

A narrative review of Brazilian and Portuguese students' perceptions and conceptions about climate change

UMA REVISÃO NARRATIVA DAS PERCEPÇÕES E CONCEPÇÕES DE ESTUDANTES BRASILEIROS E PORTUGUESES SOBRE AS MUDANÇAS CLIMÁTICAS

VICTOR HUGO COUTO¹, PEDRO WAGNER GONÇALVES², JAN SERMEUS³

1 - STATE UNIVERSITY OF CAMPINAS, GEOSCIENCES INSTITUTE, GRADUATE PROGRAM IN TEACHING AND HISTORY OF EARTH SCIENCES, PHD STUDENT, CAMPINAS, SP, BRAZIL.

2 - STATE UNIVERSITY OF CAMPINAS, GEOSCIENCES INSTITUTE, GRADUATE PROGRAM IN TEACHING AND HISTORY OF EARTH SCIENCES, PROFESSOR, CAMPINAS, SP, BRAZIL.

3 -ROYAL OBSERVATORY OF BELGIUM, PLANETARIUM. KU LEUVEN, DEPARTMENT OF PHYSICS AND ASTRONOMY AND FACULTY OF PSYCHOLOGY AND EDUCATIONAL SCIENCES, PROFESSOR, LEUVEN, BELGIUM.

EMAILS: COUTOVH11@GMAIL.COM, V184495@DAC.UNICAMP.BR, PEDROG@UNICAMP.BR, JAN.SERMEUS@KULEUVEN.BE

Abstract: Introduction and Objective. This narrative review aims to analyze the understanding of Brazilian and Portuguese students about climate change through the synthesis and discussion of the literature. **Methodology.** A mapping of misconceptions was carried out through bibliographic review with the target audience being final years of basic and high school education to the initial years of university (approximately 14 to 21 years old). **Results.** It was observed that nearly all misconceptions were shared, except for two that were exclusive to each country. Hypotheses were thus raised about the current stage of environmental education, incidence of misconceptions, national curricula, and teaching practices. **Conclusion.** Overall, more similarities than differences were found in the challenges faced by students (and teachers), which brings interesting discussions for both countries given their closely intertwined history, yet distinct realities.

Resumo: Introdução e Objetivo. Esta revisão narrativa busca analisar o entendimento de estudantes brasileiros e portugueses acerca de mudanças climáticas a partir de uma síntese e discussão da literatura. **Metodologia.** Foi realizado um mapeamento de concepções errôneas por intermédio de revisão bibliográfica de trabalhos que focalizem o público-alvo dos anos finais do ensino básico e médio aos anos iniciais da universidade (14 a 21 anos aproximadamente). **Resultados.** Observou-se um compartilhamento de praticamente todas as concepções errôneas, à exceção de duas que foram exclusivas de cada um dos países. Foram assim levantadas hipóteses sobre: (a) o estágio atual da educação ambiental, (b) a incidência de concepções errôneas, (c) currículos nacionais e (d) a prática docente. **Conclusão.** No geral, encontraram-se muito mais semelhanças do que diferenças nas dificuldades encontradas por estudantes (e professores), que fornecem uma base para discussões interessantes para os dois países dada sua história tão interligada, mas de realidades tão distintas.

Introduction

Climate change (CC) is one of the greatest challenges humanity will face in the coming decades. Education can, and should, play a significant role in educating students about the subject, and its increasing presence in various national curricula is proof of this (Fahey, 2012, Bodzin & Fu, 2014, Chang & Pascua, 2017, Colliver, 2017, Howard-Jones et al., 2021). The academic world has also significantly increased research studying CC education in the last decade (Bhattacharya et al., 2020).

In this work, we will primarily investigate students' conceptions of CC. Conceptual understanding is of great importance in educational research, being particularly relevant in this specific topic. Understanding is intrinsically linked to students' global mental models, including their preconceptions and misconceptions. While it is a phenomenon of global impact, previously referred to as global warming, its impact on a small scale is quite variable and depends on various local parameters (Wilbanks & Kates, 1999). Additionally, Reser (2014) observed that percep-

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tions about the subject differ across various local communities. Therefore, the question arises as to whether students' conceptions can also vary from one locality to another.

We conducted a narrative review of the literature on the perceptions and conceptions (both defined later in the text) of Brazilian and Portuguese students from the final years of elementary school (8th and 9th grades) to undergraduate level regarding CC. The subject is not introduced in the early grades (although they learn about environmental education in general), so these were excluded. The comparison between Brazil and Portugal can offer interesting hypotheses, as both share a language and have historical and cultural ties, but at the same time, they have deep social and geographical contrasts.

In the methodology, we present the search terms and databases used and explain the reason for choosing a narrative review instead of a systematic literature review. In the Results section, the data found will be presented separately for Brazil and Portugal, with considerations involving each country followed by a general discussion of the findings. Thus, this work seeks to develop a discussion on the following questions:

- What are the misconceptions/alternative conceptions about climate change among students (from the final years of elementary school to university) in Brazil and Portugal?
- Are there misconceptions exclusive to one country or the other?
- What does this imply for educational practices in each country?

Educational Systems in Brazil and Portugal

It is important to briefly describe the structure of basic education in each country. In Brazil, basic education comprises Elementary School (1st to 9th grade) and High School (1st to 3rd grade). Portugal has the Basic Cycle (1st to 9th grade) and Secondary Education (10th to 12th grade). This research focuses on students from the 8th grade to higher education.

Both countries have a single Science subject for most of Elementary School. In Brazil, Science is divided into Biology, Physics, and Chemistry in High School. Portugal divides Sciences into Physics-Chemistry and Biology-Geology from the 9th grade. Earth Sciences is not a separate subject in Brazil; it is usually divided between Sciences and

Geography. Considering the curricular structure of the two countries, Portuguese students in principle have more exposure to Earth Sciences than Brazilian students.

Methodology

The narrative review is an approach that allows more flexibility in exploring the literature but is subjective from the authors' perspective. Although the search methodology is not entirely reproducible due to its exploratory nature (Rother, 2007), we describe the bibliographic research process as comprehensively as possible. Searches were conducted on Google Scholar, SciELO, and Web of Science using specific terms (see Table 1).

