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Climate Change in Chile's School Science Curriculum

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Abstract: Climate change is considered one of the greatest threats to human and natural ecosystems. In the search of options for action from science education, this paper aims to analyze the Chilean science curriculum to understand and act upon the socio-environmental climate change emergency. We developed a content analysis of curriculum documents, focusing on climate change, curriculum integration, and climate action. We explored 15 Chilean science and general curriculum documents for nine different school subjects. By understanding curriculum documents as a critical aspect to promote an educational response to climate change, we evidence that, even though only 5% of all learning goals are explicitly connected to climate change, there are opportunities to promote an integrated curriculum on climate change. Activities in the Chilean curriculum regarding climate change are mainly linked to concepts such as sustainability and biodiversity, and climate action from a critical approach of scientific literacy is primarily promoted in the last two years of schooling. This unbalanced science curriculum throughout all levels might be producing potential tensions in pedagogical practices about climate change education.

Keywords: climate change education; curriculum integration; science education; science literacy; school curriculum; content analysis

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1. Introduction

Our planet is being affected by a climate crisis provoked by human activity [1]. This crisis urges environmental education researchers and educators to take action toward understanding climate, mitigating climate change inducers, and adapting lifestyles for harmonious coexistence. Following this urge, we have begun to analyze opportunities to adapt the curriculum in our context: Chile.

Chile is a country already exposed to multiple climatic risks, such as extreme droughts, scarcity of water resources, forest fires, floods, and glacial retreats, among others [2]. Chile meets most of the nine vulnerability criteria set forth by the United Nations Framework Convention on Climate Change [3]: low-lying coastal areas; arid and semi-arid zones; forest areas; territory susceptible to natural disasters; drought- and desertification-prone areas; urban areas with air pollution problems; and mountain ecosystems. Consequently, Chile will have to deal with significant economic growth and development implications, particularly for energy production (e.g., electricity generation), agriculture, and public health [4]. Without mitigation measures, the impact of global climate change in Chile can be devastating.

Globally and locally in Chile, the scientific community has pointed to the need for urgent initiatives to adapt to and mitigate climate change and address it culturally [5]. As a cultural action, climate change education should address learning about climate concepts and learning about the actions needed to confront the challenges related to living in a world experiencing a changing climate. Scientists understand the multidimensional nature of the consequences of climate change in the world, which calls for approaches to understanding climate from a socio-ecological and complex systems perspective. Science education researchers have understood the challenge of learning the science of socio-ecological systems, such as water and energy [6–8]. The topical idea of climate and the climate crisis calls for the use of knowledge from the sciences beyond disciplinary borders and the inclusion of other aspects of human experience, such as history, social studies, and artistic and literary expressions.

The urgent need for actions to address climate change meets with a lack of clarity about how educational systems worldwide would respond to the call. A review concluded that climate change education lags behind the social movements that provide awareness and discourses that are responsive to the emergency [9]. The authors of that review are aligned with the co-created and participatory manifesto to make climate change meaningful for youth and children [10]. In the same line, UNESCO's 2021 global review report about how environmental issues are integrated into primary and secondary education, policies, and curricula across 46 nations shows that over half of the studied education policies and curricula made no mention of climate change [11]. For its importance in organizing future generations' school experiences, curriculum documents are a vital aspect to understand the educational response to climate change.

In our case, the Chilean curriculum is an example of a national educational program where the Chilean Ministry of Education has placed specific guidelines for planning classroom instruction based on normative documents and instruments [12]. Additionally, the Chilean curriculum and assessment policy is regarded as one of the engines of standardization practices in Chilean schools, which, through prescription and assessment pressures for curriculum coverage, influences and affects teachers' autonomy and decision making [13]. Given its national reach, the Chilean school curriculum documents can provide information about the educational system's response to climate change, a need given the particular susceptibilities of the Chilean territory for suffering climate change consequences.

As researchers, we agree that action about climate change is needed, and it is urgent for such action to be taken within the school system. In addition, we understand that focusing only on the science of climate change is not enough, and the school curriculum should address the need to act upon the crisis. Nonetheless, the importance of science in understanding the crisis is paramount, so we address an analysis of national science curriculum materials in Chile and link it to other elements of the formal Chilean school curriculum. We assume that the science curriculum, both in general natural sciences and in specific subject area specializations (e.g., physics, chemistry, and biology), represents the formal science education proposal for Chilean schools. Thus, students' understanding of climate science and climate change is the primary focus of addressing climate change education in this study. The research question guiding our work is: How does the current Chilean school science curriculum address understanding and acting upon the socio-environmental climate change emergency? We explored the content of Chilean curriculum documents through the lenses of critical scientific literacies [14,15] and curriculum integration, which "involves applying knowledge to questions and concerns that have personal and social significance. In doing this, the boundaries between separate subject areas are dissolved and knowledge is repositioned in the context of those questions and concerns" [16], p. xi. Scientific literacies and curriculum integration can frame an analysis of calls to action and links within the curriculum and the experiences of learners and communities.

The paper is set out as follows. We start by providing an overview of scientific literacy approaches and informative views about curriculum integration, focusing on climate change education. Specifically, we briefly present Chile's current school curriculum documents. We continue explaining our research methodology, where we propose an analytical framework to develop the content analysis of school curriculum documents, illustrating the step-by-step process for content coding. Next, we present the findings of this study, focusing on a panorama view of climate change education in Chile's school science curriculum. Finally, we present and discuss our findings, along with recommendations and future directions in research.

2. Theoretical and Contextual Background

2.1. Critical Scientific Literacies

Transformations in contemporary societies, an increase in inequalities, environmental crisis, violence, and racial, ethnic, and gender stereotypes have impacted the purpose of science education [17,18]. Scientific literacies have been conceptualized as views that promote people having science learning experiences that appropriately equip them to face socio-scientific issues in meaningful contexts, such as their environment and health [19]. Critical perspectives have owned the concept, signaling its importance not only for knowledge but also for action from a comprehensive understanding of the social and humanistic components of science [20]. Thus, critical science literacies should equip individuals with the knowledge and capacity to act in social systems, exceeding mere science learning, but stimulating concrete and direct action from learning it [21].

Views of scientific literacies have been impacted by critiques to the purposes of science education. Roberts [22] described two visions of scientific literacy. *Vision I* focuses on acquiring scientific knowledge and processes relevant to understanding its applications. *Vision II* aims to understand the practicality of scientific knowledge in life and society. Sjöström and Eilks [14] discussed a third vision of scientific literacy, considering the relevance of science education associated with the different visions of scientific literacy from a humanistic approach. This is *vision III*, critical scientific, technological, and environmental literacy. Hodson [23] reduced it to critical scientific literacies, implying a politicized scientific education that promotes critical thinking for dialogic emancipation and socio-ecojustice, emphasizing transdisciplinarity and global sustainability-oriented praxis. Accordingly, Hodson elaborated and proposed distinct encompassing levels of critical scientific literacies. Vision III articulates scientific literacies with socio-political, economic, and environmental dimensions, making references to experiences, reflections, and collective actions, which investigate relations of power and justice and incorporate elements of transformation of social reality [24]. Critical scientific and environmental literacies provide lenses through which we analyze educational aspects and initiatives, such as curricula and educational practices [15]. This framework allows for an examination of how socio-scientific issues regarding climate change are addressed in the science curriculum, given the contribution of science in understanding the phenomenon and the need for action. In this sense, climate change is way beyond a merely scientific issue.

