and participants can draw on the “expertise of more knowledgeable others” (p.1), i.e. a research scientist or teacher. These features are present in the episodes we describe here.

**APPROACH**

The basis of our research was to focus on the development of ideas through discussion and on how students might
draw on what they already knew; in this case cell division and differentiation at A-level standard. We wanted them to talk through ideas of a contemporary research problem prompted by a research scientist. The research problem we asked them to consider was the mechanism behind post-mitotic cell movements in the developing spinal cord of the chick embryo. As any multicellular living organism develops, cells divide and move in particular patterns. But what drives this process? How come the pattern is faithfully repeated each time?

We asked students to work in groups of six. We also made it clear that this was ongoing research, and that there were no right or wrong answers. We encouraged speculation: i.e., at first the students were told the nature of the problem and presented with a simplified model (Figure 1) to stimulate initial discussion.

![Figure 1: Simplified Model](image)
For each stage the students were asked to suggest a possible mechanism, i.e. what might explain cells with the same function separating in the same way each time, as represented by orange and green spheres (Figure 1A). They were also asked to propose possible experiments to test their hypotheses. As the discussion progressed they were shown further stages (B-F) to deepen the problem.

The discussions were recorded with the students’ informed consent. Researchers also took notes sitting aside from the group. The students could ask the scientist any questions they wanted at any time, and indeed, did so. We also asked the students to complete a short questionnaire about the subjects they studied at A-level and their perceptions of scientific research both before and after the intervention. These were identified through content and word cloud analysis. Students’ names are anonymised throughout.

FINDINGS

DISCUSSION

At first, we had to accept that what would transpire in the discussion was unknown. We had piloted talk about the model in Figure 1 with trainee science teachers without a background in this type of research and decided there was sufficient material at an appropriate level to initiate this project. But we were concerned that the students would run out of ideas at an early stage, boredom would set in and we would have to abandon the programme. With the first group there was hesitancy at the beginning but with some gentle scaffolding from the researcher the discussion deepened. In this article we present three episodes from the discussion from one group of students that illustrate many of the salient features of this discussion.

For the first seven minutes students had been discussing with little progress what makes the two types of cell (modelled as orange and green) separate (see Figure 1A). What we mean by little progress is that when a student makes a suggestion (initiates an idea) it is either not followed up by another participant, dismissed, or fades out of the discussion. After some hesitant student contributions, the research scientist (RS), prompting the discussion, reminds the students that the cells are in a post-mitotic phase, i.e. they have stopped dividing. So how does that influence the problem? At this point one of the students, Muna, initiates an episode with a statement resulting in a dialogue with RS, which we reproduce below.
In this episode, similar to initial episodes with other groups, Muna rephrases the question out loud, assisted by the research scientist, who tries to break down the question into its component parts (what would you need to attract cells? You've got red and green cells randomly mixed at first so what might work in terms of attraction?) to enable explanation. Muna tentatively attempts a general explanation ‘common factors’, and after RS’s encouragement, suggests more specific potential causes (‘pH levels’, ‘iron levels’).

Many researchers have advocated the role of the sort of support that RS offers to help explicate fruitful inquiry questions. There is a lot at stake here for Muna, and for other students at a similar phase. They have not regularly engaged in open inquiry, certainly at research level, and there is an understandable risk of being out of their depth. Kawalkar and Vijapurkar (2013) argue that questioning in the context of inquiry is aimed not at evaluating conceptual knowledge but in eliciting students’ ideas so that they can clearly explicate them and hold them up to critique by their peers.

The support of the RS, together with affirmation after tentative responses, enables Muna to develop ideas that help the group move on in its explanation. As we shall see in episode 2, which follows on directly, RS now looks to others in the group to contribute.

1. (F) indicates female, (M) male
In episode 2 RS supports Rabia in explicating in sufficient detail to construct a testable model. There are three points to note about Rabia’s intervention.
i. Her suggestion does not follow from any fact or idea that Muna has proposed. Whereas Muna has suggested environmental factors might be responsible for cell separation and organisation, Rabia focuses on a structural aspect, the cell membrane. It is not the concepts, therefore, that are central here but the discursive opening up of ideas.

ii. RS works initially on helping Rabia to detail her model as fully as possible by repetition, rewording and reassurance.

iii. Rabia draws on her school knowledge – glycoproteins in the membrane responsible for cell signalling, antibody-antigen interactions – to develop the model.

By the end of this episode, a workable model is now presented for discussion. In terms of research science (table 1), a theory has been constructed, postulating mechanisms with unobservable entities, e.g. molecular bodies attached to proteins in the cell membrane. Rabia also draws on her knowledge of school science about antibody-antigen mechanisms and uses this as an explanatory model.

While not all discussions relied on a research scientist to support initial explication this was true of the majority of discussions. Note that the researcher’s role is not in producing new information but through rewording and affirmation to support confidence in advancing an idea.

Episode 3 follows directly on from episode 2 where the group test the model as RS has asked. Muna again initiates the discussion.

**EPISODE 3 (TESTING THE MODEL)**

MUNA(F): We could take away the membrane and see if the same thing happens, so if there is something on the membrane that differentiates them from being green and orange, and then take that away and if they keep on dividing then we know, OK, so there’s something different other than the membrane.

NITA(F): Yeah.

DON(M): So how do you test for it?

MUNA(F): How would we take away the protein you mean, like...

DON(M): Yeah, but what if you can’t identify the protein?

MUNA(F): How would you test for protein, so we can’t see it under...?

DON(M): No. so like what if you know there’s a protein but you don’t know which protein causes the change?
NITA(F): Yeah, because that’s true, it’s not like cells have just one, like the whole, yeah...
MUNA(F): Can’t we check like DNA sequences inside of it, and see then what codes, what codes it?
DON(M): Yeah, but if we don’t know what protein we are looking for then we don’t know what basis to look for.
MUNA(F): Oh OK OK. How could we test that? <10 second pause> We could look for common practice, and if we’ve loads of proteins on then we first see what’s the same and then we can cancel those out and continue in that way.
DON(M): What about if we denature the proteins... so we heat up the cells and let the proteins denature but the cells don’t get destroyed, and then we see, if they still split...
MUNA(F): Yeah, that would be good. But what would that...?
NITA(F): That would affect the specific protein you are trying to target.
MOH(M): But we could just denature it, like if it still goes through there’s no protein in it, so...

NITA(F): Right. Cause the cell to...
MOH(M): So the cell breaks but there’s no protein to denature.
NITA(F): But would it be possible to denature the protein without affecting how the cell works? I think that changes too many factors <9 second pause>
DON(M): So can we identify the protein? Or know exactly what protein it is? Or say that it is a protein?
NITA(F): You don’t know that it’s a protein.

In episode 3 a space is created to acknowledge complexity and failure. The model is discussed but they fail to provide any suggestions for empirically testing the model successfully.

Muna starts once again by suggesting that an active protein in the membrane might be responsible: remove the protein and see if the cells behave differently. But this is where the complexities of scientific research become evident because Don asks how one would identify the protein. There are many different proteins in the cell membrane and how do you distinguish whether it is just one acting, or more than one? And how would one know which protein this is? He suggests an alternative approach: denature the proteins, presumably by heating or changing pH. This would test whether proteins in the membrane are implicated. But here Nita’s
interventions are crucial: effectively you can’t separate off the functioning of the cell from the protein activity. Nita has identified a central problem and one which also distinguishes school science from research science. In school science received knowledge is often passed on as illustrative where the variables are distinguished and controls can be simply applied (see numbers 5, 6 and 7 in Table 1). So, for example, the effect of light on a seedling can be explored by subjecting some seedlings to light and not others. Any difference can be accounted for by the effect of the light. Light operates as a single discrete variable. But the same cannot be said about the proteins – because proteins are essential to all the functions of the cell, removal of all proteins will reveal nothing as the cell would not survive.

The students were then not able to suggest examples to test their model but this is far from a failure. What they have learned as evidenced from the answers to the questionnaire, and later reports from teachers, is that scientific research is about trying to solve seemingly intractable problems through collaborative – and dissonant – thinking, what is referred to as exploratory talk (Mercer & Dawes, 2008). For the students this aspect of research as collaborative problem-solving introduces a new dimension to their expectation of studying science at university, one which they see as exciting and full of possibilities.