The main combination of search terms and operators used were:

- (“misconceptions” OR “alternative conceptions”) AND “student★” AND (“climate change” OR “global warming”) AND “Brazil”
- (“misconceptions” OR “alternative conceptions”) AND “student★” AND (“climate change” OR “global warming”) AND “Portugal”

The choice of the term “student” proved suitable to encompass the entire spectrum of age groups of interest to the study. It also returned articles on the early years of basic education, but these were excluded as they are not within the scope of this work. The above combination of terms was repeated in Portuguese.

As the focus of this work is to map and compare misconceptions, initially, articles directly related to students' conceptions about CC and that had surveys with students within the chosen age range for the research were selected. Articles that only discussed environmental education in general were not included in this first stage.

Table 1. Search terms used to find articles directly related to CC misconceptions. Source: elaborated by the authors

Portuguese	English
Brasil	Brazil
Portugal	Portugal
estudantes	students
concepções errôneas	misconceptions
concepções alternativas	alternative conceptions
mudanças climáticas	climate change
aquecimento global	global warming

Subsequently, additional works referenced in these initial selections were included (backward reference search). The analysis of these references led to the creation of two tables of misconceptions, one for Brazil and one for Portugal. The tables are detailed in the Results section and analyzed and compared in the Discussion section.

The mapped misconceptions were classified according to their Category, which could be Definitions, Causes, or Consequences. In addition, the Incidence of each misconception by article and school year was mapped. When possible, the percentage of students who had that particular misconception within the group studied by the article was highlighted. It should be noted that it was not always possible to obtain this information, either because the statistic was not available or the conception appeared only in some discursive responses and was not counted.

Finally, for each misconception, a Degree of Concern was established, which could be Low, Medium, or High. Misconceptions of a High degree are understood as priorities to be mitigated by educators and in the preparation of teaching materials. The Degree of Concern is the result of the authors' interpretation and does not have quantitative parameters, only observations and justifications that will be detailed throughout the Results and Discussion.

Factual Analysis of the Mapped Misconceptions

To assist the reader who may not be so familiar with the physical-chemical phenomena and mechanisms involved in climate change, we prepared a brief descriptive in the Supplementary Material. We chose to do this analysis based on the mapped misconceptions, as this way it already bridges the explanation of the phenomena with the conceptions discussed.

Limitations and Considerations on the Method

As previously described in the Methodology, because it is a narrative review, it does not have the rigor of analysis of a systematic review. Therefore, there is a possibility that some reference was not identified in the search process, especially since it was necessary to resort to dissertations and theses for a more in-depth analysis. As will be discussed later, the very works consulted - recent ones - mention the scarce literary production in conceptions about CC.

Furthermore, grouping common misconceptions from different works proved to be a challenge because each research has its own structures of questionnaires and presentation of results. Thus, it was necessary to phrase each misconception in a way that encompassed as best as possible how it was treated in most studies.

Results

The exploratory search aimed at finding works specifically addressing the research question returned nine references for Brazil and seven for Portugal. Among these references are also master's and doctoral theses, reflecting the scarce number of studies on CC conceptions conducted in these countries. Therefore, what is discussed here should not be taken as a generalization but may indicate important trends.

During the research, it became apparent that the questions asked of students could be divided into two groups, which for the purpose of this article, were named perceptions and conceptions.

Perceptions are questions that measure opinions and impressions, not involving knowledge of the mechanisms and science behind CC. Questions such as:

- Have you heard about global warming?
- Do you think that, if nothing is done, the climate will change in 30 years?
- Do you believe in CC?

Conceptions are questions that involve students' technical knowledge about the mechanisms and science behind CC. Questions such as:

- What are the causes of global warming?
- What are the gases commonly associated with the greenhouse effect?
- How much will the temperature increase on average in the coming decades?

The literature review is described first focusing on findings from Brazil and then Portugal. The initial analysis in each country explored the students' perceptions to understand their general thinking, followed by an analysis of their conceptions that are the primary focus on this article. At the end of each topic, the main misconceptions/alternative conceptions found in each country were summarized.

Brazilian students' understanding of CC

Nine references dealing directly with student conceptions were found (Tab. 2). Of these, four involve Elementary School students, five involve High School students, and four involve University students. The total exceeds nine as some references work with more than one segment.

Perceptions of Brazilian students

Most of the reviewed works discussed the perceptions of Brazilian students. It was observed in all the research that most students are aware of environmental changes, mainly global warming, regardless of the school year (Reis & Silva, 2016, Santos et al., 2019, Mesquita et al., 2019). This reflects the growing public debate on the topic, largely influenced by media coverage, and its integration into the school environment. Most interviewed students demonstrated a clear understanding of the future risks associated with global warming, aligning with the general perception of the Brazilian population (Pinto et al., 2020).

The perception of the severity of CC remains relatively consistent across different school years.

Borges et al. (2021) analyzed students from the 9th year of Elementary School and the 3rd year of High School, finding similar results in both segments. Students from both groups were already familiar with the topic and its negative impacts on the environment, the main difference being that the older students tended to have more advanced knowledge of related terms and definitions than the younger students.