A critical scientific literacy-based approach would imply that teachers, scientists, science educators, and students, in general, might have access to scientific knowledge that leads to questioning the sources of funding for science, the impact of economic development not only on the environment but also on social aspects, and recognizing that science is also political and has history and context [21]. Critical approaches to scientific literacies mean promoting educational processes based on emancipation and transformation that articulate scientific and environmental literacies with social and environmental justice. Thus, critical science literacy perspectives contribute to understanding climate change education, allowing analytical categories that recognize linkages between science, technology and society towards an understanding of opportunities for action in curricula.

2.2. Informative Views about Curriculum Integration

Curriculum theorist William Pinar [25] summarized that "curriculum theory is the interdisciplinary study of educational experience" (p. 2). Pinar also proposes that the curriculum becomes an autobiographical method, using the concept of *currere* or "running of the course." This conceptualization of curriculum is counterintuitive in an environment that has chiefly incorporated an idea of curriculum design as an institutional task organized by a government, which has led to processes—such as standardization of educational assessment—that reflect a controversial approach to curriculum [13,26,27]. Traditional curricula have been discussed thoroughly in the educational literature given the specific patterns of accommodation of curriculum experience that become the official curriculum. Among those, we can count the distribution of time, sequences of goals, and experiences in schooling, primarily organized with a developmental view of the disciplines, which are "assigned" time in schools as subject matters (e.g., language and reading, mathematics, science, social studies, among others).

Curriculum as experience is consistent with views of curriculum integration for understanding both knowledge and experience. Beane [16] proposed that a comprehensive theory of curriculum integration should deepen the convergence of four aspects: (i) integration of experiences; (ii) social integration; (iii) knowledge integration; and (iv) integration as curriculum design. Beane distinguished curriculum integration as a unique approach, different from views that call curriculum integration a multidisciplinary or interdisciplinary curriculum. One of such views is the approach to curriculum integration that organizes integration in a continuum between two extreme forms [28]. Fogarty proposed ten ways or models for curriculum integration, which include: fragmented, connected, nested, sequenced, shared, webbed, threaded, integrated, immersed, and networked. At the baseline, most perspectives on curriculum integration question the unarticulated separation of school subjects in schooling. From Beane's perspective, a curriculum integration design would challenge the identity of school subjects, establishing sources for "curriculum organizing centers" that include topics already part of isolated subjects, social problems or issues, or issues of students' interest, among other sources. Authors from different world contexts agree that curriculum integration challenges the traditional separation of school subjects; they suggest that the curriculum could be organized in theme-, community-, or problem-based approaches, developing a "worldly perspective" as a form of re-imagining the curriculum and developing teacher collaboration, e.g., [29,30].

Any practical approach to curriculum integration can provide a basis for an analytical lens to understand teaching practices, part of any educational experience, which face the socio-scientific issue of the magnitude of climate change. Climate change education exceeds the frontiers and limits of the disciplines, even when science becomes an ideal place for starting it [31], and it becomes an important model when discussing contemporary curricula, e.g., [32].

2.3. Climate Change Education Curriculum

Scholars and policymakers agree that placing climate change-related subjects on school curricula will help young people cope better with the reality of global warming and other manifestations of climate change, both practically and psychologically. Globally, international institutions call for climate change studies to be taught in schools as a formal part of curricula. However, and typically, climate change and environmental education is taught in classrooms by integrating the topic into school subjects' syllabuses by 'infusion' [33]. Different countries worldwide have tried to implement policies and initiatives relating to climate change curriculum, with some difficulties. For instance, in Brazil, environmental education policies and programs have been reported to have a limited impact on mainstream Brazilian educational, environmental, and climate change policies [34]. In several curricula in the world, climate change is approached in two ways: as part of a cross-curriculum inclusion or by creating a non-disciplinary or cross-disciplinary space in the curriculum [35].

UNESCO's international report "The Climate Change Education Ambition Report Card" [36] shows that some countries are moving in a similar direction of promoting climate change education and learning strategies. For instance, Argentina recently approved a National Law of Comprehensive Environmental Education in 2021. In 2019, Italy was the first country to make climate-related school studies compulsory, where all state schools must dedicate around an hour a week, or 33 h per year, to climate change issues. Cambodia recently started with a policy about climate change education by expanding the Earth science curriculum for higher secondary schools. In Singapore, climate change in the curriculum was discussed as well [37]. In China, it was recently reported that the country is beginning to include climate change issues and put forward national policies on climate change mitigation and adaptation. China has a national climate change mitigation program and has been actively investing in climate change initiatives. Education, moreover, is said to have become an integral part of the national sustainable development goals and climate change education strategies [38].

Globally, a consensus is beginning to emerge that climate change must be addressed in the curriculum by interdisciplinary frameworks of understanding, including its ethical and bio-ethical dimensions [39].

2.4. Current Chilean School Curriculum Documents

Chile's current school curriculum has undergone transformations, including two reforms between 1990 and today. This process has been impacted both by legislation left by Pinochet's dictatorship (1973–1990) and by the high impact of student protests in the middle of the 2000s, which sparked changes in the school system's organization, including changes in curriculum policy. Current curriculum policy stems from the idea that curriculum principles and concepts at the policy level were understood but not usually expressed in changes in the classroom experience. Addressing this issue, curriculum policy focused upon the elaboration of learning goals in order to precisely define curriculum expectations [40].

We understand curriculum documents as norms, general guidelines, and practical recommendations for developing sequences of activities to teach in classrooms. These curriculum documents can include legal documents, lesson plans organized to achieve learning goals, and resources for organizing classroom experiences (e.g., worksheets or reference materials). The primary audience for such curriculum documents is teachers. Current official Chilean curriculum documents include general and specific normative documents and documents directed toward the organization of instruction and evaluation. As of 2022, normative documents included the General Education Law 20.370 [41], which lays out the organization of the whole education system from a constitutional perspective, and Chile's Curricular Bases [42–44], which are government decrees that formulate learning expectations for students throughout their schooling in each school subject. These are considered the main instruments for the national curriculum and are organized as a list of mandatory and common learning goals upon which curriculum documents such as study plans and programs for the organization of instruction should be based. Study plans are also normative and describe the expected allocation of time for each school subject in a school year by grade level and by types or modalities of mandatory education. Study programs focus on instruction and provide an organization for learning goals within proposed curriculum units to be addressed in an academic year by school subject. The programs include a series of school activities and assessment proposals; thus, it is a tool strongly targeted to guide classroom experience. We assume that understanding the curriculum proposal as it is means recognizing a proposal for school experience. Other curriculum documents in Chile are school textbooks, which are nationally distributed to public and publicly funded schools, but these change as publishers are granted to develop them and are thus is different from normative and general government guidelines. This is one reason to consider textbooks outside of the scope of this study.