QUESTIONNAIRE RESPONSES

Students were asked to complete a statement ‘To me the purpose of research science is to’ both before and after their discussion of the contemporary research problem. Initial analyses of the responses are indicative: students pre-intervention responses focused on ‘increasing knowledge and understanding of biological processes’, or ‘solidifying knowledge’ but after the intervention new terms such as ‘complex decision-making’, ‘serendipity’, ‘uncertainty’, ‘a lot of unknowns’, ‘flexibility’ were used.

It suggests that once students have had a chance to explore research problems discursively, they begin to entertain doubts about the certainty of the knowledge they have, and that revelation somewhat paradoxically unveils what is not known, a key feature of research.

Teachers mentioned that those students who were not high academic
achievers surprised them in their fruitful and perceptive contributions to the discussion. We also found that the main source of rebuttals and initiating new ideas came from students who studied at least one non STEM subject for their A-level examinations.

THE QUESTION OF KNOWLEDGE

Some years ago one of the authors had a residency with a large chemical company. A senior manager in the company told him about their strategy in employing analysts: sixteen year olds from school brought an intelligent freshness to problems which often evaded those with postgraduate science degrees. Too much knowledge appeared to conceal obvious solutions. The manager claimed that young recruits straight from school often had a ‘sixth sense’ borne of practise which enabled them to quickly detect problems and find solutions. If you asked them how they did it, he added, they probably wouldn’t be able to tell you. Their knowledge is tacit.

The point about this story is not to debunk knowledge. On the contrary knowledge is important and depends on the context in which it is used. For example, here, Rabia draws on her school knowledge to help her devise a functional model, namely that glycoproteins in the cell membrane might have a determinant role. But all the students are hindered by the fact that they cannot think of a way to validate or refute this model. It did not matter that they did not know how to use sophisticated techniques – the researcher could help them think about these – but that the ways in which they had thought about procedural inquiry in schools could not help. Failure stimulates new opportunities.

Ryle (1945) raised the question of “knowing that and knowing how”, one that has been chewed over by philosophers and science educationalists, particularly in relation to inquiry and problem-solving. According to Ryle, to ‘know that’ is to know a proposition, for example, hydrogen has an atomic number of 1 or magnesium is a metal. To ‘know how’ is to act or do something with that knowledge.

But this distinction between knowing that and knowing how raises all sorts of problems. For example, what precisely does a driver need to know to drive a car safely – clearly not the intricate mechanics of the car. Much of the knowledge they will derive from experience, simply by
driving first in safe empty spaces and gradually accustoming to busier roads. So experience helps to provide a structure and meaning for the knowledge we gather. For example, a child who has seen their parents stir sugar into tea has noticed things that help give meaning to the concept of dissolving.

‘Knowledge that’ forms the basis of many testing regimes as it has the advantage of being easy to measure. As the students discovered in this experience, researchers need knowledge but they work in professional and social contexts endowing them with the skills and experience – the wherewithal – to address problems which are intractable to school students. To attempt to solve the problem of cell movement the researcher needs to know relevant knowledge about the structure and physiology of cells as well as procedural knowledge. But the failure the students experienced in being unable to provide relevant empirical evidence for their theory, makes clear to them the importance of knowing experimental procedures as well as the related theoretical knowledge which supports their quest for an explanatory model. Hence we argue that discussing contemporary research problems enables students to “know how” which gives a reality to the need for and excitement of scientific research.

**CRITICAL PEDAGOGY**

Why does this approach have possibilities for a critical pedagogy? One of the purposes of schools is to socialise students into disciplinary thinking. But this process of learning presupposes a kind of unavoidable tyranny – incorporating a world that has been created and moulded by others, e.g. learning a language, the symbols of the elements in the Periodic Table, the role of the heart. Of course, all this is unavoidable but, as Arendt (1993) points out, the paradox is that each generation grows into the world of the older one. She coined the term ‘natality’ to open up this problem: is it inevitable that the political, economic and indeed epistemological structures of an older generation constrict the possibilities of renewal for those not yet born? Do established certainties, laws, theories and principles staunch the possibilities of more fruitful thinking?

Critical pedagogy, drawing on Freire, makes visible the sources of oppression of ideas and the tools to overcome that oppression. But the very tools that we use – language, knowledge, ideas – are those that emanate from power and hence oppressive structures. To abandon that knowledge would be utterly self-defeating. Here, we draw on critical pedagogy to raise awareness of the problem of the “banking” model of education: new knowledge is not an asset
to deposit for social and political status but is always contentious. New knowledge should be conjoined with experience to open up new ways of explaining the world. In this study, we bring into tension within the pedagogic frame the relationship between learning science in school and doing scientific research. Opening up new discursive spaces has then the potential to influence how science is taught at school.

Much of school science follows the banking model wherein knowledge from an authority, e.g. a teacher or lecturer, is transmitted as authoritative knowledge to a learner, often to be reproduced in tests and examinations. As we have seen, however, students need support in using this knowledge to address new types of questions, in this case, in research science, but when they do so they become aware of its limitations. This, in itself, is an empowering process.

**IMPLICATIONS FOR PEDAGOGY**

From our research we claim that exposing students to contemporary science research problems alerts them to the uncertainty and tentativeness of scientific knowledge but also to its value. It opens learning avenues for those who have not necessarily considered following a science course at university, but who crucially have the excitement of looking at nature from a different, and differently, informed perspective.

We understand the difficulties for teachers to generate group discussions about contemporary research. As we have indicated, students might well be hesitant at first but patience and a willingness to make mistakes can reap unexpected benefits. One of the future directions of this research study is, therefore, in supporting teachers or willing research scientists in running these discussions in classrooms. The biomedical faculty at UCL, for example, has developed research problems for potential bioscientists to discuss (UCL 2021) covering topics such as dealing with plastic pollution, the possibilities for further study and use of light activated proteins, and secrets of biological survival of tardigrades.

**REFERENCES**

SOCIO-SCIENTIFIC ISSUES IN SCIENCE EDUCATION – CONTRIBUTIONS OF A COMMUNITY OF PRACTICES FOR THE DEVELOPMENT OF CRITICAL APPROACHES TO EMERGENT SOCIOENVIRONMENTAL THEMES

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Abstract: This paper discusses the contributions of a community of practices for the construction of a proposal of science education practices based on critical pedagogies and channelled towards the construction of a complex vision about the socio-environmental crisis caused by the current model of production and socio-economic development. The text aims to present reflections built by a community of practices (CoP), here defined as a group of actors with different expertise, focused on the production of knowledge of teaching and learning of socio-scientific issues (SSI). We consider that learning and education occur at multiple times and in many spaces of the University and the School and, as principles of educating individuals based on critical pedagogy, horizontality, reflexivity and autonomy. Based on this premise, we present an experiment of building an SSI focused on the subject of mining, stemming from the collaboration between the actors of this community, composed of teachers of Basic Education (pedagogues), undergraduates in biology and researchers in the areas of physics, biology and science education. To this end, we briefly point out conceptual aspects of socio-scientific issues and communities of practice. Next, we present the conceptual construction of the SSI, aimed at addressing the environmental crime of Brumadinho (Minas Gerais, Brazil) in 2019, an event considered in the country as one of the biggest social and environmental disasters resulting from human action. Examples of didactic experiments on the subject carried out by professors and undergraduate biology students with students aged between 6 and 11 are also presented. We conclude by defending the idea that working in communities of practice represents an effective and politically important platform for the construction of practices supported by working with SSIs, as it favours the construction of complex and broad representations of the themes proposed by all those involved in the community.

INTRODUCTION

This work discusses the contributions of a community of practices to the construction of a proposal for science education practices based on critical pedagogies which understand education as an act and experience of interrogation and questioning of existing social structures (SILVA, 2013). In this context, the unveiling of social arrangements acts as
a process of raising the people awareness of the injustices, contradictions and inequalities arising from the dominant socioeconomic processes.