Another important aspect of the students' perception, that emerged from the consulted literature, is how they "see" the environment, that is, whether they see nature as something distant from their daily lives, as a vital part of each of our existences, or simply as a resource to be exploited. In this line of analysis, Costa (2016) observed that 70% of the interviewed students had a "reductionist" view of the environment, which is defined in the article as:

Bringing the idea that the environment refers strictly to the natural physical aspects such as water, air, soil, rocks, fauna, and flora, excluding the human being and all its productions. Unlike the "romantic" category, it does not proclaim the exaltation of nature (Costa, 2016, p.396)

Table 2. Selected references in Brazil that directly address misconceptions/alternatives in CC (in ascending order by year)

Title	Author and year	Type	Segment
Alternative conceptions of 8th grade elementary school students about the greenhouse effect phenomenon [As concepções alternativas de alunos da 8ª série do ensino fundamental sobre o fenômeno do efeito estufa]	Libanore (2008)	Master's Dissertation	Middle
Global warming: an investigation into the social representations and conceptions of elementary school students [Aquecimento global: uma investigação sobre as representações sociais e concepções de alunos da escola básica]	Muniz (2010)	Master's Dissertation	Middle / High / College
Analysis of Brazilian dissertations and theses on Environmental Education: understandings elaborated on the topic "climate change" [Análise de dissertações e teses brasileiras de Educação Ambiental: compreensões elaboradas sobre o tema "mudanças climáticas"]	Reis & Silva (2016)	Journal article	Middle / High / College
Environmental perception of young and adult students in basic education (EJA Program) in municipal public schools [Percepção ambiental dos estudantes jovens e adultos da educação básica (Programa EJA) de escolas públicas municipais]	Costa (2016)	Journal article	High
University Student's Perceptions About Climate Change: The Case of Interior Design and Architecture Students of a Brazilian University	Alves et al. (2017)	Journal article	College
Assessing the Knowledge of Undergraduate Students in Chemistry on the Possible Depletion of the Ozone Layer	Santos et al. (2018)	Journal article	College
Perception of first year high school students about global climate change [Percepção de alunos da primeira série do ensino médio acerca das mudanças climáticas globais]	Santos et al. (2018)	Journal article	High
Perceptions of university students about climate change and its impacts: case study in the Federal District [Percepções de universitários sobre as mudanças climáticas e seus impactos: estudo de caso no Distrito Federal]	Mesquita et al. (2019)	Journal article	College
Study on climate change in the last years of basic education in Jaboticabal (SP) [Estudo sobre as mudanças climáticas nos últimos anos da educação básica em Jaboticabal (SP)]	Borges et al. (2021)	Journal article	Middle / High / College

This view is reinforced in research by Muniz (2010), in which most elementary and high school students presented a spatial view of the environment, which has characteristics very similar to the reductionist view described above. Both represent a simplistic view of the environment, not considering the integration and relationship between nature and the human being.

Most students see nature as something external to their daily lives but agree and are concerned about humanity's role in global warming. Perhaps, this contradiction is due to a lack of reflection on the interconnection between the environment and our lives, or even a tendency to place humans as the protagonists of the functioning of the world and nature as a supporting actor.

Younger students tend to point to humans as the main or sole agent causing global warming (Muniz, 2010, Borges et al., 2021) attributing humanity as a "predator," but when questioned individually, they distance themselves from this notion, claiming to have personal values contrary to those (Muniz, 2010). University students have a broader perception, recognizing natural and human causes for the phenomenon (Mesquita et al., 2019).

The main source of information for students beyond television and the educational institution (school/universities) is the internet (Muniz, 2010, Mesquita et al., 2019). This brings an additional challenge, as the internet allows the easy circulation of lies and misinformation, even if not intentionally (Santini & Barros, 2022).

Conceptions of Brazilian students

The fact that students know about CC and its severity does not necessarily mean they understand its basic operating principles. In the research by Santos et al. (2019), all students (1st year of High School) interviewed were familiar with the terms "climate change" and "global warming", but when asked about what global warming is, 35% left the question blank; and when asked about the greenhouse effect, 62% left it blank.

Some of the most common misconceptions are related to the greenhouse effect and global warming. Most students in the later years of elementary school correctly associate air pollution with greenhouse gases (Borges et al., 2021), but they also say that it is the creator of the greenhouse effect (Libanore, 2007). This shows a lack of understanding that the greenhouse effect is a natural phenomenon, and some students may

treat the greenhouse effect and global warming as synonyms. The difficulty in distinguishing the two phenomena is also shared by high school students (Muniz, 2010). Therefore, some students claim that the greenhouse effect is responsible for melting glaciers (Libanore, 2007). In the same research, the author shows that this conceptual confusion between the phenomena was also shared by the teachers, so the students ended up repeating what they were taught.

Pollution frequently appears in students' responses, leading to interesting misconceptions. A common notion is that it causes the greenhouse effect, especially among elementary school students (Libanore, 2007). When asked about pollution sources, students usually mention smoke, fires, industries, and transportation (Muniz, 2010, Santos et al., 2019, Borges et al., 2021). However, they rarely explore which sources generate more polluting gases or the impact of consumption habits. Some students mistakenly believe that trash, especially when thrown on the street, significantly contributes to climate change (Costa, 2016, Santos et al., 2019). There is a tendency to focus on individual habits, such as energy saving and recycling, without fully grasping the complexities of production chains and the economic actors involved (Costa, 2016).

There is also a lot of confusion in identifying the main gases responsible for the greenhouse effect. Santos et al. (2019) conducted a survey in which 54% of the participants did not answer the question, and 88% provided incorrect answers, citing oxygen, hydrogen, and nitrogen; with only 10% of students correctly naming methane. In the research by Borges et al. (2021), approximately 75% of students knew that carbon dioxide is the most abundant greenhouse gas on Earth.

Misconceptions related to the degradation of the ozone layer are prevalent among students. Some associate it with global warming, attributing its destruction to carbon dioxide, or see it literally as a hole in the atmosphere, causing increased solar energy passage and atmospheric warming (Libanore, 2007, Muniz, 2010). Such misconceptions were observed in elementary students and persisted until the 1st year of high school (Santos, 2018). Although university students showed a reduction in misconceptions compared to elementary school students (Muniz, 2010, Costa, 2016), they remained among university students, even in students that take up specialized Chemistry subjects (Alves et al., 2017, Santos et al., 2018).

One of the most cited consequences of global warming is the melting of glaciers and the consequent rise in sea level (Muniz, 2010, Santos et al 2019). Although it is a correct consequence, many students do not distinguish between glaciers on the continent (responsible for the sea level rise when melted) and glaciers already floating in the ocean (whose melting does not influence sea level). There is also no mention of permafrost melting. As many students consider the greenhouse effect synonymous with global warming, they attribute it as the cause of polar ice cap melting and flooding (Libanore, 2007, Muniz, 2010).