3. Materials, Methods, and Analytical Framework

We explored general Chilean curriculum documents and science curriculum documents to address the research question: How does the current Chilean school science curriculum address the understanding of and the possibility of action in response to the socio-environmental climate change emergency? Below, we specify data sources and analytical procedures for this study.

3.1. Data Sources

Two primary groups of documents served as data sources: the learning goals for schooling (displayed as part of Chile's Curricular Bases) and Chile's School Study Plans and Programs for science. From the Curricular Bases, we extracted learning goals for major school subjects by grade level. Study Programs organize learning goals into teaching units, becoming auxiliary material for teachers, and provide a distribution of the yearly school time and orientations for sequencing, combining, and addressing learning goals by grade level and subject. Our decision to study these documents is based upon the presumption that they are essential for planning classroom experiences, which allow a starting point in exploring climate change education in the school system. Table 1 lists all documents that served as sources for our analysis. Notice that normative documents for analyzing learning goals are only available up to grade 10, while science study programs are available up to grade 12.

Table 1. List of source documents for analysis of climate change education in Chile.

Document *	Type of Document	Published Year
Supreme Decree of Education No. 439 Establishes Curriculum Bases for basic education in the subjects indicated.	Normative	2012
Supreme Decree of Education No. 433 Establishes Curriculum Bases for basic education in the subjects indicated.	Normative	2012
Supreme Decree of Education No. 614 Establishes Curriculum Bases from grade 7 (12-year-old students) to grade 10 (2nd high school grade, 15-year-old students) in the subjects indicated.	Normative	2013
Supreme Decree of Education No. 369 Establishes Curriculum Bases from grade 7 (12-year-old students) to grade 10 (2nd high school grade, 15-year-old students) in the subjects indicated.	Normative	2015
Natural Sciences. Study program grade 1 (6-year-old students), primary level. Ministry of Education. Government of Chile.	Study Program	2012/2018
Natural Sciences. Study program grade 2 (7-year-old students), primary level. Ministry of Education. Government of Chile.	Study Program	2012/2018
Natural Sciences. Study program grade 3 (8-year-old students), primary level. Ministry of Education. Government of Chile	Study Program	2012/2018
Natural Sciences. Study program grade 4 (9-year-old students), primary level. Ministry of Education. Government of Chile	Study Program	2012/2018
Natural Sciences. Study program grade 5 (10-year-old students), primary level. Ministry of Education. Government of Chile	Study Program	2012/2018
Natural Sciences. Study program grade 6 (11-year-old students), primary level. Ministry of Education. Government of Chile	Study Program	2012/2018
Natural Sciences. Study program grade 7 (12-year-old students), secondary level. Ministry of Education. Government of Chile	Study Program	2016
Natural Sciences. Study program grade 8 (13-year-old students), secondary level. Ministry of Education. Government of Chile	Study Program	2016
Natural Sciences. Study program grade 9 (grade 1 high school, 14-year-old students), secondary level. Ministry of Education. Government of Chile	Study Program	2016
Natural Sciences. Study program grade 10 (grade 2 high school, 15-year-old students), secondary level. Ministry of Education. Government of Chile	Study Program	2016
Study Program Science for Citizenship, grades 11 and 12 (grades 3 and 4 high school,16-17-year-old students), secondary level. Ministry of Education. Government of Chile	Study Program	2020

* All document titles have been freely translated by the authors.

3.2. *Content Analysis of Curriculum Documents*

Krippendorf [45] defined content analysis as "a research technique for making replicable and valid inferences from texts (or other meaningful matter) to the contexts of their use" (p. 18). We engaged in a content analysis of curriculum documents and looked for meaning in texts that are significant for teachers who develop learning experiences. Content analysis refers to the analysis of messages [46], including the content of curriculum documents, which are intended to guide the organization of school learning experiences. We developed coding schemes for each type of document and proceeded to code them.

3.3. Procedures for Coding Learning Goals

To analyze learning goals from the Chilean curricular bases, we extracted and compiled the learning goals texts for each of the nine school subjects from grades 1 to 10: (i) Natural sciences; (ii) History, geography, and social sciences; (iii) Technology; (iv) Visual arts; (v) English (as a foreign language); (vi) Music; (vii) Physical education; (viii) Language and communication or Language and Literature (Spanish); and (ix) Mathematics. These nine school subjects represent the core of the curriculum in Chile. We coded up to grade 10 since grades 11 and 12 are highly differentiated in their offerings. All learning goal content was organized in a spreadsheet format, and each learning goal was assigned to a row with information about grade level and school subject. Inspired by a previous analysis of NGSS [47], we adapted the analysis to interpret learning goals and code them relying on the proximity of its content to climate change, assigning a code as "concerns climate change," "could concern to climate change," or "does not concern to climate change". Four coders performed three initial rounds of 30 learning goals each, coding for calibration, which resulted in over 70% agreement, which was considered as substantial agreement. Disagreements were discussed and resolved as a team. Because of the substantial agreement, the rest of the learning goals were coded by two independent coders, overlapping 5% of the coding rows, which resulted in over 72% agreement, a substantial agreement. Disagreements were resolved here as well.

3.4. Procedures for Coding Climate Change Content

To analyze the content of study programs for natural sciences, digital copies of documents (in portable document format, or pdf) were organized using specialized qualitative analysis and research software (Atlas.ti), and the content of their proposed classroom activities was coded. We considered two layers of coding content: a "structural" and a "conceptual" one. We used three structural codes, "activity," "assessment," and "curriculum integration," in order to interpret the nature of the message. Conceptual codes were developed by first listing terms that concern the study of climate change and could be present in official education documents. We used the IPCC glossary [48] and created a list, which was later shortened to 10 terms, as these were the most explicit or proximal to climate change. Three climate change experts consulted on this list of 10 terms and their descriptions, and their opinions were considered to make the descriptions more precise and to help come to a final list of terms. A final list of nine terms or concepts resulted, which was used for coding curriculum materials. After developing exploratory coding, we then refined the terms and their descriptions. Table 2 lists and describes the structural codes, while Table 3 lists and describes the conceptual codes applied in the content analysis. Two or three coders coded documents for calibration, with Krippendorf's alpha values ranging from 0.75 to 0.97 for structural codes and a global alpha of 0.80 for conceptual codes. Then, the documents were distributed to two coders working independently, with two documents overlapping both coders. Coding disagreements in the overlapped documents were discussed and resolved.

Table 2. Coding information (structural codes) for science curriculum programs/study plans document content analysis.

