Part 13 / Strand 13

Science Curriculum And Educational Policy

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Science curricula development including design, adoption, and comparison, as well as reform implementation, dissemination, and evaluation. Includes evaluation systems and practices adopted and implemented in schools and institutions; and construction, interpretation, implementation, implication and reflection of policies and reforms at the local, regional, national, or international levels concerning science education.

Sub-themes:

1) STEM Curriculum for young learners (<7 years)
2) STEM Curriculum for primary level
3) STEM Curriculum for secondary level
4) International perspectives in STEM policy & curriculum
5) Evaluations systems and practices

Contents

Strand 13: Science Curriculum And Educational Policy

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Introduction

We are living in a transformative era shaped by profound technological advances. While these developments offer fascinating opportunities, they also present major societal and environmental challenges. Science Education should be responsive to these societal and environmental challenges and refine its practices and purposes (White & Tytler, 2025).

Under the theme *Transitions in Science Education: Sustainability and Digital Advances*, this chapter explores how science education can best prepare future citizens to face such challenges. Within this context, the science curriculum plays a crucial role, given that educational systems remain heavily curriculum driven. By examining how science curricula and educational policies worldwide are being reshaped, we contribute to a broader scholarly dialogue on what it means to educate scientifically literate and globally competent citizens. The Science Curriculum and Educational Policy Strand within ESERA focuses on the design, development, interpretation, implementation and evaluation of science education policies across local, regional, national, and international levels, as well as critical reflections on their border implications for science education.

Aligned with the main topics presented at the ESERA 2025 Conference within this strand, this chapter offers eight selected works, three of which are presented together as part of an ESERA symposium paper. The contributions span a wide variety of geographical contexts, displaying a cross-national, critical perspective with an emphasis on the interplay between science curricula and sustainability issues. Specifically, the selected works examine different curricular aspects, including the contribution of influential educational frameworks and comparative analyses of textbooks and guidelines across various countries. Furthermore, they explore teacher preparedness and the role of co-designed lessons involving researchers, scientists, and teachers to translate educational aspirations into school practice.

Among the frameworks discussed in this chapter are DeSeCo 2003 (OECD, 2003), the Learning Compass 2030 (OECD, 2019), GreenComp (Bianchi et al., 2022), the new Guide for Climate Literacy (USGCRP, 2024) and PISA 2025 (OECD, 2023) — including the concept of Agency in the Anthropocene (White et al., 2023, 2024). Among the studies examining curricular guidelines and textbooks, Watson and Li present a content analysis of curricular documents in Canada and Taiwan, based on the PISA 2025 framework. Following a similar approach, Dawud et al. focus on the presence of dynamic equilibrium as a key concept in Israeli and Manitoba textbooks. Climate Change Education (CCE) is the focus of the textbook content analysis conducted by Lampoudis and Mogias in Greece, as well as that by Tytler et al. in Finland, Australia and Taiwan.

The work by Tytler et al. presents two further studies aimed at identifying opportunities and systemic constraints for CCE. The first of these additional explorations was a cross-national survey of teachers' knowledge, practice, and confidence in teaching CCE. The second exploration involved a process of co-designing research-based sequences through iterative cycles of evaluation and improvement. This evaluation was based on observations, interviews and students' pre- and post-tests. The cross-national insights presented contribute to sharpening our understanding of how science education can support CCE as well as the contextual factors that frame the possibilities for innovation.

The work by Scarongella analysed several international competence frameworks providing an important reference point to curriculum shaping, with a view to the introduction of sustainability education. The analysis reveals an evolution from literacy-based, economics-driven skills to fostering transformative agency for sustainability. The emphasis on sustainability, especially in GreenComp, PISA 2025 (Bianchi et al., 2022) and "Learning Compass 2030" (OECD, 2019) marks a shift from training knowledge-based competence to cultivating change agents who can think systemically, collaborate, and foster hope to collaborate on climate challenges actively. It is worthy to mention the introduction of the concept agency, defined as “the belief that students have the will and the ability to positively influence their own lives and the world around them, as well as the capacity to set a goal, reflect and act responsibly to effect change" (OECD, 2019). Three key developments stand out from the analysis conducted by Scarongella: the evolution of sustainability from a marginal concern to a central guiding principle, transforming it from "a theme among many" into a paradigm through which education itself must be rethought; the incorporation of agency-related concepts and the redefinition of teachers as catalysts for transformation, highlighting the pending need to translate aspirations to concrete curriculum strategies.

Watson and Li highlight the importance of promoting scientific literacy as a central goal of science education to thrive in an era of uncertainty. Specifically, they present the results of a comparison between the Taiwan and Manitoba science curricula (grades 7-9), which share a similar structure, using the PISA 2025 Science Framework that emphasises scientific literacy through the development of scientific competencies. According to the content analysis, while both curricula align with PISA 2025 in content coverage, they fall short in fostering epistemic and procedural knowledge or general scientific competencies, and a sense of science identity, suggesting key areas for improvement. The authors argue that PISA should not be treated as the sole measure of education quality, but it can serve as a useful tool to identify gaps and inform directions for curriculum development.