Many associated the increase in skin cancer cases with global warming (Libarone, 2007, Muniz, 2010). This mistake may be related to the fact that they associate ozone layer degradation with global warming. The increase in skin cancer is indeed related to the deterioration of the ozone layer, as it allows more ultraviolet rays

to pass through, but it is not directly related to global warming.

Students' responses often mention environmental damage because of global warming (Muniz, 2010, Santos et al., 2019), including the destruction of fauna and flora species. However, their explanations often lack specificity, indicating a superficial understanding. Santos et al. (2019) found that only 12% of students mentioned "climate change", reflecting little habit of using the term. Surprisingly, in the same research, about 25% of students cited pollution as a consequence, possibly indicating alternative conceptions of climate dynamics or misunderstanding the intention of the question. Additionally, in Muniz (2010), some students associated global warming with tsunamis and earthquakes, revealing a correlation between phenomena with distinct causes. Table 3 summarizes the main misconceptions/alternative conceptions of Brazilian students along with their categories (causes, consequences, or definitions)

Table 3. Misconceptions/alternative conceptions mapped in Brazilian students. The percentages next to the references indicate the number of students who presented that conception out of the total sampled. In some cases, it was not possible to obtain the percentage (x) because the statistic was not available or the conception appeared only in some discursive responses and was not counted. Source: elaborated by the authors

Misconception	Category	Incidence		
		Middle	High	College
Greenhouse effect as a synonym for global warming	Definitions	Libanore (2007), 2,5%	Muniz (2010), ~12%	x
Ozone layer as a synonym (or cause) of global warming [1] / greenhouse effect [2] / climate change [3]	Definitions	[1] Libanore (2007), 2,5%	[2] Santos et al. (2019), ~12%	[3] Alves et al. (2017), 66%
				[2] Santos et al. (2019), ~60%
The "hole" in the ozone layer is literally a hole	Definitions	Libanore (2007)	Muniz (2010),	Santos et al. (2019)
Atmospheric pollution causing the greenhouse effect	Causes	Libanore (2007), 75%	Costa (2016), ~41%	x
The degradation of the ozone layer is caused by pollution or the accumulation of CO ₂	Causes	Libanore (2007)	Muniz (2010)	Santos et al. (2018)
Litter on the streets is directly and significantly related to climate change	Causes	x	Costa, (2016) ~80%	x
			Santos et al. (2019), ~7.5%	
Increase in cancer cases due to global warming/greenhouse effect	Consequences	Libanore (2007), 37.5%	Muniz (2010)	x
Oxygen, hydrogen, and nitrogen are greenhouse gases	Causes	x	Santos et al. (2019), 5 a 15%	x
The greenhouse effect is responsible for the melting of glaciers	Consequences	Libanore (2007), 40%	Muniz (2010), 25 to 36.4%	x
			Santos et al. (2019), ~45%	
Pollution as a consequence of global warming	Consequences	x	Santos et al. (2019), ~22%	x
Global warming is related to earthquakes and tsunamis	Consequences	x	Muniz (2010)	x

and their incidence by school segment where they were detected.

Portuguese students' understanding of CC

Similarly to the research conducted for Brazil, in Portugal, there is a limited number of works specifically about alternative conceptions (García-Vinuesa et al., 2021). Most references focus on perceptions and there are important contributions from master's dissertations and doctoral theses.

Seven references dealing directly with student conceptions were found (Tab. 4). Of these, three involve students from the Basic Cycle, four involve students from Secondary Education, and two involve University students. The total exceeds seven because some references work with more than one segment.

Perceptions of Portuguese students

Most students who participated in the research know and believe in CC (Santos et al., 2016, García-Vinuesa et al., 2021). However, a significant percentage still believes there is no consensus among scientists. García-Vinuesa et al. (2021) found that this is true for approximately 26% of Basic Cycle students, while Santos et al. (2016) conducted similar research among university students, revealing that 25% of the interviewees shared this view. Notably, Santos et al. (2016) observed the same trend among students in environmental-related courses.

In the exploratory research conducted for Portugal, no references were found that conducted research like that of Costa (2016) and Muniz (2010) to understand how Portuguese students "see" the environment and categorize their views. Most questions in the works explore students' views on environmental issues (causes and consequences), rather than their relationship and how they conceive nature itself.

Fernandes et al. (2007) conducted an extensive study on the general perception of students in the 5th and 8th grades from different regions of Portugal. There was an increasing maturation among grades in topics such as the importance of environmental issues for professional life and the need for environmental legislation. However, in many other aspects, 5th-grade students had better perceptions than 8th-grade students, standing out: frequency of the subject in the classroom, participation in activities (inside and outside the school) related to the environment, family discussion, sensitivity to environmental issues, and general interest in the subject.

Roque (2011) conducted a study with students from the basic cycle (1st to 9th grade) and observed a positive evolution in the global perception of students over time. The research revealed a gradual increase in concern and individual recognition of the importance of addressing CC. Recognition does not always translate into immediate action, but it signifies a recognition of its necessity. When

Table 4. Selected references in Portugal that directly address misconceptions/alternatives in CC (in ascending order by year). Source: elaborated by the authors

Title	Author and year	Type	Segment
Global warming and ozone layer degradation: Teaching and learning in secondary education [Aquecimento global e degradação da camada de ozono: Ensino e aprendizagem no Ensino Secundário]	França (2002)	Master's Dissertation	High
Analysis of environmental perception of basic education students in Portugal [Análise da percepção ambiental de estudantes do ensino básico em Portugal]	Fernandes et al. (2007)	Research report	Middle
Greenhouse Effect and Global Warming: A study with 3 rd Cycle and Secondary Physics and Chemistry students [Efeito de Estufa e Aquecimento Global: Um estudo com alunos de Física e Química de 3 ^o Ciclo e Secundário]	Peixoto (2009)	PhD Thesis	Middle / High
Environment and sustainability: the students' point of View [Ambiente e sustentabilidade: o ponto de vista dos alunos]	Roque (2011)	PhD Thesis	Middle
Assessing student perceptions and comprehension of climate change in Portuguese higher education institutions	Santos et al. (2016)	Book chapter	College
Assessing high school student perceptions and comprehension of climate change	Azeiteiro et al. (2018)	Book chapter	High
Assessing climate knowledge and perceptions among adolescents. An exploratory study in Portugal	García-Vinuesa et al. (2021)	Journal article	High

asked about the need for a lifestyle change to combat global warming, most students did not feel compelled to make such adjustments. While many expressed willingness to give up consumer products to contribute to the issue, older students seemed more hesitant.