Code	Description
Activity	Text segments that can be interpreted as an indication for the development of a classroom activity, proposed by the curriculum material.
Assessment	Text segments that have an explicit indication for the development of an assessment activity, proposed in the curriculum material.
Curriculum integration	Text segments that explicitly mention a link to other learning goals, activities, or school subjects' part of other curriculum documents.

Table 3. Coding information (climate change conceptual codes) for science curriculum programs/study plans document content analysis.

Code	Description
Anthropocene	This code refers to content that incorporates discussions or references to the human experience on the planet and its consequences. Anthropocene can incorporate terms such as pollution, human activity, carbon footprint, hole in the ozone layer.
Energy balance	This code refers to content that discusses or refers to the difference between the total values of incoming and outgoing energy at the planetary level. Energy balance can incorporate terms such as: solar radiation, terrestrial radiation, radiative forcing, albedo, radiative balance, energy balance.
Biodiversity	This code refers to content that incorporates discussions or references related to understanding biological diversity and biodiversity loss in general. Biodiversity can incorporate terms such as ecosystems, biological diversity, ecological relationships, variety of life on Earth.
Global warming	This code refers to content that discusses or refers to the phenomenon of global warming, understood as the change in global temperature in the historical climate record, as well as the discussions surrounding this phenomenon. Terms that may accompany the content associated with this code are global temperature, greenhouse effect, greenhouse gases, carbon dioxide, fossil fuels, emissions, sea level rise (due to changes in the amount of water), melting of glaciers, carbon cycle, ocean acidification.
Climate change	This code refers to content in which discussion is made with explicit reference to the idea of climate change, understood as long-term shifts in temperatures and weather patterns as consequence of human activities. Climate change can incorporate terms such as climate crisis, climate change, climate emergency, or climate urgency.
Land-use change	This code refers to content that discusses or refers to perceived changes in land use and its explicit or implicit link to climate change. Land-use change might appear along with references such as deforestation, desertification, changes in reflectivity, and storage of greenhouse gases.
Extreme climate events	This code refers to content that discusses or refers to meteorological or atmospheric phenomena in relationship (explicit or implicit) to the phenomenon of climate change. Extreme events include associations with cycles and marine and ocean movements in relation to climate. In addition, this code might be associated with distribution of water on the planet along with terms such as extreme weather events, hydrological cycle, flood or floods, drought, heat waves.
Climate system	This code refers to content in which key concepts are presented to discuss or make an explicit reference to understand the climate change phenomena. Climate system can incorporate terms such as atmosphere, weather and climate, the Gaia hypothesis, sea or ocean currents.
Sustainability	This code refers to content that discusses or refers to the ability to maintain or support a process continuously over time considering human actions linked to sustaining life on Earth in consideration of current development conditions, recognition of climate vulnerability situations and responses to environmental crises. Sustainability incorporates terms such as sustainable development, sustainable or sustainability (in Spanish: *sustentable* or *sostenible*), mitigation, adaptation, resilience, vulnerability associated with climate risk.

3.5. Procedures for Coding for Critical Scientific Literacy and Curriculum Integration

After finishing conceptual coding, all the segments coded with climate change conceptual codes were extracted, organized in a spreadsheet, and another layer of coding was applied in order to understand the alignment of the proposed activities with different conceptualizations of scientific literacy (that is, *vision I*, *vision II*, or *vision III*). Two coders independently coded all the extracted text segments, after which all disagreements were discussed and resolved, having a full agreement in the whole set of segments. Table 4 shows a description of the codes from this third layer of coding.

Table 4. Coding scheme for critical scientific literacies in extracted curriculum content coded for climate change.

Scientific Literacy Vision	Description
Vision I	Focuses on acquiring scientific knowledge and relevant processes for understanding science and its further applications. This vision focuses mainly on learning about scientific content. However, learning and knowledge do not incorporate links to social, political, or environmental dimensions.
Vision II	Focuses on understanding the usefulness of scientific knowledge in life and society. This vision exposes applications of science in the daily lives of students by contextualizing scientific knowledge. This vision promotes science for all and typically gives more relevance to science in action or in contexts, aiming to understand the practicality of scientific knowledge in life and society.

Table 4. *Cont.*

Scientific Literacy Vision	Description
Vision III	Implies a politicized and action-based (e.g., climate change activism) knowledge aiming at promoting the development of critical thinking for dialogic emancipation and socio-eco justice. This vision emphasizes transdisciplinarity and sustainability; is oriented towards praxis and action; aims at articulating scientific literacies with socio-political, economic, and environmental dimensions; and makes references to experiences, reflections, and collective actions. This vision investigates relations of power and justice and incorporates elements of transformation of social reality.

Additionally, segments coded as "curriculum integration" were coded with another layer to indicate which school subject explicitly connected to it. Coding information was organized to create a descriptive quantitative and qualitative view of the presence of climate change topics in the Chilean curriculum's learning goals and science curriculum materials, as well as curriculum integration and critical scientific literacies.

4. Results

These results are intended to show a panoramic view of climate change content in the Chilean curriculum, the form of curriculum integration of science study programs, and a perspective about climate action in the science curriculum through the lenses of critical scientific literacies.

4.1. Climate Change in Chile's Curriculum Learning Goals and Science Curriculum

Understanding climate change in Chile's curriculum starts with the proximity of its learning goals to climate change topics. For the reviewed nine school subjects, there are 1188 learning goals throughout ten years of schooling (grades 1 to 10). The results show that the Chilean curriculum tends to favor learning goals for language, communication and literature, and mathematics in general, followed by history, geography and social sciences, and natural sciences. These are, then, the subjects with more prevalence in the curriculum.

Table 5 shows the conceptual proximity of learning goals to climate change content. Overall, the analysis yields that less than five percent of the total learning goals are closely related to climate change content ("concerns climate change"), while about a quarter of the total learning goals could concern climate change. Thus, over 70% of learning goals are not concerned with climate change content. The highest proportion of climate change content appears in natural sciences, followed by visual arts and technology, and history, geography, and social sciences. The proportion of school subject learning goals potentially connected to climate change content is more prevalent in subjects such as technology, history, geography and social sciences, language and communication and literature, and natural sciences.

Table 5. Proportion of learning goals in proximity to climate change content in each of the nine school subjects. Percentages are relative to the number of learning goals in each subject.

School Subject	Concerns Climate Change	Does Not Concern Climate Change	It Could Concern Climate Change
Language and communication/Language and literature	0.0%	68.2%	31.8%
Mathematics	0.0%	96.7%	3.3%
History, geography, and social sciences	7.2%	58.7%	34.1%
Natural sciences	17.9%	53.8%	28.2%
Physical education	0.0%	95.3%	4.7%
Technology	9.2%	29.2%	61.5%
Visual arts	9.3%	70.4%	20.4%
Music	0.0%	98.6%	1.4%
English (as a foreign language)	1.6%	68.8%	29.7%
Total	4.6%	71.4%	24.0%

When the distribution is displayed among school grades, the proportion of learning goals in proximity to climate change content is largest in fifth grade (7.1%) and second grade (6.3%) (see Table 6). When learning goals are potentially linked to climate change content, the highest proportions are found in grades four, six, eight, and nine.