In a different context, Dawud et al. focus on the importance of Dynamic Equilibrium (DE), a structuring concept in learning natural sciences that fosters students’ systems thinking. The study presents a qualitative mixed-methods content analysis of the content and representations related to DE in the main high school textbooks and national standards of Israel and the US across biology, chemistry, and physics. According to the findings, DE-related phenomena are present in roughly 14% of science curricula, though not always explicitly. While students struggle to connect microscopic processes with macroscopic phenomena, computational models appear valuable for improving systemic understanding. The study recommends developing unified, cross-disciplinary representations of DE and suggests that future research should explore its integration across more scientific fields.

Lastly, the work by Lampoudis and Mogias highlights the value of the recently updated Climate Literacy Guide (USGCRP, 2024) and advocates for it as a solid foundation for raising students’ climate literacy in formal education. Taking this guide as a referent framework, these authors investigate the presence of climate change issues in Greek Special Education science textbooks. The content analysis shows rather limited and fragmented information concerning the eight essential principles and the seventy-six fundamental concepts of the Guide, identifying key areas for improvement.

We hope that this chapter contributes to sharpening our understanding of the contextual factors that support or hinder responsive and innovative education, while stimulating debate about how best to prepare students to address current societal and environmental challenges through science education.

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he Evolution Of Competence And Agency In Science Education: A Conceptual Analysis

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The development of competence in science education reflects a significant shift from literacy-focused, economically driven models to comprehensive frameworks that incorporate transformative agency and sustainability. This study traces the conceptual journey from Aristotle's fundamental distinction among episteme, techne, and phronesis—which already highlighted the ethical aspect—through modern frameworks such as OECD DeSeCo 2003, Learning Compass 2030, GreenComp 2022, and PISA 2025. The analysis shows how competence has progressed from simply acquiring knowledge to the ability to act within complex socio-ecological systems, illustrating the enduring presence of Aristotelian ethical components over centuries. Three key developments stand out: the evolution of sustainability from a marginal concern to a central guiding principle; the incorporation of agency-related concepts (systems thinking); and the redefinition of teachers as catalysts for transformation. In particular, values and ethical responsibility in current frameworks have experienced a revival—from DeSeCo's economic focus to PISA 2025's —that reflects a return to the holistic roots of competence. Yet, a persistent tension remains between these comprehensive visions and their practical realisation. This analysis underscores both the persistent influence of ethical dimensions from Aristotle to today and the ongoing challenge of translating transformative aspirations into practical curriculum strategies for the Anthropocene.

Keywords: sustainability agency, science education, competence

Introduction

Over the past three decades, competencies have become a key topic in European and international debates. In Europe, this policy began with the European Council's December 2006 recommendation on key lifelong learning competences, which influenced Italy and other EU countries. Student competencies are divided into four areas: languages, mathematics, science-technology, and social history, later adding citizenship skills. Anyway, despite growing interest, schools struggle to define essential competencies and what it means to develop them (European Council, 2006).

Nevertheless, competencies must be defined to provide students not only with knowledge content but also with holistic, complex skills and attitudes that enable them to navigate an increasingly challenging and uncertain society. In this context, knowledge alone is insufficient; systemic thinking, critical analysis, and ethical judgment are also essential. This is particularly evident in a society and era where the climate and sustainability emergency has gained significant importance, especially in recent years, leading to personal and general uncertainty.

At the international level, attention to the competence topic began in 2003 with the emergence of the first frameworks that began discussing competencies, such as the OECD DeSeCo. However, the historical origin of competence dates back considerably further. Indeed, as Pellerey analysed in his book "Competenze", the philosophical foundations of competence can be traced back to Aristotle (4th century BC), who already provided a complex and holistic definition of competence. He distinguished between episteme (theoretical knowledge), phronesis (ethical wisdom), and techne (technical ability). Aristotle, therefore, was the first to highlight the importance of conceiving knowledge not only in terms of practical action but also as encompassing a much more holistic and complex dimension, emphasising the ethical and moral dimension (Pellerey, 2010).

The legacy of this can be noticed, considering that recently the evolution of the concept of competence has shifted from an economic drift—oriented satisfying society's financial needs and requirements, as exemplified by DeSeCo, to more complex aspects of the individual who tends to value ethical and moral agency aspects in the challenges and choices of society.