Of the students (10th to 12th grades) researched by García-Vinuesa et al. (2021), more than 90% believe that the main cause of climate change is anthropogenic. This percentage is lower in students specializing in humanities (76.1%) and higher in the natural sciences group (91.3%). It is striking in Roque's (2011) research that most students do not believe that the solution to climate problems is the responsibility of richer countries, lacking a definitive opinion on the subject. In García-Vinuesa et al. (2021) research, students attributed low responsibility to Portugal in the issue but pointed out that the country is very sensitive to climate impacts.

The main sources of information for Portuguese students about the environment beyond school are television and the internet (Fernandes et al., 2007). This reinforces the care that educators must take in developing teaching materials, which, if poorly developed, can contribute to the dissemination of misconceptions (Roque, 2011).

Conceptions of Portuguese students

In the research conducted by Fernandes et al. (2007), 12.1% of participants admitted to not knowing the concept of global warming, while 8.3% stated that it does not exist. Peixoto (2009) found that none of the interviewed students provided a scientifically accurate and complete explanation of the greenhouse effect in discursive questions, with only a minority offering incomplete answers with misconceptions. Furthermore, in the work of França (2002), an analysis of secondary school students with technical and chemical specialization showed that less than 10% recognized the greenhouse effect as a natural phenomenon. This demonstrates that even in specific courses, there is a persistent difficulty in accurately defining the main phenomena involved in CC.

One of the most common misconceptions is that the greenhouse effect and global warming are synonyms (França, 2002, Roque, 2011). It is more common among younger students and tends to decrease in older ones, but it is still present. The difficulty in distinguishing each phenomenon leads to wrong conceptions about their causes, for example, with 37.5% of students (10th to 12th

grade) attributing pollution as the cause of the greenhouse effect (França, 2002). In several studies, it was reported that they erroneously associate the greenhouse effect with the hole in the ozone layer, or treat one as the cause of the other (Peixoto, 2009, Roque, 2011, Azeiteiro et al., 2018).

Conceptual confusion leads to contradictory beliefs among students. For example, in the research of França (2002), although no student established a reciprocal relationship between global warming and the degradation of the ozone layer (which is correct, as there is no direct relationship between these phenomena), 30% of the students believed that global warming would increase if more ultraviolet rays reached Earth (a direct consequence of the degradation of the ozone layer, recognized by 87% of the analyzed students). The author suggested that the way the questionnaire's propositions were written might have influenced the students' responses. In other research (Peixoto, 2009, Roque, 2011, Azeiteiro et al., 2018), students made the erroneous association between global warming and the ozone layer.

Regarding the knowledge of gases causing global warming, most students recognize the participation of carbon dioxide as one of the main ones (França, 2002, Peixoto, 2009). A significant portion of Portuguese students also correctly listed other important gases such as methane, tropospheric ozone, nitrous oxide, and chlorofluorocarbons (CFCs), although they may have been selected due to a wrong association between the destruction of the ozone layer and the greenhouse effect (Peixoto, 2009). Thus, in general, Portuguese students seem familiar with the different gases that make up the atmosphere and know their relationship with the greenhouse effect. However, in the same research, a significant number of students (10th to 12th grade) also pointed to ozone (58.8%), hydrogen (27.7%), and nitrogen (43.6%) as participants in the greenhouse effect, which is incorrect.

Regarding the relationship between environmental pollution, a significant portion of students associate atmospheric pollution directly with the greenhouse effect, reinforcing the conceptual confusion between the phenomena (Peixoto, 2009, Roque, 2011). Most also erroneously associate street litter and sewage as direct influences (Fernandes et al., 2007, Peixoto, 2009). Portuguese students also mentioned nuclear waste as related to CC (Peixoto, 2009), which was not observed in Brazil.

Specific conceptions about the ozone layer also show the conceptual confusion between the phenomena. Many maintain the idea that the “hole” in the ozone layer is literally a hole (França, 2002), facilitating the passage of ultraviolet rays that are directly responsible for heating the atmosphere or even the greenhouse effect (Peixoto, 2009, Roque, 2011). In the research of França (2002), they demonstrated good knowledge that the main responsible for the degradation of the ozone layer are CFCs, but a significant portion associated general pollution as the cause of the problem.

Regarding the consequences of global warming, one of the most cited is the melting of ice at the poles, causing sea level rise and flooding (Fernandes et al., 2007, Peixoto, 2009). As many students have difficulties with the definitions of global warming and the greenhouse effect, they can attribute the cause of the melting of the polar ice caps to it.

A frequently mentioned incorrect consequence is that global warming increases the incidence of skin cancer (França, 2002, Peixoto, 2009). The degradation of the hole in the ozone layer can indeed lead to more cases of cancer, but they also point to this for global warming because they mix the two phenomena. There were also some students who referred to an increase in deaths from heart attacks (Peixoto, 2009).

A correct consequence of CC mentioned by Portuguese students and not appearing in the Brazilian researches is heat waves, more felt in regions with colder climates (Fernandes et al., 2007). However, as seen in the Brazilian researches, some Portuguese students associate global warming with extreme events such as earthquakes and tsunamis (Peixoto, 2009).

Portuguese students have a good perception of the impacts of global warming on biodiversity and ecosystem alteration (Fernandes et al., 2007, Santos et al., 2016). However, in the conducted researches, it was not possible to define to what extent they know the mechanisms by which global warming influences the functioning of the various ecosystems.

Table 5 synthesizes the main misconceptions/alternative conceptions of Portuguese students along with their Category (Causes, Consequences, or Definitions) and their incidence by school segment where they were detected along with the references.