Table 6. Proportion of learning goals interpreted in proximity to climate change content in each grade level. Percentages are relative to learning goals in each grade level.

Grade Level	Concerns Climate Change	Does Not Concern Climate Change	It Could Concern Climate Change
1	3.1%	73.2%	23.7%
2	6.3%	72.3%	21.4%
3	3.4%	79.5%	17.1%
4	2.4%	71.5%	26.0%
5	7.1%	72.1%	20.7%
6	4.1%	66.4%	29.5%
7	5.3%	74.6%	20.2%
8	4.5%	70.5%	25.0%
9	4.3%	62.9%	32.8%
10	5.4%	72.1%	22.5%
Total	4.6%	71.4%	24.0%

Overall, the analysis of learning goals shows that the close relationships of school subjects to the topic of climate change stem mostly from science. Other relationships show the potential of climate change content to aggregate learning goals, especially in technology, visual arts, and social sciences, history, and geography. The lowest levels of connection of learning goals to climate change are in the subjects of mathematics, physical education, and music. On a second level of analysis, most of the learning goals at each school level are potentially linked to climate change, given its "could concern" link.

In the Chilean science curriculum, our analysis identified a total of 1569 activities distributed throughout grade levels. As mentioned, we coded each activity with one or more conceptual codes related to climate change. Our findings show a high frequency of activities where the content relates to sustainability and biodiversity, which together appear in about 38% of the total codes assigned to climate change content (see Table 7).

Table 7. Percentage of conceptual coding (non-exclusive) of activities proposed in the Chilean science curriculum documents (study programs) in relation to total codes for grade level (n = frequency of code).

Grade Level	Anthropocene (n = 71)	Energy Balance (n = 43)	Biodiversity (n = 117)	Global Warming (n = 73)	Climate Change (n = 45)	Land-Use Change (n = 25)	Extreme Climate Events (n = 55)	Climate System (n = 77)	Sustainability (n = 122)
1 (n = 23)	4.3%	13.0%	65.2%	0.0%	0.0%	4.3%	0.0%	4.3%	8.7%
2 (n = 81)	7.4%	12.3%	28.4%	1.2%	0.0%	0.0%	11.1%	32.1%	7.4%
3 (n = 33)	6.1%	0.0%	51.5%	3.0%	0.0%	0.0%	3.0%	0.0%	36.4%
4 (n = 51)	19.6%	2.0%	25.5%	5.9%	2.0%	0.0%	2.0%	3.9%	39.2%
5 (n = 72)	11.1%	0.0%	5.6%	8.3%	2.8%	0.0%	22.2%	19.4%	30.6%
6 (n = 30)	20.0%	13.3%	20.0%	10.0%	0.0%	10.0%	6.7%	10.0%	10.0%
7 (n = 71)	7.0%	5.6%	4.2%	18.3%	16.9%	0.0%	9.9%	28.2%	9.9%
8 (n = 27)	14.8%	0.0%	3.7%	25.9%	3.7%	0.0%	7.4%	14.8%	29.6%
9 (n = 63)	17.5%	0.0%	33.3%	12.7%	6.3%	4.8%	3.2%	0.0%	22.2%
10 (n = 7)	0.0%	0.0%	0.0%	71.4%	0.0%	0.0%	0.0%	0.0%	28.6%
11 & 12 (n = 170)	10.6%	12.4%	8.2%	15.3%	14.7%	10.6%	8.8%	4.1%	15.3%
Total (n = 628)	11.3%	6.8%	18.6%	11.6%	7.2%	4.0%	8.8%	12.3%	19.4%

This analysis also shows that in the science curriculum, climate change education concepts are more likely to be addressed in the activities proposed for grades 2, 5, 7, and 8 and particularly grades 11 and 12, the last years of high school.

4.2. Chile's Science Curriculum and Curriculum Integration

In the study plans and programs, teachers are meant to work on the learning goals of the same grade level with one or more school subjects. In science, we coded a total of 426 segments as curriculum integration, where we identified explicit "calls" to other disciplines. Those calls to other subjects were made throughout all educational levels, mainly to Mathematics (107); Language and communication (63) and Language and literature (40); and History, Geography, and Social Sciences (51), these being the subjects with the most references, while Music (9) and English as a foreign language (14) are the ones with the fewest mentions. Philosophy (3) also appears with a few connections, but it is only presented as compulsory in the last two years of the curriculum (grades 11 and 12).

The last levels of schooling (grades 11 and 12) have a plan of compulsory subjects and other elective modules. For the purposes of this analysis, we only worked with the first group, which are: Language and Literature, Mathematics, Foreign Language (English), Citizen Education, Philosophy, and Science for Citizenship. Figure 1 presents a Sankey diagram to show how the science programs are connected explicitly to other subjects.

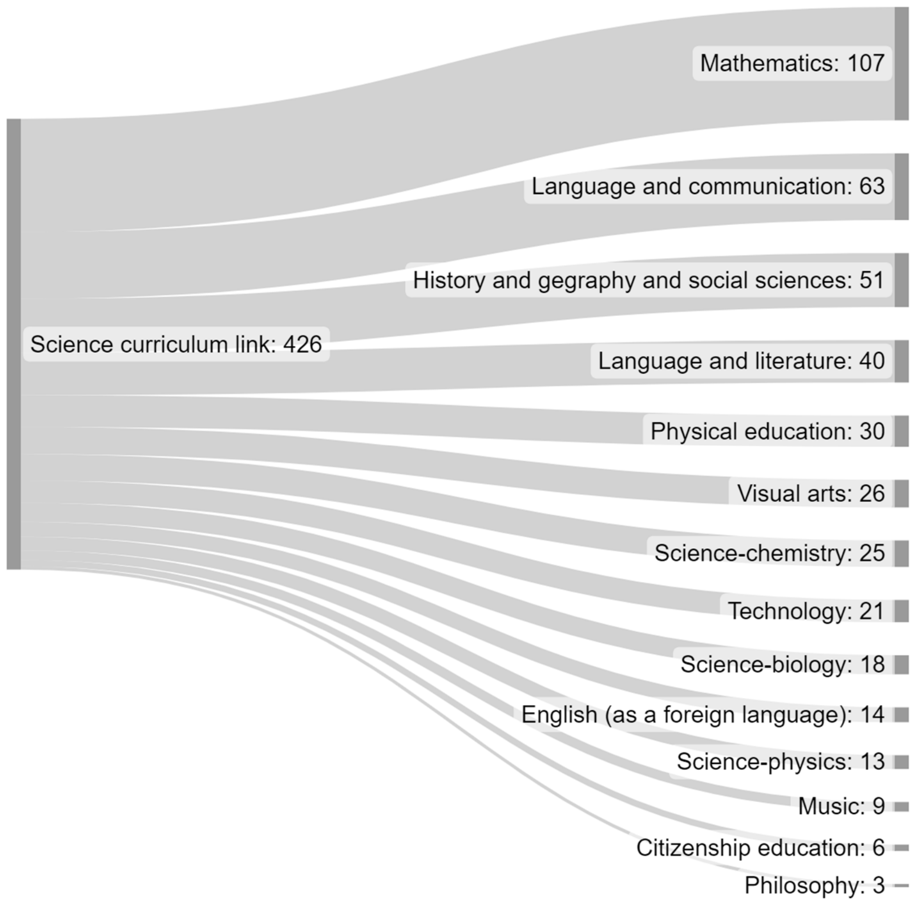

Figure 1. Sankey diagram summarizing the frequency of coding for explicit connections between the science program and other school subjects (curriculum integration codes).