The explicit introduction of sustainability competence into the European Key Competences Framework occurred with the 2018 Recommendation (European Council, 2018), in response to the global challenges articulated in the United Nations' 2030 Agenda (United Nations, 2015). This integration rendered environmental sustainability a transversal component spanning multiple key competences, with particular emphasis on scientific, citizenship, and entrepreneurial competences (European Council, 2018). It's clear that a significant transition has occurred from the literacy model of the 2000s—articulated around linguistic, mathematical, and scientific competencies—to a comprehensive sustainability-oriented paradigm. Also, the OECD has been forward-thinking in this regard, placing sustainability as a **central priority**, even if its central role has only recently been recognised in PISA-25, with some aspects already addressed in the OECD Learning Compass 2030. Besides, the OECD has been forward-thinking in its approach with respect to the evolution of the literacy paradigm, shifting from a focus on practical skills to fostering transformative capacity. In 2019, following the European Green Deal (European Commission, 2019), which established sustainability as a central EU priority, the integration of sustainability into education was significantly accelerated, transforming it from "a theme among many" into a paradigm through which education itself must be rethought. GreenComp comes up within this revolutionary context. The year 2020 marked a pivotal shift, during which the Joint Research Centre conceived GreenComp as a framework explicitly dedicated to sustainability competencies (Bianchi et al., 2022). This last framework encompasses systemic complexity, ethical dimensions, critical thinking, and uncertainty management, thereby promoting active and transformative citizenship.

In this work, we want to provide a comparative analysis of the conceptual, structural, and purposive evolution of international institutional frameworks, particularly about the emergence of transformative and sustainable dimensions, to review competence in science education. In relation to this, the research question is the following:

How has the concept of competence evolved in science education to address sustainability challenges and transformative agency?

Methodology

To address our research questions, we implement a comprehensive scoping review methodology to map and analyse the historical trajectory and conceptual development of competence and agency in science education. This methodological approach proves particularly valuable for investigating complex, cross-disciplinary subjects that necessitate comprehensive concept mapping, gap analysis, and theoretical integration across multiple perspectives (Arksey & O'Malley, 2005). Our research process follows five systematic stages:

Stage 1 - Research Question Development: Our investigation examines how competence, specifically sustainability competence, has evolved in science education, using international and European conceptual frameworks.

Stage 2 - Literature Identification: We conducted an extensive review of seminal works ranging from OECD-DeSeCo (2003), to more recent educational frameworks, including the OECD Learning Compass 2030 (2019), GreenComp (2022), and PISA Science Framework 2025.

These frameworks were selected because they represent both policy-driven and academic contributions that have significantly shaped the development of the concept of competence. They provide insight into the evolution of competence by offering a reading that is grounded in the relationship between education and society. Furthermore, these frameworks enable us to trace the emergence and institutionalisation of sustainability competences as a concept—from its first academic articulation to its current status as a central dimension of international and European educational policy.

Stage 3 - Selection Process: We established specific inclusion parameters centred on theoretical frameworks of competence and agency in education, while deliberately excluding research focused solely on specific scientific content knowledge.

Stage 4 - Data Analysis: The analysis focuses on key aspects, including tracking the development of competence as a concept, observing the emergence of transformative competences, and examining the gradual integration of values and ethics. We systematically coded whether sustainability was explicitly included or omitted in each framework, enabling the identification of patterns in sustainability incorporation. Finally, we analysed the persistence and evolution of the classical Aristotelian structure and potential implications for curriculum applicability.

Stage 5 - Synthesis and Documentation: Our findings are presented comprehensively, highlighting both the continuity and evolution of competence and agency concepts, with a specific focus on their implications for science education.

The following section presents our analysis, which reveals a gradual evolution from economically oriented competence definitions toward frameworks that emphasise transformative agency, values, and sustainability. Here, we present the key frameworks chronologically, highlighting the conceptual shifts and emergent themes."

Results And Discussions

The Evolution Of The Concept Of Competence In Major Frameworks In Science Education

The following section highlights three phases in the development of competence: the economic-focused phase (1997-2003), the transformative and agency-oriented phase (2018-2019), and the sustainability-centred phase (2020-2025). Throughout this progression, the traditional tripartite model—reflecting Aristotle's distinction among episteme (knowledge), techne (skills), and phronesis (ethical wisdom)—remains but evolves, with values and ethical considerations gaining increasing importance.

At the educational level, two key frameworks at the European and international levels that provide essential guidance for shaping educational paths are the OECD framework for different periods and GreenComp. Comparing these frameworks will specifically highlight how and why the concept of competence shifts from a simple understanding, such as knowledge, to a more complex and articulated notion. This will also be analysed in relation to societal change, as well as the historical origin and initial purpose of the framework. The emergence of environmental competencies over time will also be examined. The first frameworks to be analysed are the OECD frameworks across different periods, starting with their origin. The OECD (Organisation for Economic Co-operation and Development) is an international organisation founded in 1961 to promote policies that improve the economic and social well-being of people worldwide by reducing disparities, poverty, and social inequalities. His birth occurred after the Marshall Plan, established by the United States after World War II to address Europe's economic crisis. Its predecessor was the **Organisation for European Economic Co-operation (OEEC)**, which coordinated the distribution of financial aid and helped European countries rebuild their economies by promoting economic cooperation, and was active from 1948 to 1961. It primarily focused on managing the Marshall Plan and post-war economic reconstruction, with a limited scope confined to Europe. The OEEC had not yet developed a competency framework. During this period, due to social needs, the emphasis shifted to technical and professional education, with a focus on practical knowledge and skills. This approach was adopted to better address the socio-economic problems faced at that historical time. Then, in 1961, the OECD was born to serve as a source of information, providing economic data, policy analyses, and recommendations to its 38 member countries, both European and non-European (OECD, n.d.).