Based on Apple, Au and Gadin (2011), we understand that education, under the label of “critical”, would be engaged (i) with the critical analysis of the relations of exploitation/domination of society and the role of education in its social reproduction; (ii) with the evidence of the social and economic contradictions of the hegemonic capitalist system, promoting spaces for action and construction of counter-hegemonic discourses; (iii) with the resignification of knowledge, placing it at the service of “progressive” and social needs, democratising it and expanding its base from an intercultural connection; (iv) with the recognition of the teacher’s role as an intellectual who, through a critical analysis of their actions and the policies that guide their praxis, can provide specialised knowledge to the struggles against inequality and injustice in education; and (v) to educate for active citizenship, forming skills for decision-making in society and for social transformation.

As we know, the disciplinary tradition (Goodson, 1995) of the natural sciences has barely incorporated critical thinking into its discourse and only in recent decades has it been possible to find strong proposals that elaborate the theoretical articulations necessary for science education based on critical pedagogies (see, for example, the books edited by Hadjichambis et al, 2020 and Bencze and Alsop, 2014). Naturally, science education on these bases would require a reorientation of curricula and teaching practices, since, given that they are socially and culturally defined, they are presented as non-neutral, partial and biased by particular conceptions of the world (Silva, 2013), offering individuals their own way of seeing, interpreting and acting in society and in the environment.

In particular, it would seek to demystify the “social utopia” preached by “economic developmentalism” which, supported

1. The interculturality proposal assumed here defends “the recognition of the ‘other’ […] in the dialogue between different social and cultural groups”, using “cultural negotiation” to build a common project in which “differences are dialectically integrated” (Candau, 2009).

2. Political-economic thinking that permeated several Latin American governments, based on the basic premise that social development depends on economic growth, which stems from investments and capital productivity
by technicist ideology, places Science and Technology as the spearhead of “progress”\(^3\), in a perspective that is salvationist, linear and socially neutral. This thinking influences many curricular proposals and teaching practices, fostering the idea of the “practical” power attributed to Science and Technology, which justifies its pseudoneutrality and encourages increasingly higher levels of consumption of natural resources, disregarding the limits of the planet’s sustainability (Svampa, 2019).

According to sociologist Maristella Svampa (2019), this representation nourishes the developmental thinking preached in Latin America:

“The development model was not only supported by an instrumental and productivist vision, but also implied the updating of social imageries linked to the (historical) abundance of natural resources: the vision of the continent as an Eldorado.” (Svampa, 2019, p. 41).

In the international dynamics of goods production through mineral extraction, this region (Latin America) is considered an (inexhaustible) source of raw material. This representation permeates microsocial relationships, with the media’s exaltation of the profits obtained by mining companies and the jobs generated by them. However, the multiscale problems (biological, geomorphological, water, atmospheric, social, cultural and economic) arising from this form of exploitation of nature are erased.

For example, in recent decades, Brazil has had several social and environmental disasters caused by open pit megamining

(Filho & Morais, 2018). This means the massive production and consumption of goods, generating a great demand for raw materials, such as minerals produced by mineral extraction.

3. Technical-scientific progress, as the first productive force, became the foundation of the social legitimation of the dominant development model in Latin America.
and oil expansion, among which we highlight: the oil spill from the oil tanker Tarik Iba Ziyad in Guanabara Bay, Rio de Janeiro (1975); the release of toxic gases by the industries of the petrochemical complex of Cubatão, São Paulo (1980) with consequences for the air, water and soil of the region, highly polluted by the tons of toxic gases released daily; the explosion of the Petrobras pipeline in the Socó slum in Cubatão, São Paulo (1984), with an official death toll of 93 and 400 still missing; the oil spill in Guanabara Bay, Rio de Janeiro (2000); the breach of the dam in Bom Jardim de Miraí, Minas Gerais (2003) which dumped 200 thousand liters of toxic mud containing bauxite tailings, causing the death of fish in the region; the collapse of the Fundão dam in Mariana, Minas Gerais (2015) which dumped 43.7 million cubic meters of mining tailings, killing 19 people and causing immeasurable damage to the environment; and the collapse of the Brumadinho tailings dam in Minas Gerais (2019) which dumped 12 million cubic metres of toxic mud, killing 270 people and causing numerous social and environmental problems.

With an estimated three tailings dam accidents recorded per year⁴, Brazil ended 2021 with 40 dams in a declared state of emergency⁵. These aspects are absent in the narratives produced by the mainstream media and, in general, in the curricular proposals and teaching of Sciences that cover this topic from subjects such as extractivism, the production of goods, natural and technological resources, and non-renewable resources, among others. This content is uncritically presented without any problematisation and associated with the production of common goods, alienating people from the political-economic interests and the socio-environmental implications related to them.

In light of this and from the perspective of critical education, teachers are required to take a stance away from banking practices⁶ that focus on the memorisation of facts, information, and skills, without questioning or critiquing the underlying power dynamics and ideologies that shape the way knowledge is produced and distributed. Teachers must encourage critical thinking, promote active participation, and engage students in discussions that challenge the status quo and promote a more equitable and sustainable future.

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⁶. According to Freire (1987, p. 41), ‘the ‘banking’ concept of education is the mind as a wide-open empty space waiting for information to fill it. The educator deposits ‘content’ into the students, the ‘depositories’.
of concepts and phenomena, and that “deposit” the products of Science in the student as definitive, complete and free of socio-environmental implications. On the contrary, it seeks to build practices that (i) show, as public understanding, the political, social and economic intersection of Science and Technology and their implications (impacts, consequences, damages, interests) in society and for the environment; (ii) question the current demands of society and the social role played by Science and Technology in maintaining and reproducing the status quo and socio-environmental injustices; (iii) articulate scientific knowledge to an expanded and critical view of the place of science in contemporary society, allowing students to learn not only the priceless value of scientific knowledge, but also its role in the predatory and unfair development model; (vi) educate those capable of engaging in socio-environmental causes and, at the same time, act in the training of those who will follow scientific careers, so that they are not alienated from the impacts of the knowledge they produce.

In this case, the objective is the education of “a new individual and a rationality that seeks to involve the ethical dimension through a dialogic action, whose ultimate aim is the consensual construction of new social meanings” (Sgró, 2001, p.19, our translation); deconstructing understandings that alienate, such as the view of Science and Technology as exempt from questioning and social influence. This is not a simple goal, as it demands didactic means of inducing reflection and construction of knowledge on the part of students and teachers on the subject in question.

In our projects’ proposals of socio-scientific issues (SSIs), we recognise a didactic-pedagogical strategy for the development of aspects of critical pedagogies in science teaching. Based on controversial topics, the SSIs propose to highlight the complex character of Science and Technology, which, as social practices, are influenced by economic, political, social and cultural interests. This allows for moral and ethical discussions around these institutions’ objectives for society and the environment, highlighting how the production of scientific knowledge is submitted to the hegemonic development model, which can install or worsen inequality and the destruction of biomes and species, in addition to producing the scarcity of essential resources for life, such as water.

7. “Un nuevo sujeto y una racionalidad que busca abarcar la dimensión ética a través de una acción dialógica cuya fin último es la construcción consensuada de nuevos sentidos sociales” (Sgró, 2001, p.19)
Below, we discuss the main characteristics of the approach to socio-scientific issues, and then we present how this reference guided the construction of the controversies around mining, taking the Brumadinho dam failure as a point of discussion, questioning the representations conveyed about the event. Finally, we evaluate the teaching of Science from the experiences had by community of practices.

SOCIO-SCIENTIFIC ISSUES

The inclusion of critical teaching practices that consider systemic issues such as those mentioned above, depends on changes in current teaching models, seeking to develop creative and reflective educational actions for teacher and student education. In the science education research field, there are many papers that present proposals and alternatives for this renewal (Binatto, Duarte & Teixeira, 2020; Capelo & Pedrosa, 2011; Galieta, 2021; Bernardo & Reis, 2020) seeking the engagement of individuals in themes of citizenship and social justice, promoting a sense of emancipatory scientific education. In the work at hand, we dedicate ourselves, through the approach of socio-scientific issues, to building practices that develop emancipatory scientific education. That is, actions based on processes of problematisation/critical reflection of reality and commitment to the promotion of “student autonomy”, “valuing and respecting their culture” and indicating “possibilities of intervention in the world” (Moreira, 2010, p. 146).

The approach to socio-scientific issues (SSIs) provides an interesting basis for learning experiences in science aligned with the sense of science education that we wish to promote in our training proposals. This is because the approach incorporates the discussion of problems whose origins and solutions are multifaceted, uncertain and part of a complex reality and therefore demand certain knowledge and skills for their treatment (Reis, 2013; Levinson, 2006; Kolstø et al., 2006), such as mining.