Qualitatively, at the lower elementary education levels (grades 1 to 4), activities proposed in the science program generally describe what teachers can implement with their students. At higher levels of schooling (e.g., grades 7 to 12), these activities specify suggestions for texts and topics to work on in class, while also incorporating explicit questions to be addressed to students. Figures 2 and 3 show examples of coding for activities that instantiate these differences.

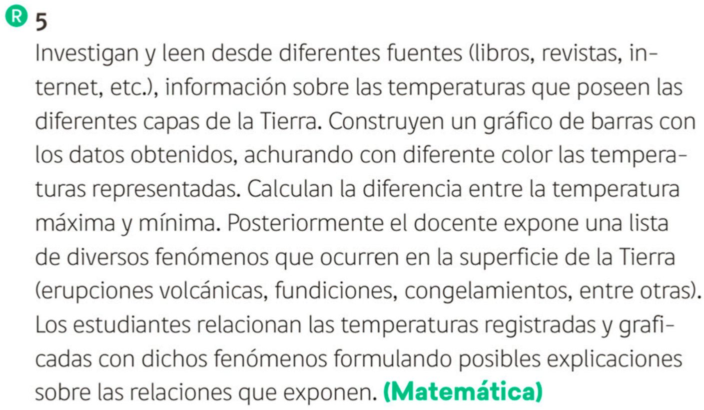

Figure 2. Coding example for a curriculum integration code, which show a link of science to mathematics in grade 4 science curriculum material. Translation: [Activity] 5: [Students] investigate and read from diverse sources (books, magazines, the Internet, etc.) information about temperatures in different layers of the Earth. They build a bar graph with the data they have obtained, shading represented temperatures with assorted colors. They compute differences between maximum and minimum temperatures. Subsequently, the teacher presents a list of diverse phenomena happening over the Earth's surface (volcanic eruptions, melting, freezing, among others). Students link the recorded and graphed temperatures to these phenomena, formulating possible explanations for the relationships they show. (Mathematics).

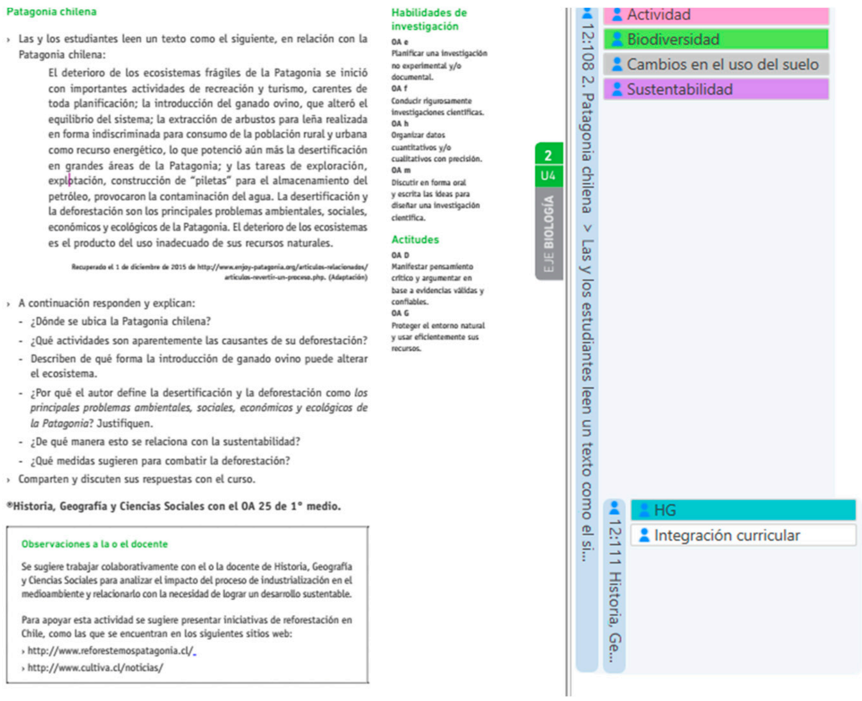

Figure 3. Coding example for a link of science to mathematics in grade 9 science curriculum material, Biology. Translation: [Activity]. Chilean Patagonia. Students read a text like the following, in relation to Chilean Patagonia: The deterioration of fragile ecosystems of Patagonia began with important recreational and touristic activities lacking any planning; introduction of sheep, which altered the balance of the system; indiscriminate extraction of bushes for firewood consumption by rural and urban population as an energy resource, which further increased desertification in large areas of Patagonia; and exploration, exploitation, construction of "pools" for storing oil, which caused water contamination. Desertification and deforestation are the main environmental, social, economic, and ecological problems in Patagonia. Ecosystems' deterioration is produced by inappropriate use of their

natural resources. (Retrieved on 1 December 2015, from http://www.enjoy-patagonia.org/articulos-relacionales/articles-revert-un-proceso.php. (Adaptation)). Then [students] answer and explain: Where is Chilean Patagonia located? What activities are apparently the cause of its deforestation? Describe how the introduction of sheep can alter the ecosystem. Why does the author define desertification and deforestation as the main environmental, social, economic, and ecological problems of Patagonia? Justify. How does this relate to sustainability? What measures do you suggest for combatting deforestation? Then [students] share and discuss their answers with the class.

Regarding the Curriculum Integration code, it is generally observed that up to grade 2, there are brief mentions of subjects with which a proposed activity can be connected in the plans and programs, but without further explanations of how such activities could be carried out. At some levels, for example, the name of the subject is placed in parentheses, and it is not specified how they are connected, which can be seen in levels up to grade 4, while at higher grade levels, there are instructions provided to the teacher, signaling learning goals of the subject with which the connection can be made. Figures 2 and 3 show examples of this element of curriculum prescription.

In summary, the proposal in the science curriculum connects explicitly to other school subjects, which is particularly relevant when these connections are to subjects where climate change content is less present (e.g., mathematics). In addition, we can say that the older the students are when learning about science, the more prescribed the science curriculum material for teachers is.