Over time, the OECD has expanded its sphere of action from a purely economic area to one that first concerns education and then also the environmental aspects. For the first time, the concept of competence was introduced in 1997 when the **DeSeCo-Defining and Selecting Key Competencies** project was launched by the OECD and concluded with the final report in 2003 with **"Key Competencies for a Successful Life and a Well-Functioning Society"**, to provide a conceptual framework for identifying key competencies necessary for modern life (OECD, 2003). The definition of competence is the following, given on page 4 in OECD DeSeCo Project: *"A competency is more than just knowledge and skills. It involves the* **ability to meet complex demands** *by drawing on and mobilising psychosocial resources (including skills and attitudes) in a particular context"*(OECD, 2003, p. 4). It is clear that in this definition, the economic dimension remains fundamental, and while the social benefits are present, they are not essential. The document that follows DeSeCo and most comprehensively encompasses the ongoing changes in competencies is the new **OECD Learning Compass 2030** framework, published in **2019.** The **OECD Learning Compass 2019** is a guidance tool designed for all actors in the educational system, from policymakers to students and their families. It arises from the need to redefine the competencies necessary for 2030 and guide educational systems in addressing future challenges. It is a framework, not designed like DeSeCo, that represents an expansion of the previous one towards a concept of competencies with a connotation related to **agency, co-agency, and transformative competencies.** This framework first introduced the word agency: "*Student agency is defined as the belief that students have the will and the ability to positively influence their own lives and the world around them as well as the capacity to set a goal, reflect and act responsibly to effect change*" (OECD, 2019, p. 17). White et al. (2023) later further developed this idea for sustainability by defining individual and collective agency using measurable constructs such as hope, self-efficacy, and outcome expectancy. The framework expands by, for the first time, including not only knowledge and skills for professional use but also attitudes and values. This explicit inclusion of values marks a return to the holistic conception of competence, recalling Aristotle's phronesis (ethical wisdom). Competencies are seen as tools for navigating the uncertainties and complexities of the modern world, defining the skills students must acquire to face future challenges. The peculiarity of this framework is to identify three transformative competencies (creating new values, reconciling tensions and dilemmas, taking responsibility) and a series of values and attitudes that students must develop to be responsible citizens (respect for self, others, country, diversity, empathy, integrity and resilience). This is the definition of competence given in the document: "*A competency is a holistic concept that includes knowledge, skills, attitudes and values. The OECD Future of Education and Skills 2030 project defines a competency as more than just 'skills". Skills are a prerequisite for exercising a competency. To be ready and competent for 2030, students need to be able to use their knowledge, skills, attitudes* *and values to act in coherent and responsible ways that change the future for the better*" (OECD, 2019, p. 25).

Also, the OECD logo effectively conveys the framework's structure and founding message (see OECD, 2019, p. 24). It can be described as follows: a compass can be observed with student agency at its centre, enabling them to become active protagonists of their own learning and capable of making conscious decisions. The competencies provided by the Learning Compass (knowledge, skills, attitudes, and values) are fundamental for navigating a complex, continually changing world. They must work together to build a shared sense of wellness. At the base of the compass are the "Core foundations" (basic foundations), which are the competencies that constitute a premise for the development of any other competency. These foundations encompass cognitive competencies (including literacy, numerical competency, digital literacy, and data literacy), health (including physical and mental well-being and individual well-being), and social-emotional skills (moral and ethical). These foundations are also functional to the development of three transformative competencies: creating new values, reconciling tensions and dilemmas, and taking responsibility. In particular, creating new values means "*Creating new value refers to a person's ability to innovate and act entrepreneurially, in a general sense, by taking informed and responsible actions*"(OECD, 2019, p. 62). The concept of co-agency is also evident in the figure, which illustrates collaboration among students, teachers, families, and the broader community. While student agency is defined as the belief that students have the will and ability to positively influence their own lives and the world around them, as well as the capacity to set goals, reflect, and act responsibly to produce change. Because it is only through the joint work of multiple actors that one can achieve everyday wellness. Moreover, knowledge is intended to encompass theoretical concepts and ideas that extend beyond practical understanding, grounded in experience performing specific tasks. Besides, it recognises four different types of knowledge: disciplinary, interdisciplinary, epistemic, and procedural. And finally, skills are understood as the ability to perform processes and use one's knowledge responsibly to achieve a goal, which distinguishes between four types of skills: cognitive and metacognitive, social and emotional, practical, and physical. Lastly, attitudes and values refer to the principles and beliefs that influence a person's choices, judgments, behaviours, and actions on the path towards individual, social, and environmental well-being. Moreover, in the 2018 position paper (The future of education and skills 2030), the urgency of creating an educational system that addresses not only economic and social challenges but also environmental ones (including the depletion of natural and climate resources) is highlighted. In both documents, the ecological theme is consistently presented as one of the challenges to be addressed, but not the only one (OECD, 2018).