This is because the pedagogical strategies for addressing socio-scientific issues focus on training students to consider controversial issues based on science (its contents, processes and nature) in a way that is connected with its economic, political, ethical and environmental aspects (Hodson, 2018). According to Reis (2006), this approach
allows students to: a) perceive the implications of science and technologies in our society and in the environment, understanding that scientific knowledge is provisional and subject to change; b) recognise the different uses of scientific and technological knowledge, emphasising the ethical aspect of research; c) develop concepts, hypotheses and scientific knowledge and be able to apply them during experiences and activities; d) recognise the potential and limits of science and technology for human, social and environmental progress and well-being; e) know the valid sources of scientific and technological information and resort to them, when necessary.

However, the connection in practice is not easy to establish, requiring knowledge and skills that limit its operationalisation, especially when acting solo. Considering this problem, our proposals for the development of educational actions for the teaching of Science to students between the ages of 6 and 11, based on the criticism of the hegemonic economic development model and its impacts on people and the environment. The knowledge base that subsidises the actions of Sciences in the classroom was therefore put into discussion due to the need to contemplate not only scientific knowledge, but also axiological dimensions that agree with values, principles and dispositions oriented to the sustainability of the environment, to the fight against socio-environmental injustices and the transformation of reality.

For 8 years, our community has dedicated themselves to addressing socio-environmental problems for the teaching of Science to students between the ages of 6 and 11, based on the criticism of the hegemonic economic development model and its impacts on people and the environment. The knowledge base that subsidises the actions of Sciences in the classroom was therefore put into discussion due to the need to contemplate not only scientific knowledge, but also axiological dimensions that agree with values, principles and dispositions oriented to the sustainability of the environment, to the fight against socio-environmental injustices and the transformation of reality.

Our social collective was formed from inter-institutional partnerships involving a federal school, the Nutes Institute of Science and Health Education and the Institute of Biology, both from the Federal University of Rio de Janeiro (UFRJ), the Physics Institute of the Fluminense Federal University (UFF) and the Institute of Education of the University of Lisbon (ULisboa). In this inter-institutional
arrangement, “the community is the social fabric of learning” (Martinelli, 2014, p. 3) made up of 20 teachers of Basic Education, 5 undergraduate biology students, 3 researchers in the area of science education and 3 scientists from the areas of reference in school science (biology and physics). On the other hand, “practice is the specific knowledge that the community develops”, depicted in the product of the mobilisation of efforts, knowledge and expertise for the construction of curricula and practices that recontextualise elements and political demands posed by critical pedagogies to scientific education.

In the case presented here, the human and intellectual resources of the group were mobilised to build a socio-scientific issue around mining, using the case of the Brumadinho-MG tailings dam failure as a context for discussion and action.


THE APPROACH TO MINING AS A SOCIO-SCIENTIFIC ISSUE

INTRODUCTION OF THE ENVIRONMENTAL CRIME

On 25 January 2019, the B1 dam at the Córrego do Feijão mine collapsed®. The dam is owned by mining company, Vale, and is located in the municipality of Brumadinho. The structure is part of the Paraopeba Mining Complex, also owned by Vale. There are two dams used to hold the fine tailings from the treatment of iron ore, retaining water for reuse in the industrial process.

The dam was built in 1976 and was intended to separate impurities and increase the commercial value of iron ore. In the separation process, the remaining tailings must be dammed to avoid it flowing into the river in the region. To achieve this, dikes are built on earth elevations – the so-called upstream dam, where drainage mats are also inserted to drain out the water stored by the dam. It is the cheapest and most common method in Brazil, forming a kind of beach with mining waste such as iron, silica and water.
The collapse of the Córrego do Feijão Mine Dam occurred abruptly and violently, making it impossible or difficult for hundreds of unsuspecting people to escape the sudden impact of the mud flow. The rescue of hundreds of other victims who were in the path of the mass of tailings also proved challenging, if not hopeless. The drilling of a hole in the Córrego do Feijão dam owned by mining company, Vale, is being pinned as a potential trigger for the dam’s failure (Arroyo & Gens, 2021). Vale S.A. and its consultant, Tüv Süd, had been warned about the risks of drilling using water. The information is from a study carried out by the Universitat Politécnica de Catalunya (UPC) which carried out in-depth research with materials, calculations and information on the dam’s history, such as possible earth movements and rainfall index.

The collapse of the mining company’s dam caused the death of more than 250 people while 12 million m$^3$ of mud spilled from it and destroyed approximately 270 hectares of the Paraopeba River, making water from it undrinkable. The tailings devastated 133.27 hectares of native Atlantic Forest vegetation and 70.65 hectares of Permanent Protection Areas (PPA) along watercourses affected by mining tailings. Figures 1, 2, 3 and 4 show the dimension of the region’s destruction caused by the failure.


10. The Atlantic Forest is a Brazilian biome formed by native forests and associated ecosystems, such as mangroves, sandbanks and swamps. Occupying about 1.1 million km$^2$, extending along almost the entire coast of the country. The forest has the second largest diversity in the Americas, with over 20,000 plant species and 4,944 cataloged fauna species. Highly exploited since the colonial period and threatened at the same time by urban occupation, it is estimated that only 29% of the original forest remains. To learn more, visit: https://www.gov.br/mma/pt-br/assuntos/ecossistemas-1/biomas/mata-atlantica and https://www.ibflorestas.org.br/bioma-mata-atlantica.
FIGURES 1 AND 2: IMAGES SHOW MUD INVASION (AFTER AND BEFORE)

Photo: Arte G1/Igor Estrella. Available at: https://g1.globo.com/mg/minas-gerais/noticia/2019/01/25/antes-e-depois-veja-imagens-do-rompimento-de-barragem-da-vale-em-brumadinho-mg.g.shtml

FIGURES 3 AND 4: IMAGES SHOW AFTER AND BEFORE THE FAILURE OF THE DAM IN THE REGION OF BRUMADINHO (MINAS GERAIS STATE)

Photo: Google Earth/DigitalGlobe; Reprodução/TV Globo. Available at: https://g1.globo.com/mg/minas-gerais/noticia/2019/01/25/antes-e-depois-veja-imagens-do-rompimento-de-barragem-da-vale-em-brumadinho-mg.g.shtml

PROCEDURES FOR THE DEVELOPMENT OF THE SOCIO-SCIENTIFIC ISSUE BY THE COMMUNITY OF PRACTICES

The case of the collapse of the Córrego do Feijão Mine Dam in Brumadinho was taken on by the community of practice as a theme to be analysed through the initiative of basic education teachers who considered it a matter of socio-environmental urgency to be addressed at the school, due to (i) its environmental impact of great proportions; the (ii) repercussion in the media which guaranteed a significant amount of information; (iii) disaster-related controversies involving social, economic and political issues; the (iv) recurrence of disasters in the state of Minas Gerais, as in 2015 a similar event had occurred in
the town of Mariana; and the dialogue of the subject with the school curriculum, which provided for content such as “natural and technological resources”, “the activity of human beings in the environment”, and objectives such as “identifying damage caused by the improper use of natural and technological resources”.

Due to the topic’s complexity, there was a possibility of the emergence of different meanings which could have lead to divergences in practice. In view of this, coordination mechanisms were defined for the confluence of ideas and notions, namely, fortnightly training and planning meetings promoted by conversation circles, work and study groups.

The coordination of training meetings was shared by two individuals, alternating the dynamics between them. The group adopted problematization as a methodology, which acted as a means of raising awareness and analysing reality (Freire, 1987), and dialogue, as a process of refinement and approximation of the perceptions of undergraduates, basic education teachers and researchers about the dam’s collapse.

Initially, the representations of the media and the those affected were problematized, highlighting the categorization of what happened as “disaster” or “environmental crime”. We can understand, from the perspective of critical pedagogies, these moments as processes of “unveiling”, of acquiring a “more exact understanding of the object”, perceiving its relations with other objects or broader social dimensions (Freire, 1997, p. 23).