4.3. Climate Action in Chile's Science Curriculum from Visions of Scientific Literacies

Characterizing visions of scientific and environmental literacies guided our general analyses to consider distinct levels of depth in science curriculum contents. We assumed that visions of scientific literacy could help in analyzing the current Chilean school science curriculum, as opportunities to promote climate action and act upon the socio-environmental climate emergency can be classified as vision III. We analyzed the text-codified segments of 337 climate change activities across all educational levels. References to images and infographics were excluded in this analysis, and we only focused on segments directed at students' potential classroom experiences. Figure 4 shows how different visions of scientific literacy are distributed and represented in the science school curricula at different levels. For each vision, we provide examples to explain how scientific literacy approaches are presented in the science curriculum concerning climate change.

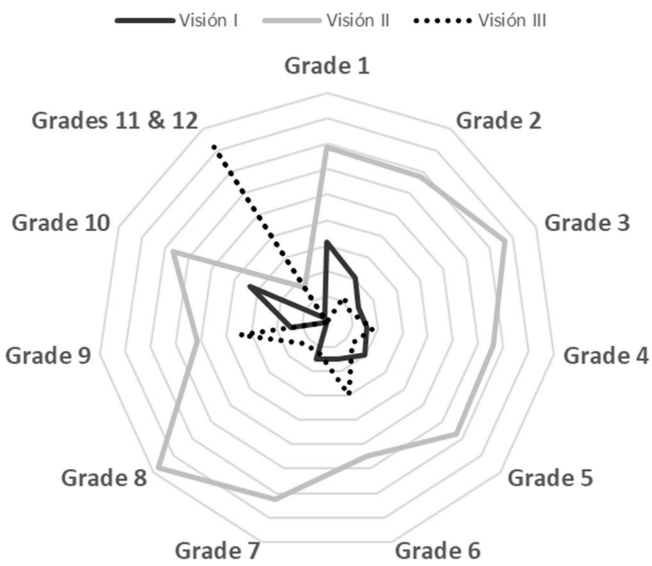

Figure 4. Spider web graph of proportions of codified segments (activities) by vision of scientific literacy and grade level (n = 357).

Vision I represents a small percentage of codes, with only 53 of 357 references (14.8%). These codes are found in all levels except for grade 8 (13-year-old students). An example of this approach can be seen in the following quotation connected with climate change concepts about solar radiation and biodiversity:

> (. . .) Students investigate to explain solar radiation. They answer: What is the nature of radiation? What do the different spectra of solar radiation represent? What types of radiation exist? What type of radiation harms living beings? What positive effects does solar radiation have on human beings? How is stratospheric ozone formed? What is meant by an ozone hole? (Grade 7, p. 191) (All quotes to reference curriculum materials are translations by the authors from original material in Spanish.)

In this activity, teachers invite students to answer different questions about solar radiation and ozone. General topics related to the nature of radiation, its effects on humans, and its relationship with ozone are addressed, while radiation is not linked to climate change or global warming. For instance, increased concentrations of greenhouse gases, such as carbon dioxide, reduce the amount of outgoing longwave radiation to space. The resulting imbalance between incoming solar radiation and outgoing thermal radiation might be an opportunity to discuss global warming or industrial emissions. In this activity, the concept of radiation is presented in complete disconnection from climate change.

In similar activities, students are asked to make a list, describe, or research topics related to biodiversity. For instance:

> (. . .) students list native trees in their area. For each one, they look for the fruit, the seed, and the flower. They collect pictures of the bark by applying a sheet of white paper to the trunk and marking the picture with a crayon. On each paper, they label the name of the tree. (Grade 3, p. 117)

Similarly:

> (. . .) Students investigate and read in different sources (web pages, texts, magazines, etc.) possible variations of the conditions that could exist on the Earth in another hundred years if global warming and pollution continue. (Grade 4, pp. 144–145)

The analysis shows how vision II is distributed in the document: it transpires that the vision of scientific literacy is the primary approach in the science curriculum, with 212 of 357 codes (59.4%) distributed at all school levels. For the purposes of climate change education, this implies incorporating content or scientific knowledge based on articulating scientific processes in students' lives. We illustrate this with an example from an activity about how to improve air quality:

> (. . .) Students conduct, in teams, an investigation on air quality in their local context and answer questions such as the following: What air quality problems are observed in your locality? What factors influence these problems? What effect do these problems have on the environment? What regulations refer to the problems observed in the locality? They predict if there is a difference in the concentration of O_2 in two air samples if both are at the same T, P and V, and they differ in that one does not present polluting gasses, and the other does. They investigate if the prediction is correct. They reflect on one of the practical problems, considering proposals for feasible measures to contribute to the solution. The teams design an informative poster with the background of the selected problem, its description and the proposed measures and present it to the class. (Grade 7, p. 100)

We can see that now the approach addresses concepts such as pollution and the environment starting from students' everyday life and moving toward a territorial or contextual perspective. Vision I appears embedded within vision II. Students are to investigate, make predictions, build graphs, and reflect on this problem to propose measures or solutions. A similar example is the following:

> (. . .) Students collect, in small groups, information on fossil fuels: their origin and forms (petroleum, gas or charcoal), petroleum derivatives (benzine, paraffin, diesel), on the devices or machines that use them (cars, stoves, kitchens, etc.) or the most common uses of petroleum derivatives (paints, detergents, plastics, cosmetics, fertilizers and others). They present the results of their investigations in a poster that calls for trying to restrict the use of fossil fuels. (Grade 6, p. 124)

In this example, we can see how the activity promotes fossil fuel analysis. The examples and information students need to gather are only connected to science and omit political or economic dimensions. In this sense, vision II is only promoting a scientific understanding of climate change, even though students are presenting investigations about restricting the use of fossil fuels.

Finally, the number of codes related to vision III is 92 (25,8%). However, forty-five of these are in the current science curriculum for grades 11 and 12, science for citizenship (16- and 17-year-old students), developed in 2019. Figure 4 shows a "spike" for vision III in these levels. This approach is mostly absent throughout the science curriculum at the primary and secondary levels. An example of a coded segment is shown below:

> (. . .) Students learn and research the climate change that the planet is experiencing, describe the climatic phenomenon and explain the formulated hypotheses to account for and explain the studied phenomenon. They find out how this affects the country concerning temperature, availability of water and accumulated snow in the mountain range. They describe socio-natural disasters experienced in Chile and the world that can be associated with climate change. They relate the main climate changes to the availability of resources for our society. In this regard, they answer: what will happen to biodiversity, agriculture, fishing, energy sources and work, among others? They recognize the adaptation and mitigation strategies to climate change promoted by international organizations and national institutions. (Grade 9, p. 181)

This example presents a request for students to reflect upon the intertwined and transdisciplinary understanding of climate change, representing a critical approach to scientific literacies and showing how the current Chilean science curriculum might promote and address an understanding of the socio-environmental climate change emergency at this level. Other examples are:

> (. . .) Students analyze public controversies about climate change, considering social, economic, ethical, and environmental implications and debate the necessary measures for sustainable development of the country and humanity. (Grades 11 and 12, p. 190)

> (. . .) Students analyze the relevance of the climate change phenomenon based on the currently available evidence and its projections and critically analyze mitigation solutions to climate change. Students make and communicate evidence-based arguments about the importance of immediate action on climate change. (Grades 11 and 12, p. 178)

As we can see, if vision III is considered as a representation of inclinations toward collective action rather than only learning about science for its regard to democracy. Climate action in the Chilean curriculum is highly regarded only in the last two years of schooling, mediated by the proposal of a curriculum that incorporates notions of citizenship into the science curriculum.