The Rise Of Sustainability Competences

What follows reveals a critical turning point around 2020: in this year, sustainability shifted from being one challenge among many to becoming a central dimension of educational competence. The following section examines this transformation through GreenComp and PISA 2025, which shows how sustainability competences have been systematically integrated into contemporary educational frameworks.

Analysis shows a shift in the role of sustainability in frameworks. Before 2020, sustainability competence was minimal or embryonic, but from 2020 onwards, it gained importance. According to GreenComp (2022), it became central to educational competencies, reflecting the urgency of the climate crisis and a shift from training competitive workers to shaping change agents within planetary boundaries (Bianchi et al., 2022).

GreenComp belongs to the five frameworks developed by the European Union (LifeComp, EntreComp, DigComp, GreenComp, and Competences for a Democratic Culture), which specify additional, more detailed competences that allow for a more precise definition of the objectives within the eight key competences (Bianchi et al., 2022).

It differs from the first in that it was specifically created to address environmental and climate-related issues, and it is European rather than international. The GreenComp (European Sustainability Competence Framework) is aimed at educators, trainers, policymakers, and students of all ages. It was created by the European Commission in 2022 through the Joint Research Centre (JRC) and aims to provide a reference framework for teaching and learning sustainability-related competencies. This framework guides the integration of sustainability-related competencies into educational and training systems. The main objective, therefore, is to help people develop the knowledge, skills, and attitudes necessary to live, work, and act sustainably.

In it, sustainability is defined as: "sustainability means prioritising the needs of all forms of life and the planet, ensuring that human activity does not exceed the planet's limits". GreenComp, therefore, tends to foster an image of sustainability that balances nature and humans and develops in humans an awareness of their own limits.

In this framework, competencies are consistently linked to sustainability: "A sustainability competence enables learners to embody sustainability values and accept complex systems, to act or request actions that restore and maintain ecosystem health and increase justice, by envisioning sustainable futures". The teaching/learning of sustainability, therefore, aims to develop a sustainable mindset throughout the entire lifespan, from childhood to adulthood, promoting awareness that human beings are an integral part of nature and depend on it. Through greenComp, students gain knowledge, skills, and attitudes that empower them to be agents of change. They contribute both individually and collectively to create a future that respects the Earth's ecological boundaries. In the framework, the following definition of competence is given: *"a dynamic combination of knowledge, skills, and attitudes"*. Specifically, the GreenComp articulates competence into 12 competencies organised into four main areas: sustainability values, systemic thinking, sustainable future, and sustainability action.

These peculiarities ensure that GreenComp focuses not only on knowledge acquisition but also on the ability to act for change, promoting sustainable development at both personal and collective levels. As can be seen, all four areas refer to different approaches: some are more practical and action-oriented, while others are more theoretical, focusing on the development of mental strategies. It is important to note that GreenComp also emphasises the value dimension. Still, unlike the Learning Compass ‘30, it highlights three specific values related to sustainability: valuing sustainability, supporting fairness, and promoting nature.

Furthermore, the authors of the framework use a pollination metaphor to represent how the different areas of the framework are interconnected (see Bianchi et al., 2022, p. 12). In this scheme, the bees symbolise the 'acting for sustainability' area, as each bee plays a fundamental role in the colony's well-being and collaborates to achieve common goals. The flowers represent 'imagining sustainable futures' because they produce new fruits and seeds, fostering continuous renewal. The hive represents 'embodying the values of sustainability' as it protects and supports the bees. Finally, the pollen and nectar, which attract the bees to the flowers, symbolise the 'accepting the complexity of sustainability' area. This image thus highlights an ecosystemic vision where everything is interconnected.

GreenComp's ecosystemic vision exemplifies a growing trend where sustainability is no longer just one aspect but a key, organising element in education. This change is clearly demonstrated by PISA 2025, marking a significant shift in how the idea of competence in science education has developed.

PISA 2025 exemplifies a crucial new phase in the conceptualisation of competence within science education. The omission of the term "literacy" from this framework indicates a significant transition: it is no longer only concerned with students' capacity in science, but also emphasises their connection to the subject.

A key innovation in PISA 2025 is the concept of "Agency in the Anthropocene," which aligns with the OECD Learning Compass 2030's transformative vision but explicitly emphasises sustainability. The core competencies assessed include understanding how human actions affect Earth systems, making decisions informed by evaluating various evidence sources, applying creative and systemic thinking to sustain and regenerate the environment, and respecting diverse perspectives while maintaining hope in addressing socio-ecological challenges (White et al., 2023).

PISA 2025 attributes particular relevance to sustainability and environmental education, not as a separate theme but as a transversally integrated dimension. A person with scientific preparation must be capable of engaging in reasoned discourse on science, sustainability, and technology to inform action.

The supporting document 'Agency in the Anthropocene' (White et al., 2023) offers theoretical insights into these competencies, explaining the concepts of hope, self-efficacy, and outcome expectancy. It also distinguishes between individual aspects (such as critical evaluation and personal resilience) and collective aspects (such as consensual decision-making and action across various scales) of agency.