In this way, moments of idea sharing, speech and exchange of knowledge took place, allowing the group to build a critical understanding of the disaster. During the process, the community was updated on the environmental, economic, social and political aspects involved in the environmental crime in Brumadinho, “building new knowledge [...] from the interaction and sharing of different worlds” (Zitkoski, 2010, p. 118). In this case, new elements were connected to the group’s perceptions, expanding the discussions and aspects to be dealt with. According to Freire (1987, p. 53), true dialogue takes place with critical thinking and does not accept “the present should be something normalised and well behaved”.

Figure 5 presents a map of the concepts mobilised in the formulation of the approach to mining as a socio-scientific issue, which was produced from the interactions of the community of practices, in the context of the environmental crime of Brumadinho.
The heterogeneity of the group’s expertise with specialists from different areas (Ecology, Environmental Education, Arts, Mathematics, Portuguese Language and Science Didactics) allowed for the articulation of different contributions of knowledge on the issue as can be seen in Figure 5.

In this case, concepts are perceived contemplating the following dimensions highlighted in different colours: environmental (green), economic (red) and health (yellow) which represent an expansion in the understanding of the aspects involved in the topic. In addition, a large number of multilevel and intersecting interrelationships on the topic are jointly constructed, adding complexity to the diagram and consequently, to the representation of the identified thematic fields. We understand that this fact favours a complex and critical perception, evidencing the multidimensionality of the impact of mining on ecosystems and human life, which in turn, expands the curricular scope and thickens the discussions of pedagogical practices.

In this interaction, aside from the new elements included in the group’s conceptual repertoire which expanded the discussions and aspects to be worked on, suggestions for activities and work...
plans were being created. In this case, the practice proposals were organised into three modules that aimed to (i) problematise the meanings attributed to the tragedy in Brumadinho, (ii) establish responsible relationships with society, the economy, political decision makers and the personal actions of consumption, and (iii) problematise the socio-environmental implications of the use of natural resources in the production of goods and energy through the investigation of the life cycle of technologies. To achieve this, didactic sequences were set up for application in a group of 16 students aged between 10 and 12. The meetings took place fortnightly over a period of 6 months.

With the definition of the roles of the participants, the community’s roles were identified. In this case, the high school teachers with the collaboration of biology teachers in training put the sequences into practice while researchers and scientists from specific areas provided theoretical and material support for the development of activities described in detail below.

**PROBLEMATISING THE BRUMADINHO DAM COLLAPSE WITH STUDENTS: NATURAL DISASTER OR ENVIRONMENTAL CRIME?**

One of the group’s initial concerns was to jointly build a critical understanding of what happened in Brumadinho that included questioning the idea conveyed by the media and the initial impressions of the community about the dam’s collapse. To this end, a conversation circle with the students was proposed to discuss the definition of what happened either as a “disaster” or an “environmental crime”.

Based on the orientation of the reference of socio-scientific issues, construction of positions and hypotheses from evidence, different teaching materials were used such as video footage, reports, technical texts in the engineering area, models and simulation experiments, for students to be able to gather data and analyse the situation. To trigger discussion, videos and reports of the collapse were presented.
The representation conveyed by these materials that classified the failure as “accident”, “disaster”, “tragedy” and “environmental crime” was then questioned, generating discussion of what really happened and what the social and environmental implications were.

With this, the proposal was constituted as a study problem for the children, for which they raised initial hypotheses that represented their previous knowledge about the event. In general, the causes of what happened were considered by the students as being of a natural nature, arguing that, possibly, heavy rains had generated the “disaster”.

To problematise this idea, the teachers proposed the study of the structure of the dam, seeking to understand how the failure occurred. For this, texts and technical engineering video footage were presented that explained the types of existing tailings dams, namely: upstream, downstream and mixed. In order to work with the information objectively, the teachers proposed the construction of the three types of structures with biscuit dough and the simulation of the dam failing, using trays and a mixture of sand, silica and water, representing the mine's tailings.

The students were divided into two groups, named A and B, to carry out the experiment. Group A was responsible for producing a more watery mixture in which the components were much more moist. This mixture, after the construction of three dikes, was poured into the container, causing the slope to break from the starting dike, similar to what happened in Brumadinho. Group B, on the other hand, produced a less moist mixture and started the dam construction process for the simulation according to the proposed structure, in upstream heightening dikes, as shown in Figure 6.

![Figure 6: Preparation of the experiment to simulate the failure of the Córrego do Feijão mine tailings dam.](image)
The second group started dumping the tailings at the level of approximately three steps, which was unable to disrupt the built dam. With the analysis of the specific characteristics of each of the models – especially the financial cost and the risks of failure – and with the data obtained from the failure simulation, the students were able to show that in the upstream model the heights did not have the structure necessary to avoid the dam from shifting, with greater possibility of shifting of the dike and liquefaction due to the ease of water penetration. In the downstream model, the new dikes had a more fixed containment structure that worked as a way of strengthening the previous dike, being less prone to shifting and liquefaction.

Based on this data and a report presented after the experiment which reported that the tailings storage operations deposited wet material in Brumadinho, facilitating liquefaction and sludge formation, the students reconsidered their initial position, evaluating what had happened as an “environmental crime”. The students argued that the mining company managers were aware of the risks of failure, evidenced by the “irresponsible” choice of the type of dam – upstream, considered cheaper, but with higher accident probability.

**MINING PRODUCTION CYCLE: WHAT ARE OUR RESPONSIBILITIES?**

Although the community of practice had noticed the students’ ability to use scientific knowledge and the understanding of economic and political interests, and integrating them to understand the “environmental crime” of Brumadinho and its impacts on society and the environment, there was a concern with the construction of a more complex understanding, which does not intend to point out culprits, but rather understand the nature of mining activity and its socioeconomic relationship with the cycle of demand and consumption of the community and the industry.

In this sense, a practical proposal was designed to promote the study of this extractive activity with a focus on the production of ores. To understand the attribution of value to minerals, the group sought to understand the formation and composition of rocks, conceptualising ores and minerals. For this, different types of rock were analysed (granite, basalt, gneiss, marble, soapstone, slate, siltstone etc.) considering their composition (quartz, mica, feldspar, hematite etc.).
The rock components were presented as minerals and those valued by the market/humanity as ore. From this activity, it was possible to build, in addition to the definition of rocks and minerals, the value relationship with the types of materials, such as iron ore and other metals used by the industry.

The students were then invited to reflect on how we, individually, are linked to what happened in Brumadinho and our responsibility with mining.

Initially, some students were unable to establish a relationship, while part of the group highlighted that we use some products from mining such as gold, iron and metals in general. To prove and reflect on the mining demand that we generate with the daily consumption of products, it was suggested that students, in groups, disassemble electronic devices (cell phones, remote controls, energy stabilisers, DVD players, etc.) and identify parts where ore had been used in their composition. These were analysed and labeled according to the material, and later, presented to their colleagues on posters. For example, in a remote control, the students identified the use of silicon, and in a stabiliser they found copper, aluminum and iron.

The teachers pointed out other components of the devices that had not been identified, such as cell phone batteries that use lithium. The teachers questioned the way minerals, such as copper, appear in nature and how we know them, in the form of wires, for example. Students were asked about the processes involved in arriving at the product as it is presented to us. This direction of the discussion emphasised the process of industrial separation of minerals, adding more clarity to the activity of mining and production of tailings.

In addition, the activity generated discussions about consumerism in our society, in which students reported people's constant changing of cell phones and video games, that affect the environment. Through some accounts on the registration forms, students expressed considerations about the controversy involving society's constant need for raw materials and the predatory effects of the exploitation of nature. For example, in the report "I liked the mini-braking experiment, we learned that we cannot run out of ore and that we can save and use what we already have at home", the student reflects on responsible decision-making. Although it does not indicate broad social
and political dimensions, we understand that this type of position expresses the analysis and understanding of the impact of one's actions on nature, which also involves understanding that the application of science and technology can generate harmful effects on the environment and society itself.

**MINING AND ENERGY PRODUCTION**

Another proposal for practice sought to establish a relationship between mining and energy based on the supply of raw materials, on the production of energy itself – as in the case of radioactive ores (e.g. uranium 235) – and on the supply of inputs for energy transformation technologies.