5. Discussion

The findings of our initial approach to understand climate change education curriculum and action in Chile are as follows:

- About five percent of learning goals in the Chilean curriculum is connected to climate change content, while most of the learning goals are from science as a school subject.
- The curriculum on climate change is highly linked to concepts such as sustainability, biodiversity, global warming, and the climate system.
- Curriculum proposals in science explicitly connect to other school subjects, such as mathematics, that have fewer learning goals connected to climate change topics.
- Activities to be developed using the science curriculum appear to have more prescriptive elements at higher levels of schooling.
- Climate action is promoted with more emphasis in the Chilean curriculum in the last two years of schooling, where the science for citizenship proposal offers a different approach to understanding science than the curriculum for the previous years of schooling.

We can say that the Chilean curriculum shows open possibilities for developing climate change education in integrated approaches. The criteria we used in our study highlight opportunities for future connections from different disciplines—at all levels—with climate change topics. Our study assumes that understanding climate change involves a complex and transdisciplinary intersection of subjects and topics, from meteorology and atmospheric chemistry to oceanography, geochemistry, ecology, and history, among others. While the Chilean curriculum in general does not offer an integrated approach where climate change can be an "organizing center" [16], it does somehow assume a more instrumental form of connection, similar to what Fogarty [28] called the "connected" way for curriculum integration, where suggestions to connect to other school subjects are made as "calls" in the curriculum document, that is, a call to connect one discipline with other disciplines by incorporating a topic, skill, or concept. Our analysis of educational science programs show activities are typically connected to other subjects in terms of learning goals being given as suggestions for teachers to develop. This approach is challenged by the inclusion of the science for citizenship curriculum in grades 11 and 12, where a seemingly project-based approach addresses climate change in a more holistic way within one subject. This is likely to be a model similar to what Fogarty called the "nested" approach to curriculum integration, where, within one subject area, a teacher can target multiple skills, individual or social, and promote the understanding of multiple dimensions in a topic. In any case, we should consider that curriculum integration is a highly regarded model for teaching and learning [32], which makes these opportunities for integration in the curriculum a sound avenue of exploration. How what Beane [16] calls a "comprehensive theory of curriculum integration" can be included in analyses of curriculum integration for climate change has yet to be explored. That is, how can we study (and propose) approaches that consider the convergence of the integration of experiences, social integration, integration of knowledge, and integration as curriculum design?

Another finding of this study refers to the increasingly prescriptive nature of the science curriculum in relation to grades. Teachers are perceived as executors of curriculum policies [49], which can be explained as curriculum environments being greatly influenced by standards and processes where countries integrate ambitious reforms in their curricula. These reforms can reasonably have differential responses from teachers, maybe acquiescing, accommodating, or resisting elements of the curriculum [50]. These responses highlight the importance of teacher education and professional development for both understanding the reasoning behind the curriculum and the implications and demands that are to be expected, not only as educators, but also as recognized social actors. It is hardly a novelty to argue that radically educative perspectives on climate change are needed, where science education conceives of students as concerned agents:

> Science education, therefore, needs to present an idea of environmental action that is both individual and collective. If we are to be serious about global climate change, we need science education that presents to students such an idea of environmental action. [31] (p. 39)

This recognition is also important for teachers. However, it is likely that this approach could demand effort from both schools and teachers in Chile to coordinate and make these connections possible, particularly given the increasingly prescribed nature of curriculum documents as we move into higher levels of schooling. Climate change education could benefit from flexible curriculum policies for making connections as part of more robust guidelines for teachers to develop integrated approaches. Experiences in other countries have included transitioning to a crosscutting curriculum or including new school subjects that address the climate change crisis, cf. [51,52].

We have adopted a view of climate action in the science curriculum that refers to the conceptualization of a critical perspective on scientific literacies. As shown, most of the science curriculum activities linked to climate change concepts are based on vision II of scientific literacy, thus making it the main approach in the Chilean science curriculum throughout levels 1 to 10. These findings are consistent with previous reports on critical discourse analysis of Chilean science curriculum documents [15]. Critical approaches of scientific and environmental literacies, based on vision III, are typically seen only in levels 11 and 12, when students are introduced to visions that incorporate a citizenship view of science. This incorporation is a recent development in Chile's curriculum, given that most inclusions of citizenship in the curriculum have fallen outside the area of science and more into subjects such as civics education, history, and social sciences, e.g., [52]. This can also be the result of the influence of international discussions about sustainability, Chile being the country with the greatest achievements in reaching UNESCO's goals for sustainable development in Latin America in 2019, which includes goals in education and climate action [53].

Our approach for analyzing the curriculum might have the shortcoming of addressing the curriculum from its representation as a prescriptive document rather than provide a view of curriculum as the "school" biography of teachers and students alike. We did not include other resources and instruments that might be highly present in teachers' practice, such as textbooks. More research is necessary to understand if the results presented here are consistent with classroom experience.

6. Conclusions and Future Directions

As a conclusion, we can certainly say that an integrated curriculum on climate change is possible to develop in Chile's schooling if given certain institutional conditions. In addition, it is likely that recent development in Chile's science curriculum can be conflicting for teachers and create several sorts of responses, particularly within teachers who teach in grades 11 and 12. We close this article with future directions that stem from this study.

Future directions that stem from this research imply a study of the influence of climate change policies in education, so we can have a clearer picture of how these policies generate change in teaching practices. In addition, we believe that tensions in teachers' practices with curriculum focused on climate action should be better addressed, both in schools and in teacher education. As the science curriculum for grades 11 and 12 in Chile is focused on climate action (Vision III), we could reasonably expect that teachers have developed practices to cope with a new view of the science curriculum, which include thinking and acting upon the global climate emergency. This leads to other types of research, maybe more action-focused research that seeks the development of materials—closely aligned with the curriculum—that can serve as interventions to provide experiences for climate change education using curricular integration. Studying these interventions might be a well-meant contribution to focusing on climate action in curriculum materials.

However, our analysis of the science curriculum in Chile shows some tensions in the translation of policies and their relationship with pedagogical practices. For instance, how do schools implement educational policies about climate change? How are teachers conducting new and innovative approaches and being active agents in climate change education when they were not trained to teach about the climate crisis or in project-based education? These are questions to develop further with empirical research.

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