The analysed frameworks reveal varying curriculum specificity. Some provide operational guidance through detailed competency descriptors that break down knowledge, skills, and attitudes (GreenComp, Appendix 2), practical scenarios that demonstrate real-world application (GreenComp, Appendix 1), and specific pedagogical approaches, including active learning, place-based education, and systems thinking. Others explicitly clarify their non-curricular nature (OECD Learning Compass 2030), offering generic principles without operational indicators. Regarding the teacher's role, all frameworks reject transmissive models, positioning teachers as "transformative facilitators" who co-construct learning with students, model sustainability values, and facilitate democratic processes. The concept of co-agency is strongly evident, yet frameworks offer minimal guidance on preparing teachers for these demanding roles or on transitioning from current practices.

Conclusions

The evolution of competence frameworks from DeSeCo (2003) to PISA 2025 reveals a shift from literacy-based, economics-driven skills to fostering transformative agency for sustainability. Tracing the evolution from Aristotle's complex structure (episteme, techne, phronesis) to modern models, it shows both continuity and change in the integration of knowledge, skills, and ethics. The emphasis on sustainability, especially in GreenComp, PISA 2025, and "Learning Compass 2030," marks a shift from training knowledge-based competence to cultivating change agents who can think systemically, collaborate, and foster hope to collaborate on climate challenges actively. However, a tension exists between holistic visions and practical application: while frameworks promote interconnected approaches, they also need some metrics that may fragment curricula. All agree on shifting from transmissive to transformative and co-constructive teaching roles, which lack clear guidance and have no standard methods for transversal skills. Sustainability education faces the challenge of turning transformative visions into a practical curriculum. Future efforts should create concrete pathways for holistic integration and provide teachers with support and tools to empower students amid the complexities of the Anthropocene.

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EUROPEAN SCIENCE EDUCATION RESEARCH ASSOCIATION ESERA 2025 Copenhagen

Ready for PISA 2025? A Comparative Analysis of Taiwan and Manitoba Science Curricula

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The PISA 2025 framework shifts focus from scientific literacy to scientific competencies, emphasizing the ability to apply knowledge effectively as a key aspect of scientific competence. Given this radical shift, we, as teacher educators, wonder whether our current curricula are preparing students to succeed in the updated PISA framework. Although using a specific test as an evaluation mechanism for the overall curriculum is problematic, the PISA 2025 can provide a systematic method to understand whether students possess the critical competencies needed to face the rapidly changing modern society. This study employs a document analysis method, using the PISA 2025 Science Framework to analyse the science curriculum guidelines for grades 7 to 9 in Taiwan (TWN) and Manitoba (MB), Canada. Results reveal the curricula in both TWN and MB are lacking in procedural knowledge and epistemic knowledge, which is a major critique of modern curriculum guidelines. In terms of context, both TWN and MB have a significant gap compared to the PISA 2025 goals. This might make it more challenging for students to deal with scientific problems in various situations. Finally, regarding science identity, the analysis results reflect the environmental differences between TWN and MB. To summarize, both the TWN and MB science curriculum documents have rich content knowledge, but they fall short of the PISA 2025 goals in other aspects. This study provides a potential direction for curriculum developers and further expands the possibilities for teaching scientific literacy and the nature of science. Although the PISA 2025 framework is not perfect, it serves as a meaningful goal for continuous improvement.

Keywords: PISA 2025, Science Curriculum, Comparative Analysis

Introduction

Since 2000, Programme for International Student Assessment (PISA), one of the most influential, international, student learning assessments (McGaw, 2008), has used a globally recognized framework to assess the performance of national education systems. In 2023, a new assessment framework in PISA 2025 Science Framework (PISA 2025) was unveiled and it prioritized scientific competencies, marking a departure from the previous structure, which focused on scientific literacy.

Scientific literacy is a goal of education, yet scholars cannot agree on its definition (DeBoer, 2000; Osborne & Allchin, 2024). DeBoer (2011) called for science education to determine the knowledge and competencies needed for global citizenship. Scientific literacy points to a diverse set of aims for society and citizens (Osborne, 2023), whereas scientific competencies focus on those skills required for a person to engage in reasoned discourse about science (OECD, 2023). Shifting from literacy to competencies implies the goals of science education, under PISA 2025, are defined in terms of what an individual can do with their knowledge instead of by what they know. Competencies opened space to consider more types of knowledge, such as epistemic knowledge (Zetterqvist & Bach, 2023), than previously included in PISA efforts.