For this purpose, sequenced discussions mediated by experiments were suggested on the use of ores (e.g. coal, oil and uranium) for energy production, highlighting the environmental and social impacts, understood from (a) industrial and technological revolutions; (b) the types of energy; (c) the process of transforming mechanical/kinetic energy into electrical energy; and (d) technologies necessary for transformations between types of energy (nuclear, hydroelectric, (geo)thermal, wind and solar).

One of these didactic proposals consisted of an experiment that proposed to understand the transformation of light energy into electrical energy from the construction of electrical circuits powered by solar energy. As a result, models of houses were built, and their lighting generated by solar energy.

During the discussions to understand the dynamics of light interaction with the filling of voltaic cells which causes the movement of electrons in the silicon layer (material used in the manufacture of chips and computer processors), the students were requested to carry out research on the nature and origin of this material. This proposal created a relationship with mining, making it possible to understand the environmental impacts with the construction, maintenance and operation of solar parks. For example, visual pollution, contamination of the environment with silicon, among others.

These proposals provided students with a complex understanding of the socio-environmental issue that involves mining, by establishing relationships that create a consumption network, from the “life cycle” of the technologies used in the energy conversion process.
In this way, the students were able to problematise the classification of energy production as “clean”, considering that other factors, in addition to the non-emission of polluting gases, needed to be considered. In this context, it was possible to highlight the role that Science and technology play in this process and the social and private interests involved. In view of this, we corroborate the idea of the critical approach as a promoter of complex thinking, which, through a contextualised and significant action, allows the establishment of “a complex view of Science and Technology and the mutual relationships they establish with each other and with Society and the Environment” (Fernandes, Pires & Delgado-Iglesias, 2018, p. 877).

**CONCLUSIONS**

We understand that the articulation of critical pedagogies to science teaching is a necessary and urgent construction process since it can enable the view and understanding of the intricate world relationships that involve Science and Technology. Based on scientific contributions, new perspectives are possible not only in relation to ourselves, but also in relation to society and the environment; there is openness to new dispositions with the environment, when we assess, judge and make conscious and responsible choices in everyday life with a view to sustainable development and a better quality of life. This is because the identification of contradictions/controversies represents not only a breakaway from the hegemonic vision, but also the constitution of spaces of action in which subjects can intervene in the world, building counter-hegemonic discourse.

However, teaching under the label “critical” will require creativity from teachers when making knowledge accessible to students, developing didactic strategies to facilitate learning and adapt content to the cognitive and social reality of the classes. The SSI approach represents a strategy with great potential for this, but entails a strong mastery of content, in addition to knowledge of the socio-political-economic aspects of the subjects covered. This demand has been reported as one of the major obstacles to the development of this approach in the classroom, as it requires a complex understanding of the relationships involving Science, Technology, Society and Environment (Reis, 2013).
Based on our research and experiences, we emphasise the work in a community of practices, which, through the “meeting of worlds”, contributes to the construction of a complex and broad representation of the proposed themes, providing a powerful and interesting platform to think about and build science actions based on SSIs and a critical disposition in individuals.

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BUILDING EDUCATIONAL RESOURCES FOR THE CURRICULAR APPROACH TO SOCIO-SCIENTIFIC ISSUES: AN EXPERIENCE OF COLLABORATION BETWEEN UNIVERSITY AND BASIC EDUCATION SCHOOL

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Abstract: In this chapter, we describe an online environment with open and free access aimed at basic education teachers which discusses curricular approaches to socio-scientific issues (SSIs) and their potential to promote science teaching committed to the objectives of scientific literacy and training. SSIs are contemporary issues related to science, technology and society, controversies, and moral and ethical considerations in both individual and collective decision-making. In this online environment, we favour SSIs related to topics such as pandemics, vaccination, climate change, water resource management, ethnic-racial issues, among others. The possibilities for the curricular approach of the SSIs include the need to understand aspects of the nature of science, the processes of production of scientific knowledge, the relationship between theory and evidence, methods of data collection and analysis, and the development of critical thinking and argumentative skills. The environment comprises explanatory texts, a reference database for consultation, and educational resources such as scripts, educational sequences, games, videos, and scientific dissemination actions and connections with social network. It is arranged by means of horizontal methodologies and collaborative actions between university researchers, teacher trainers, basic education teachers, and undergraduate and graduate students. It incorporates teaching knowledge, values the performance of basic education teachers as authors, and promotes the university-school articulation of basic education.

BACKGROUND: MOTIVATIONS, PREVIOUS PUBLICATIONS

In March 2020, a working group was set up at the Nutes Institute of Education in Sciences and Health of the Federal University of Rio de Janeiro. Their objective was to develop curricular resources for emergency remote teaching practices introduced to universities and schools of basic education during the period of social isolation brought about by the Covid-19 pandemic.

The working group was institutionalised through a university extension project and gathered researchers in science education, teacher trainers, practicing teachers, undergraduate and graduate students. Content was initially produced for a website that
dealt with emerging issues related to SARS-COV-2, such as its origins, ways of transmission, morbidity, lethality, preventive measures, etc., and others related to the social, economic, and political dimensions of the pandemic. The characterisation of the pandemic as a socio-scientific issue (SSI) and the working group's tradition in the development of collaborative methodologies were the starting point for the development of the site. This is where we seek to articulate contributions from different profiles of science educators in the proposition of an interdisciplinary approach to topics related to science, which affect teachers and students daily, and require positions and decisions. A prototype went live in May 2020 (Martins et al 2020) and was assessed by practicing teachers who took part in training promoted by the Nutes Institute (Martins et al 2021).

The development of this content allowed us to problematise the approach to SSIs in the curriculum in general, and the project was extended to include other issues such as water resource management, racism, resistance to vaccination, among others. The research aimed at the creation of this content allowed for access to a large number of bibliographic references which were catalogued and made available to the teaching public through a reference database. Likewise, proposals for educational activities were developed that opened discussions presented on the site and established its dissemination strategies.

The project currently consists of a virtual environment that integrates different resources to support the development of contextualised and interdisciplinary curricular proposals on socio-scientific issues by basic education teachers. The project considers challenges inherent to the didactic treatment of SSIs and intensified demands in the context of the Covid-19 pandemic, such as working with hybrid teaching models (face-to-face and distance) and the fight against fake news and misinformation. It is structured in the form of a web portal (figure 1).
In our daily lives, we are often faced with issues that involve controversy, even among specialists whose understanding involves not only the contribution of different areas of knowledge, but also moral and ethical values.

**How can these socio-scientific issues be debated in the classroom?**

**What knowledge is relevant for the debate?**

**What curricular approaches should be adopted?**

On this site we organise resources for the treatment of these socio-scientific questions from an interdisciplinary perspective, through dialogue with research that explores aspects of the history of science, the nature of scientific knowledge construction processes and their relationships with different cultures, the relationships between science-technology and society, characteristics of scientific discourse, the development of critical thinking and reading and argumentation skills.

Learn more and send your suggestions!
The portal is available at www.qsc.nutes.ufrj.br and consists of four environments which correspond to four work approaches. They are:

- **Socio-scientific Issues at School**: preparation of content for web pages in Q&A format, containing explanatory texts that explore different angles and dimensions of socio-scientific issues and indicate additional reading possibilities by means of links to texts available on the web;
- **Database of Source and Context References**: organisation and provision of a reference database of educational and scientific dissemination texts, interviews, journalistic articles, and videos which deepen aspects relevant to the curricular treatment of SSIs;
- **Database of Educational Resources**: development, analysis, assessment and dissemination of strategies and educational resources – such as scripts, games, didactic sequences, etc. –, aimed at curricular work with SSIs;
- **Dissemination and Social Network**: creation and updating of the web portal, connections with social media, organisation and dissemination of webinars, panels, debates, etc.

In this text, we present the rationale and methodology employed in this research and development experience. We establish connections between the SSI approaches and the objectives related to scientific literacy and argue about the possibilities of such an approach for science education committed to citizenship training, through the discussion of examples of content available on the site.

**RELATIONSHIP BETWEEN SSIS, SCIENTIFIC LITERACY AND CITIZENSHIP TRAINING: CHALLENGES FOR SCIENCE EDUCATION**

In general, in the field of Science Education, the expression “Socio-scientific Issues” (SSIs) refers to a research programme on contemporary issues, whose debate involves controversial topics, scientific knowledge, and moral and ethical observations. The nature
of these issues as well as proposals for their inclusion in curricular programmes, have been the subject of research by the community of science educators (Sadler, 2011; Souza & Gehlen, 2017). Such issues of a complex and multifaceted nature often articulate knowledge from different areas and require positions and decisions at individual and/or collective level (Evagorou, 2011).