Discussion

From the consulted literature it is clear that both Brazilian and Portuguese students of all ages are aware of CC and recognize the role humans play in CC. Despite this awareness, there are several misconceptions with respect to causes, consequences and definitions of climate change and global warming. These misconceptions are persistent, in line with what other research on misconceptions has shown (Viennot, 1979, Chi, 2005), lasting from elementary to higher education.

There are some works in Brazil that specifically address students’ views (Reis & Silva, 2016), but overall there is little research published on this topic. Furthermore, the work that does exist is predominantly concentrated in the Southeast region of Brazil with little interinstitutional collaboration, and with foreign authors (Cararo et al., 2022). As such, this work does not aim to generalize what Brazilian students think about CC, only to point out trends and raise hypotheses. In Portugal, there is also a scarcity of works that specifically deal with misconceptions (García-Vinuesa et al., 2021). However, as it is a small country with a much smaller population than Brazil, it is relatively easier to conduct a national survey like the work of Fernandes et al. (2007), which covers schools from almost all regions.

The first highlight about the perception of topics related to CC is that they are widely known by most students in all segments analyzed in both countries. For example, students in both countries see humans as the main responsible for climate changes (Muniz, 2010, Borges et al., 2021, García-Vinuesa et al., 2021), although this notion seems to be more consolidated in Portugal. Furthermore, students demonstrate great concern for the topic, which reflects public opinion research for the general population in both countries (Schmidt & Delicado, 2014, Pinto et al., 2020). This is expected, as the main sources of information for Brazilian and Portuguese students are school, television, and the internet (Fernandes et al., 2007, Muniz, 2010, Mesquita et al., 2019).

The works of Muniz (2010) and Costa (2016) addressed how students see nature, establishing categories for different perspectives. These studies specifically address Brazil, with no similar research found in Portugal. However, from the interpretation of studies on the perception of Portuguese students, it was found that as they grow older, they tend to develop a “reductionist” view (Costa, 2016) of the environment, coinciding with Bra-

Table 5. Misconceptions/alternative conceptions mapped in Portuguese students. The percentages next to the references indicate the number of students who presented that conception out of the total sampled. In some cases, it was not possible to obtain the percentage (x) because the statistic was not available or the conception appeared only in some discursive responses and was not counted. Source: elaborated by the authors

Misconception	Category	Incidence		
		Middle	Médio	Superior
Greenhouse effect as a synonym for global warming	Definitions	Roque (2011)	França (2002), ~50%	x
		Peixoto (2009), 18 a 25.7%	Peixoto (2009), 5 to 8.8%	
Ozone layer as a synonym (or cause) of global warming [1] / greenhouse effect [2] / climate change [3]	Definitions	[1] Roque (2011), 9 a 63%	[3] Azeiteiro et al. (2018), 81%	[3] Santos et al. (2016), 57%
		[2] Peixoto (2009), 6 a 12.8%	[2] Peixoto (2009), 1 to 8.8%	
Atmospheric pollution causing the greenhouse effect	Causes	x	França (2002), ~7,4%	x
			García-Vinuesa et al. (2021), 50%	
The “hole” in the ozone layer is literally a hole	Definitions	x	França (2002), 8,6 to 63.6%	x
The degradation of the ozone layer is caused by pollution or the accumulation of CO ₂	Causes	Peixoto (2009),	França (2002), ~9%	x
			Peixoto (2009),	
Litter on the streets is directly and significantly related to climate change	Causes	Peixoto (2009), 67.4%	Peixoto (2009), 59,8%%	x
Increase in cancer cases due to global warming/greenhouse effect	Consequences	Peixoto (2009), 86.7%	Peixoto (2009), 84,5%	X
			França (2002), 26 to 45%	
Oxygen, hydrogen, and nitrogen are greenhouse gases	Causes	Peixoto (2009), 21.5 a 43.6%	Peixoto (2009), 21,5 to 43.6%	x
			França, P.M.C.P. 2002	
The greenhouse effect is responsible for the melting of glaciers	Consequences	Roque (2011)	França (2002), 68 to 87%	x
Nuclear waste is directly related to climate change.	Consequences	Peixoto (2009), 74.5%	Peixoto (2009), 58.8%	x
Global warming is related to earthquakes and tsunamis	Consequences	Peixoto (2009), ~20%	Peixoto (2009), ~20%	x

zilian students. The development of this view can be evidenced in the work of Roque (2011) where, despite a positive evolution in students' perception of the climate problem, few responded that they would change their lifestyle to combat global warming. The apparent contradiction here exposed resonates with the view that nature is important, part of our lives, but plays a secondary or utilitarian role in the grand scheme of things. That is, it is important to take care of the environment enough to avoid major catastrophes, but that does not mean a radical lifestyle change.

Portuguese students have shown a slightly better maturation of their perception of climate change over the school years, notably in recognizing the importance of political action (Fernandes et al., 2007). In contrast, in Brazil, this evolution was only evident in university students (Roque,

2011, Mesquita et al., 2019). On the other hand, it was also observed that they become more apathetic towards environmental action as they age, with younger individuals showing greater engagement and sensitivity to this cause (Fernandes et al., 2007).

Over the years, although the overall interest and recognition of the importance of the subject do not diminish, students seem to see themselves less as active agents in shaping environmental policies. According to Kent (2009), the emphasis on individual responsibility in the context of climate change – especially in Western culture – is unproductive as it atomizes the solution, whereas it necessarily involves collective and democratic control and decision-making instruments. This may explain the high level of concern about the issue but low levels of actual and effective action.

Portuguese students enrolled in Earth Sciences courses demonstrated a better perception compared to students in Social Sciences (García-Vinuesa et al., 2021). This suggests that the prevalence of Earth Sciences in the Portuguese curriculum, unlike in Brazil, may contribute to nurturing the interest of students naturally inclined towards science and reinforcing accurate perceptions about these issues. Limited exposure to Earth Sciences in the Brazilian curriculum leads to shallower class discussions and challenges in promoting critical thinking in this domain.

There is also the question, especially in the Brazilian context, of finding space in an already extensive curriculum for effective and integrated environmental education in other disciplines, as evidenced by 43.5% of the interviewed teachers in Santos et al.'s work (2021). To achieve this, it takes not only time and willingness but also training and consideration of different methodologies, such as active learning, that are more effective in internalizing environmental issues for students. Also, in Santos et al.'s work (2021), 68.9% of teachers reported not being prepared to incorporate environmental education into their teaching practice.