This new framework brings the preparedness of science education curricula to meet PISA expectations into question. Are students in our contexts ready for PISA 2025? To answer this, we compare the contexts of Taiwan and Canada. Despite their geographical distance, these two nations share striking historical and cultural parallels; both are multicultural societies with deep

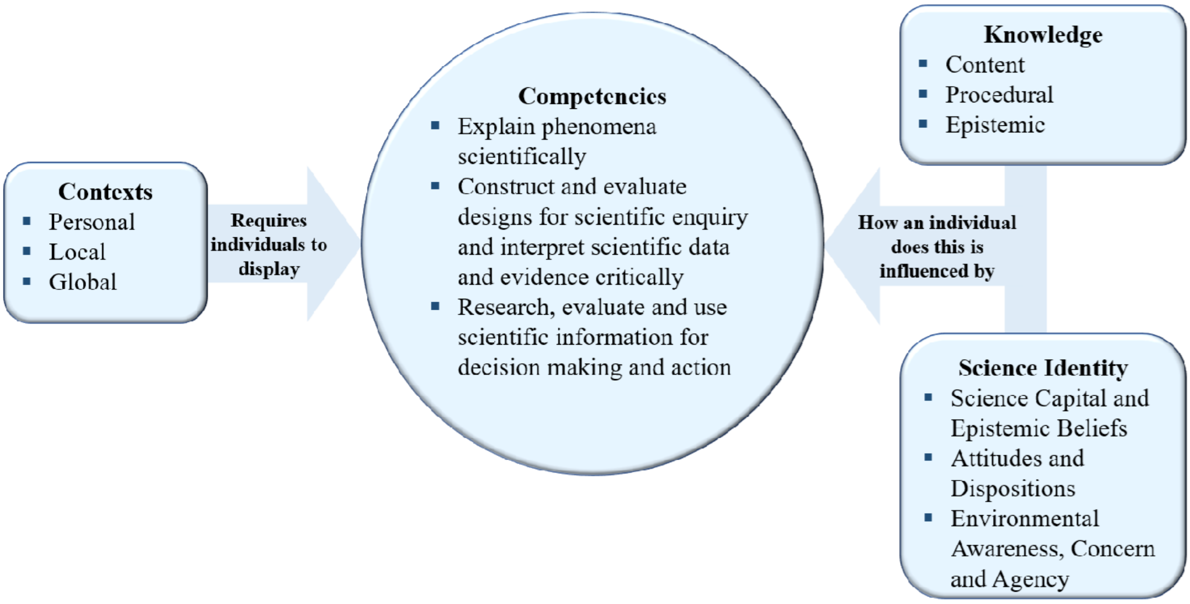
Indigenous traditions, and both have evolved into their current state following histories of European colonization. However, their geographical distinctions, Canada as a vast continental landmass and Taiwan as an island nation, expose them to different Socio-Scientific Issues. These environmental differences inevitably influence the design philosophies of their respective science curricula.

Regarding the selection of specific regions, education in Canada falls under provincial jurisdiction rather than a federal mandate. Consequently, this study selects the province of Manitoba (MB) as a comparative basis, a choice further motivated by the researchers' geographical location and familiarity with the local context. While Taiwan adopted a revised national curriculum in 2019, at the time of this research Manitoba's framework was unchanged since the early 2000s. Since both contexts use curriculum documents developed before PISA 2025, we questioned whether our curriculum contexts prepared students for PISA. That is, are PISA 2025's knowledge, context, and science identity components appropriately represented in Taiwan's curriculum guidelines (2019) and Manitoba's curriculum framework (2000)?

Study Design

The curriculum documents of Taiwan and Manitoba share a similar structure, both using lists of verb-centric outcomes. The Taiwan document has 255 specific learning outcomes, and the Manitoba document has 375. Both curriculum documents include multiple, content-focused units/topics and separate sections with outcomes intended to be woven throughout the course(s). In Manitoba, these separate sections focused on science inquiry, the design process, and scientific literacy. In Taiwan, these separate sections focus on scientific attitudes, inquiry, and cognition and on those aspects of science across content-topics.

Figure 1. PISA 2025 Framework (OECD, 2023, p.11)



Document analysis (Bowen, 2009), specifically content analysis, was used to evaluate the curriculum documents. PISA 2025 served as our a priori framework. Based on the "outcomes of science education" proposed in PISA 2025 (Figure 1), this study analysed each item in Taiwan and Manitoba grades 7-9 science curriculum documents; the PISA exam is taken in grade 9 in both countries, so we focused on grades 7-9. Each outcome item within the curriculum documents was coded using the sub-frameworks describing the *types of knowledge*, *context*, and *science identity*; general descriptions of each of these sub-frameworks are provided in Figure 1. full descriptions available in PISA 2025. Items could represent multiple aspects under each of these sub-frameworks. For example, the outcome of "Investigate Canadian and international contributions to research and technological development in the field of genetics and reproduction (MB S1-1-16)" was coded as representing content-knowledge (life sciences), both local and global contexts, and science capital and epistemic beliefs.

To ensure inter-coder reliability, two researchers independently coded each document. Through an iterative process, results were compared and any discrepancies resolved through discussion.

Results

Codes were amalgamated and, where possible, compared to PISA 2025's expectations. Charts from each of these sections will serve as focal points for prompting discussion.