Nurtamara and collaborators (2018) highlight that working with SSIs involves the development of critical thinking and argumentation skills, in addition to the understanding of aspects of the nature of science and the processes of scientific knowledge production. In this sense, Conrado and Nunes-Neto (2018) affirm that SSIs, when used as teaching strategies, can contribute to the mobilisation of values, skills, and attitudes in political and economic discussions. According to Hodson (2013), teaching proposals based on SSIs can stimulate critical reflections on topics of social relevance conveyed in the mass media, and also facilitate the understanding of scientific content that needs to be stimulated during decision-making. Silva (2016) adds that the problematising potential and appreciation of thinking from different perspectives enrich the use of this approach in the classroom. To corroborate this perception, Jafari and Meisert (2022), in a study with topics of biology in the environmental field, observed that students developed their arguments more effectively after SSI-based activities and, more importantly, presented greater support in decision-making.

Based on these characteristics and potentialities of SSIs, we can see that working with controversial topics, for example, tends to favour students’ citizenship education. Being able to take part in dialogue on issues involving science presents itself as a fundamental aspect for individuals, especially in times of the spreading of distorted and inaccurate information on topics that directly affect the quality of life of the world’s population. Based on the work with SSIs in schools, we are following a path towards the promotion of citizenship and democratic participation in society. Just as understanding a scientific concept is important, it is also essential to interpret it in a context permeated by social and cultural issues in the globalised world. The inclusion of SSIs in the school environment therefore pursues the education of a citizen who understands that political, social, cultural and economic factors directly influence science, and are also influenced by it. One can thereby assume that we are preparing students to deal with ethical and moral dilemmas in their daily lives and to take responsibility
for their decisions both individually and collectively (Santos, Silva & Silva, 2018). Perez (2012) points to some examples applied to the context of Science Education regarding the use of the SSI approach. Among these, we can highlight alternative energy, global warming, pollution, biological weapons, the development of vaccines, and the manipulation of the genome of living beings. All of these topics can be problematised and discussed in the classroom through SSIs.

Based on a Freirian perspective, Auler (2007) points out that the methodology for working with SSIs should stem from a problem of a group or community, explored in its various dimensions, such as political and economic, problematising implications and decision-making possibilities of students in contexts related to it. For these activities to be effective, it is important to analyse each dimension involved in the proposed SSI. It is therefore expected that at the end of the activity, the arguments proposed by the group will forward proposals for position and action in the context of the issue at hand. In this sense, Sasmaz-Oren and collaborators (2022) affirm that working with SSIs is effective in improving logical thinking and positioning skills when faced with the reality of the issue being studied.

Such proposals must, however, problematise the real possibilities of decision-making at individual and collective level as our decisions do not depend solely on scientific knowledge. Let’s take the adoption of responsible behaviour when it comes to people saving water, for example. In countries like Brazil, not everyone has access to piped water, and water consumption by industry and agriculture is four times greater than that of domestic use. The relativity of its effectiveness and impact must therefore be taken into account. The approaches to the economic and sociopolitical dimensions of SSIs draw our attention to the risks of adopting naive approaches.

With this in mind, we developed a framework for approaching SSIs that contemplated their intersections with different fields of theory and practice in Science Education, among them, Science-Technology-Society connections (Santos 2008) and Socially Acute Questions (Simmoneaux & Légardez, 2010).

Based on different elements of these areas which converge to ways of understanding and characterising
an SSI, we elaborate, in the form of a framework, a structure that facilitates the perception of the existence of the different constituent areas of an SSI. The objective is to aid reflection processes and prepare questions that can serve as a contribution to the creation of strategies for the work of teachers, as well as the texts that make up the site’s tabs.

The SSI Scope Framework (Chart 1) brings together different domains that we can mobilise to characterise an SSI: Interdisciplinarity, Controversies, Nature of Science, History of Science and Fake News. Going beyond a set of descriptors, the chart seeks to express the complex nature of the SSI when it shows, through dotted lines, the permeability of the boundaries between the areas. This means that the motivating questions arising from any given scope are linked to others from other areas, since it is not possible to think of an SSI as fragmented.

When we present, for example, a motivating question about the fake news associated with the Covid-19 vaccine, we explore the way in which it is influenced by: (i) disciplinary knowledge, such as virology; (ii) historical issues such as the discovery of vaccines; (iii) controversies within the scope of science such as criteria for the construction of evidence and different forms of knowledge production; (iv) institutions and political factors linked to the financing of science; (v) beliefs and representations about society and the market, among others. It is interesting to note that these meetings of different dimensions can be mobilised from any question, in any area, hence the complex and non-fragmented nature of the SSIs.

**WORK METHODOLOGY**

The work of producing content for the site is collective and presupposes horizontal methodologies (Dumrauf & Cordero, 2020), which is expressed by the participation of all those involved, regardless of their social position and the institution from which they originate. We have historically established a separation between knowledge production activities by the university and the application of this knowledge in schools, which ends up creating a type of assessment of these institutions that justifies the existence of an asymmetric relationship of powers, placing the universities at a higher hierarchical level than schools (Corrêa, 2021). Within the institutions themselves, there is a predominance of teachers over undergraduate students and even researchers over teachers.

We guide our actions based on aspects related to co-teaching, which establishes horizontal working methodologies.
### TABLE 1: SSI SCOPE TABLE.

<table>
<thead>
<tr>
<th>SSI</th>
<th>SSI Scopes</th>
<th>Scope specification</th>
<th>Motivating questions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Interdisciplinarity</strong></td>
<td>What disciplinary/academic fields are involved? Biology, Physics, Chemistry, History...</td>
<td>What is a virus, how does it spread, and how does it cause infection?</td>
</tr>
<tr>
<td></td>
<td><strong>Controversies</strong></td>
<td>Sociopolitical-economic dimension: health as an individual and collective right</td>
<td>Should vaccination be mandatory?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Scientific dimension: questions and evidence in favour of vaccination</td>
<td>How is the safety of a vaccine determined?</td>
</tr>
<tr>
<td></td>
<td><strong>Nature of Science</strong></td>
<td>Knowledge construction/Ethics: scientific method, peer scrutiny</td>
<td>What are the stages of producing a vaccine?</td>
</tr>
<tr>
<td></td>
<td><strong>History of Science</strong></td>
<td>History of ideas, practices, role of individuals and institutions in the production of scientific knowledge about vaccines.</td>
<td>How have other pandemics been controlled in human history?</td>
</tr>
<tr>
<td></td>
<td><strong>Fake news</strong></td>
<td>Post-truths, misinformation.</td>
<td>What are the arguments of the anti-vaccine movements based on?</td>
</tr>
</tbody>
</table>

Source: the authors.

This means giving voice to the different participants, allowing them act freely in the different processes and instances that make up the project. The group’s activity becomes collective and horizontal when we allow everyone to participate in decision-making in the different stages of work construction (Roth et al, 2002; Tobin, 2006; Tobin & Roth, 2005).

Subgroups are formed that are in charge of specific themes. The composition of the group includes at least one university professor, one basic education teacher, one graduate student and one
undergraduate student. The activities are initially carried out within the scope of the subgroup. The group meets weekly to report and discuss the activities carried out in the subgroups. The products developed by the group are subject to systematic evaluations and their reception by science teachers are the subject of formative assessment, which inform the development of subsequent phases.

The work dynamic begins with the construction of the texts that will make up the SSI page at the school. This construction is based on the use of the Scope Framework of the SSI (Chart 1), which is filled out by the working groups in an exercise of reflection and research for the development of the mobilising questions. It is based on the questions that arise in this framework in which the texts will be constructed, the sources and references researched, the educational proposals prepared, and the educational resources built, later to be disseminated on the website and on social network channels created for the project. At the same time, the search and selection of references is carried out to support the compilation of a database of additional references on SSIs with the objective of stimulating and deepening readings as well as facilitating the finding of materials that can support the approach to SSIs in the educational context. The selection, analysis, cataloguing and digital organisation of the reference database items is carried out collaboratively and is particularly attentive to checking the reliability of sources and information.