Regarding students' general perceptions of climate change and the role of the school in this context, three hypotheses were formulated:

Hypothesis 1 – Students' view of nature

Despite all geographical, cultural, and educational differences, Portuguese and Brazilian students generally exhibit a "reductionist" view (Costa, 2016) of the environment.

Hypothesis 2 – The role of environmental education

Environmental Education as structured in most schools (in both countries) is inefficient in showing students the real weight of each actor in the problem of global warming and how to take effective actions in relation to it, exercising their role as critical citizens.

Hypothesis 3 – Impact of the specific Earth Sciences discipline

The existence of a specific Geology discipline in Portuguese schools helps students develop more mature/correct perceptions of climate change.

The focus of this work was to map the main misconceptions/alternative conceptions and establish comparisons (Tab. 6). They were divided into three groups: Definitions, Causes, and Consequences. "Degrees of Concern" were also assigned to each one. They refer to the urgency with which the misconception should be addressed, either in formal or non-formal educational contexts. The classifications are "Low," "Medium," and "High" and are the result of the authors' interpretation based on the entire discussion in this work. The classification is primarily based on the premise that dealing with the most urgent misconceptions will make it easier for educators to address others because the most urgent ones contain fundamental concepts.

There are four common misconceptions categorized with a High degree of concern. Two of them have a high incidence in both countries: "Greenhouse effect as synonymous with global warming" and "Ozone layer as synonymous (or a cause) of global warming." These reveal a widespread difficulty among students in understanding the definitions and characterization of these phenomena. They were marked with great concern because other misconceptions may stem from them. For example, knowing that the greenhouse effect is a natural process can prevent misconceptions like "The greenhouse effect is responsible for glacier melting."

The misconception "Ozone layer hole being literally a hole" reveals students' difficulty in understanding the basic structure of the atmosphere. Part of this problem can be attributed to the careless use of the term by the media and the lack of clarity in how the subject is addressed in schools (or too quickly). This misconception had a lower incidence in Portugal, which may reflect the greater exposure of students to Earth Sciences topics.

Also classified as a High degree of concern is a concept in the "Causes" category: "The degradation of the ozone layer is caused by pollution or CO₂ accumulation." It was classified this way because it shows that many students indiscriminately associate any type of pollution with all types of atmospheric phenomena, demonstrating difficulties in defining and separating each phenomenon. Other misconceptions classified with a Medium degree of concern exhibit the same characteristic, but only this one was categorized as High degree because it is related to the degradation of the ozone layer, and this phenomenon had an extremely high incidence in the reviewed articles.

The major problem that can arise from this mixture of concepts and phenomena is a lack of clarity about the cause of each problem, its real dimension, and thus, turning everything that seems plausible into an essential component of the complex equation that is climate change. The consequence of this misinformation and confusion of concepts for a layperson can be increased climate anxiety and, in the worst case, someone genuinely concerned may start treating the climate issue as a lost cause (Oliveira et al., 2015).

There are four misconceptions with a Medium degree of concern with an emphasis on their occurrence in high school. Two are related to consequences, and two are related to causes of climate change. The analysis of these reveals, once again, students' difficulty in separating the interaction of phenomena and associating any type of pollution with climate change. They were classified with a Medium level of concern because they have a considerable incidence, are related to students' difficulties in understanding the definitions of each of the main phenomena, and can lead to ineffective actions by students and perpetuation of these misconceptions to the general public. These are concepts that may be more manageable for educators when the High degree of concern concepts, especially those in the "Definitions" category, are clarified.

It is possible to notice that some misconceptions are interconnected. For example, "The greenhouse effect is responsible for glacier melting" is a misconception because the greenhouse effect is a natural phenomenon, and glaciers have always existed even under its influence. It would be more appropriate to state, "Global warming is responsible for increased glacier melting." Making this association almost immediately leads back to the misconception "Greenhouse effect as synonymous with global warming." Thus, a student who thinks "The greenhouse effect is responsible for glacier melting" will possibly also think "Greenhouse effect as synonymous with global warming."

In this way, it highlights the need to adequately address concepts in the "Definition" category because they encompass foundational concepts that, once well understood, can help mitigate misconceptions from other categories. In this context, careful lesson preparation and teaching materials are essential. In an excerpt of material analyzed by Roque (2011), there is a schematic drawing showing the planet with factories emitting smoke with the label "Greenhouse effect," and next to it, a forest receiving rain from

a cloud with the captions "Acid rain" and "Harmful radiation" from a hole in the sky with the label "Ozone layer hole." It can be observed that many different concepts are mixed in the same image and can lead teachers and students to misinformation and erroneous associations about these phenomena. It should be noted that some degree of simplification is always necessary, and schematic drawings have their pedagogical value, but often their poor elaboration can have the opposite effect of what is intended.

There are two misconceptions with a Low degree of concern: "Oxygen, hydrogen, and nitrogen are greenhouse gases" and "Global warming is linked to earthquakes and tsunamis." The first was reported in both elementary and high schools in Portugal, but at the same time, a significant number of students also correctly recognized greenhouse gases. This greater familiarity with the atmospheric component gases compared to Brazilian students may reflect the specific Geology discipline in basic education. The second misconception shows a false causal relationship involving essentially geological phenomena, which may be partly fueled by the gravity used in news and communications about climate change and the resulting psychological association with drastic natural phenomena. Although the issue is urgent, great care must be taken with alarmism that feeds misconceptions, such as saying that global warming will cause tsunamis or that recycling all waste produced will solve the global warming problem.

One misconception was found exclusively in Brazil: "Pollution as a consequence of global warming." It was reported by about 25% of the students analyzed by Santos et al. (2019) in response to the question "What are the main consequences of global warming?" Although not explored in the article, it may reveal confusion or inattention on the part of students with the question asked. If it is indeed a misconception, it is worth exploring further whether more students have the notion that global warming generates pollution. One hypothesis may be to remove the notion of pollution by associating it with acid rain, but for a better analysis, only further research that elicits this response and explores the mental connections made can provide clarity.