Both the test versions of the database and the preliminary proposals for texts are intended for collective reading and discussion, in order to guarantee everyone’s contribution. Instruments are also developed for the assessment (questionnaires) of the products by the target audience of basic education teachers. These studies also integrate the teams transversally.

Based on teachers’ readings and feedback, suggestions for didactic activities are prepared. These activities as well as suggestions for the use of existing resources are developed jointly, in a process that integrates the views of researchers, teachers in training and experienced teachers.

Throughout the process, effective communication is maintained with the target audience of teachers in training and in service, through communication on social media. This stage involves the selection of topics for further study and debate, identification and invitation to experts, and organisation of webinars and conversation circles. Such communication
involves the preparation and dissemination of texts in different languages and exchange with researchers and teachers, expanding and consolidating contexts of collaboration between universities and basic education schools.

RESULTS

SSI CONTENT

The work front called “SSIs at School” involves the definition of the issues to be developed in view of its global and local character and its articulations with the curricula of basic education. These are problematised with respect to the areas expressed in Chart 1 and explored through texts that contain explanations and links for further study that include journalistic articles, videos, scientific articles, ebooks, etc. and which include suggestions for pedagogical activities that can be developed in the classroom related to the topic presented (see figure 2). The texts are written and assessed collectively by the whole group. They are also used by science teachers who participate in continuing education activities related to the project. These assessments are formative in nature and indicate modifications necessary for the improvement of the material.

FIGURE 2: TEXT PUBLISHED ON THE PANDEMICS PAGE

Source: <http://qsc.nutes.ufrj.br/>
So, in the end, is chloroquine effective in the treatment of Covid-19, or not?

At the time of writing this post (15/05/2020) the answer is:

**We don’t know yet.**

**But, why?**

Before being produced on a large scale and prescribed by doctors, a drug goes through several stages of testing. Initially, biochemical studies are carried out in models or animals. After the conclusion of this experimental research phase, several stages of clinical research with human beings begin. Clinical trials assess not only the therapeutic activity, but also the toxicity of drugs. In addition to these scientific aspects, the tests involve social, economic, political and ethical aspects. To date, the use of chloroquine and hydroxychloroquine in patients with Covid-19 is controversial and their use depends on the doctor’s decision regarding a specific patient. Other drugs are being tested for the treatment of Covid-19, but so far there is no conclusive clinical research that assesses the risks and benefits of their administration.

**Links for further conceptual understanding and suggestions for the creation of educational activities**

Explore possibilities for using films in the classroom for;

- Contextualisation of virology and immunology content through videos;
- Discussion of the nature of drug production processes through films

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**REFERENCE DATABASE**

This work approach includes: active searches for materials that explore conceptual, sociopolitical, historical, etc. dimensions related to the SSI, in different languages, support and contexts; critical reading activities and analysis of the discourses conveyed in these materials; recommendation of criteria to evaluate the reliability of the information on socio-scientific issues that circulate in these materials, on the different social media and systematisation of the selected texts in tables that include physical and content descriptions. The database does not store content, only links to materials published on the Internet. Its access is open and free and preference is given to materials with recent publication, also in open access and free of charge.

Items are catalogued by topic, site tab, site question, title, URL, genre, content, keywords, references, and remarks. We also recommend potential relationships between the classified items and the issues discussed on the “SSIs at School” page. The material is provided in the form of a card that lists this information (see Figures 3, 4, and 5).
FIGURE 3 – CARD REFERRING TO THE VACCINE PAGE

**VACCINE**

**Want to know more about...**

*What are the anti-vaccine arguments based on?*

*How does the anti-vaccine movement use fake news and generate misinformation about vaccines?*

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The video presents an interview carried out by Casa do Saber with the researcher and doctor in microbiology Natalia Pasternak about the anti-vaccination movement. It explains the movement’s criminal beginnings as well as the dangers arising from this movement that is fed by fake news to this day.

Keywords: Anti-Vaccine Movement; Fake News; Science.

Available in open and free access on the Casa do Saber YouTube channel.

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**The Myth and Danger of the Anti-Vaccine Movement**

THE MYTH and the danger of the anti-vaccine movement. PASTERNAK, N. (S.I.), 2021. 1 video (11 minutes and 27 seconds). Published by Casa do Saber channel.

Available at: https://www.youtube.com/watch.....
Report published in the American magazine, Jacobin, points out that Covid-19 is the result of a global phenomenon of environmental degradation. The authors claim that the less space humanity leaves nature, the more environmental problems, including deadly new zoonoses, there will be.

Keywords: Climate change; coronavirus; Politics

Available for free and open access on the Jacobin website

The climate crisis and COVID-19 are inseparable


Available at: link
Thematic panel presented at the 2021 UFRJ Knowledge Festival, coming from GT acadêmico NUTES, whose objective is to conceptualise racism as a socio-scientific issue, explore curricular approaches on the subject through historical, social and scientific aspects, highlight the controversy of scientific ideas that promote racial discrimination and highlight the intersectionality between racism and other prejudices.

Keywords: Knowledge Festival; Racism; Socio-scientific issues

Available in open and free access on the UFRJ Extension channel.
EDUCATIONAL RESOURCES

In addition to disseminating suggestions available in the research literature of the area, our group has also developed activities for curricular work with SSIs. They are the result of partnerships with basic education teachers and include workshops, didactic sequences, and debates, among others. The activities consider the school as a distinctive space for knowledge production, with a culture that favours the plurality of knowledge, including that produced by the teacher in the context of their practices (Marandino, Selles and Ferreira, 2009).

Among the examples of activities developed, we highlight:

(i) the workshop “bad hair doesn’t exist” which aims to: problematise ways in which issues of race and racism emerge in everyday school life, address stigma related to African hair, publicise social movements that embrace Afro hair as an integral part of black identity and also as an instrument of empowerment, promoting the construction of a “positive black identity” (GOMES, 2003). The workshop problematises expressions such as “bad hair”, discusses the chemical constitution of the hair, and the processes of straightening, hair transition and moisturising. It articulates a conceptual discussion of these topics – from historical, linguistic, sociopolitical and scientific aspects –, to a practical activity that shows how to enrich it with nutrients and intensify the effects of moisturising cream, based on the use of a natural base such as olive oil and vegetables like beetroot and carrots.

(ii) the theatre skit “Vaccine, Yes!” conceptualised from a visit to a science museum exhibition narrating the context of a popular rebellion against the mandatory vaccination against smallpox in the early 20\textsuperscript{th} century in Rio de Janeiro, and which motivated the discussion of scientific concepts about viruses, immunisation, and controversy related to vaccination, as well as the discussion about the circulation of fake news, as seen in the Covid-19 pandemic. Based on these discussions, a theatrical sketch was conceived that recreates arguments related to vaccine resistance in both contexts. The creation of the script, the writing of the text, the use of techniques such as flashback, and the rehearsals and presentations of the skit allowed for the development of approaches related to the Nature of Science and the History of Science in addressing socio-scientific issues.

(iii) the didactic follow-up “What mask should I wear?” explored controversies about the mandatory use of masks as personal protection against Covid-19, proposing (a) analysis of materials
produced by health authorities and campaigns carried out by the media; (b) review of prior knowledge and exploration of principles on ways of spreading the virus, Brownian movement, the role of electrostatic forces in masks; (c) the carrying out of investigative activity involving characterisation of the effectiveness of mask types available; (d) consideration of the environmental impact of mask disposal, as well as cost and availability; (e) the relevance of this information to support the creation of health policies to prevent the spread of the SARS-CoV-2 virus.

**NEXT STEPS**

For the next steps, we highlight the investments to be made in the scope of the dissemination of the group’s activity on social media, and organisation of webinars, panels, debates, among other actions. It is expected to maintain effective communication with basic education teachers, both in training and in service. This work group involves the selection of topics for further study and debate; identification and invitation of experts; and the organisation of webinars and conversation circles. For this communication to be effective, texts will be written and disseminated in different languages and exchanges with researchers and teachers, expanding and consolidating contexts of collaboration between the university and the basic education school. We also hope to deepen reflections on the potential of addressing socio-scientific issues to achieve science teaching objectives related to citizenship education about decision-making and the promotion of social justice.
REFERENCES