The second unique misconception emerged in Portugal: "Nuclear waste is directly related to climate change." It was not reported in Brazil, possibly because there is greater familiarity with the topic due to the higher number of such facilities in Europe, while in Brazil, there are only two, both

in the same state. It is worth noting that in Santos et al.'s research (2018) with Brazilian chemistry undergraduates, they were asked about a possible (incorrect) association between nuclear energy and the destruction of the ozone layer, and 73.9% said there is a connection. By answering this, they made an indirect connection with nuclear energy, as they also claim that the degradation of the ozone layer is related to an increase in the greenhouse effect.

Finding a misconception in only one country does not necessarily mean it does not exist in the other. It is important to remember that the data for this study is small, and generalizations cannot be made, but what was found may indicate some important trends. The topic of pollution was more recurrent in Brazil than in Portugal, even though students associated it with a consequence of global warming, as mentioned earlier. This may reflect the social condition of Brazil, a developing country, in contrast to Portugal, a wealthier country. Additionally, Portuguese students spontaneously mentioned nuclear energy more often, which may indicate a regional trend of this misconception being more common in Europe, where nuclear energy is more prevalent.

Despite the differences in educational systems between Portugal and Brazil, the comparison of results reveals more similarities than differences in the main misconceptions and difficulties faced by students in both countries. That means that, despite a Portuguese curriculum that includes Earth Sciences, similar misconceptions still remain. However, education about CC is still expected to be important because as seen in a lack of curriculum emphasis on the subject seen in Brazil leads to simplistic environmental perceptions, and failing to address students' misconceptions (Silva et al., 2022). It could be that the similarities on students' difficulties in both countries are a combination of multiple factors such as lack of proper educator training, media influence and inaccuracies on educational material.

One difference between the countries is the greater knowledge (or recognition) of greenhouse gases and their functions by Portuguese students, as evidenced especially in Peixoto (2009). This may be due to greater exposure to the subject in high school through Biology-Geology and Physical-Chemistry courses, which work on both the chemistry of component atoms and the participation of gases in the geological and atmospheric cycle. This raises another important discussion, which concerns the qualifications of teachers,

their specializations, and the language used in the classroom. Different backgrounds can shape different teaching methods and ways of teaching. For example, a chemistry teacher may teach global warming differently from a physics teacher. This is especially relevant for Brazil, which does not have a specific Earth Sciences discipline.

In contrast to fragmented courses, there is an increasing trend of degrees and specializations in Science and related disciplines, encompassing a holistic view of the three axes of Natural Sciences (Reis & Mortimer, 2020). These courses tend to have a greater emphasis on cross-cutting and complex topics in their structure.

As the Portuguese curriculum already includes integration between areas (Biology-Geology and Physical-Chemistry), teacher training courses already naturally function with a relatively greater cross-cutting approach. However, this does not necessarily mean that teachers are better prepared because many feel the need for additional training on the subject (Borges et al., 2012). Teachers are strongly guided through their textbooks and materials in both countries and have problems with confusing, incomplete, or incorrect presentations of climate phenomena (Libanore, 2007, Roque, 2011).

The language used in the classroom and in teaching materials can even influence students' (and teachers') responses to the questionnaires used in research. Greenhill et al. (2014) observed that the form and language of a questionnaire related to climate change can influence the responses given. They also conclude that, because it is a multidimensional and complex topic, respondents often feel unsure about which answer to mark and opt for a "middle ground" response. For example, in a question about the causes of global warming, if the option "Natural and anthropogenic causes" is available, many people feel compelled to select it, which produces different results than when the question is asked in a more discursive manner.

Three hypotheses were elaborated regarding the regional tendency of misconceptions, teacher training, and national curricula. They are:

Hypothesis 4 – Regionalization of misconceptions

Misconceptions about climate change may have a greater impact in a particular country/region, depending on the social, cultural, and geographical characteristics of that place.

Hypothesis 5 – Climate change in educational curricula

A specific Earth Sciences discipline is not sufficient to adequately address misconceptions involving fundamental climate change definitions, but it helps in memorizing topics learned in other disciplines (e.g., greenhouse gases in Chemistry).

Hypothesis 6 – Science teacher training

The teacher's qualification (Biology, Physics, or Chemistry) shapes their language, teaching methods, and familiarity with different topics. This influences their teaching methods and may be relevant for perpetuating misconceptions among students. Teachers with specific training in Science tend to teach climate change better and propagate fewer misconceptions to their students.

Conclusion

It is important to highlight that many students, both in Brazil and Portugal, claim to have moderate or good knowledge of topics related to climate change (Alves et al., 2018, García-Vinuesa et al., 2021). This seems to contrast with the high incidence of misconceptions, especially concerning the definitions of climatic phenomena.

Conceptual change is not a simple process; it encounters natural (almost involuntary) resistance and, above all, requires a predisposition from the individual. A conception is not simply replaced by another but undergoes an adjustment in its use according to the context (Pereira, 2017). There is no consensus on how this process occurs in the mind, and it is most likely that there are multiple processes, depending on the structures of each

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Therefore, there is no single pedagogical intervention or teaching model capable of addressing the main misconceptions. Possibly, the use of multiple approaches in different disciplines with the reaffirmation of scientifically accurate definitions is the path to building a more suitable climate understanding.

The social and emotional dimension is also essential for students to consolidate this knowledge (Pereira, 2017). They need to relate to what they learn to create curiosity to go beyond basic understanding, and a complex topic like climate change presents numerous challenges to their fundamental understanding. Moreover, it is an urgent issue and should be treated as such, being careful not to fall into unfounded alarmism or convey a defeatist attitude to students, treating it as a "lost cause," which can lead to climate anxiety (Oliveira et al., 2015).

Finally, this study reinforces the conviction that the challenges of environmental education do not limit themselves to national borders and should be considered globally and collaboratively. The difficulties faced by different countries are very similar, but the solution lies in the diversity of ideas and practices that grow when shared by teachers from different backgrounds and cultures.

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