Knowledge

As shown in Figure 1, PISA 2025 labels knowledge as content, procedural, or epistemic knowledge. The knowledge content was further described by the systems of physical sciences (i.e., physics and chemistry), life sciences (i.e., biology), and earth and space sciences (i.e.., geology and astronomy). During our analysis, we noted that both documents were highly focused on content knowledge, so we chose to consider both the procedural and epistemic knowledge in terms of the physical, living, and earth and space sciences.

Table 1. Distribution of Knowledge Outcomes.

		Content	Procedural	Epistemic
Physical	PISA	15-20%	10-13%	8-11%
	MB	27.7%	4.5%	2.9%
	TWN	41.2%	0.0%	0.4%
Living	PISA	15-20%	10-13%	8-11%
	MB	16.0%	1.1%	1.3%
	TWN	27.8%	0.4%	2.0%
Earth & Space	PISA	10-15%	7-10%	7-10%
	MB	10.9%	1.1%	2.9%
	TWN	21.6%	0.0%	1.6%
Content General	MB	7.7%	1.9%	1.1%
	TWN	3.1%	1.6%	2.0%
Not Content	MB		15.5%	9.3%
	TWN		7.1%	3.9%

Further, some outcomes in both documents did not address knowledge specific to physical, living, or earth and space science but did address some type of content knowledge in science as defined by PISA 2025 (pp. 24-26); hence, we added a knowledge type, "Content General". For instance, the outcome "The process and applications of various materials in life (TWN Mc-IV-3)" illustrates procedural understanding that pertains to general science rather than any specialized subject.

On the other hands, some outcomes did not connect to content knowledge but connected to procedural or epistemic knowledge; we identify these outcomes as "Not Content". For example, the outcome "Students can properly connect acquired knowledge to observed natural phenomena and experimental data, in order to make inferences, see correlations, and justify their arguments (TWN tr-IV-1)" demonstrates how to link phenomena and data to scientific claims. This reflects a deep understanding of methodology and epistemology, independent of specific content knowledge.

Table 1 (above) presents the distribution of outcomes for knowledge in both curriculum documents, Manitoba (MB) and Taiwan (TWN). PISA 2025 defines target distributions for the assessment of knowledge (OECD, 2023, p. 43), see left-most column under each physical, living, and earth and space knowledge in Table 1.

Table 2. Distribution of Context Outcomes.

		Personal	Local/National	Epistemic
Physical	MB	1.3%	0.5%	0.5%
	TWN	1.9%	0.0%	0.3%
Living	MB	1.6%	1.9%	2.7%
	TWN	1.3%	1.9%	2.9%
Earth & Space	MB	0.0%	1.6%	1.3%
	TWN	0.3%	2.4%	1.6%
Content General	MB	0.3%	0.3%	0.5%
	TWN	0.5%	0.0%	0.0%
Not Content	MB	4.8%	2.9%	2.4%
	TWN	1.1%	0.5%	0.8%
Total	MB	8.0%	7.2%	7.5%
	TWN	5.1%	4.8%	5.6%

Science Identity

PISA 2025 does not explicitly state the expected distribution of science identity. Schiepe-Tiska et al.'s (2016) identity assessment framework suggests that the four dimensions of science identity are equally important. Similar to context results, we present PISA 2025 aspects of science identity and the aspects of content knowledge as percentages of total outcomes (Table 3).

Table 3. Distribution of Science Identity Outcomes.

		Science Capital	Epistemic Beliefs	Attitudes & Dispositions	Environmental Awareness
Physical	MB	0.8%	0.3%	0.3%	0.3%
	TWN	1.2%	1.2%	0.0%	1.2%
Living	MB	0.5%	0.3%	0.0%	1.9%
	TWN	0.8%	3.1%	0.8%	9.0%
Earth & Space	MB	0.3%	0.0%	0.0%	1.1%
	TWN	0.4%	0.4%	0.0%	5.5%
Content General	MB	0.0%	0.0%	0.0%	0.8%
	TWN	1.2%	0.8%	1.2%	0.0%
Not Content	MB	2.9%	3.7%	5.6%	2.7%
	TWN	3.1%	3.1%	2.0%	0.4%
Total	MB	4.5%	4.3%	5.9%	6.7%
	TWN	6.7%	8.6%	3.9%	16.1%

- Standard Deviation for total: MB(1.1%), TWN(5.2%)

Discussion

Both Manitoban and Taiwan documents focus on preparing students for content knowledge rather than procedural or epistemic knowledge. The Taiwan document had a higher percentage than PISA 2025 expectations in every knowledge content area; the physical science content representation (41.2%) doubled the expectation of PISA 2025 (15-20%). Manitoba also focused on physical science knowledge. Both documents' inclusion of non-content-knowledge outcomes may have skewed percentages.

The distribution of outcomes representing each content area in both documents exceeded PISA 2025 expectations. However, the heavy weighting of the content knowledge in both the TWN and MB curriculum documents suggests a heavy focus on science as content in education. This was particularly evident in both contexts heavily emphasizing physical science, with TWN having over 40% and MB having almost 30% of their outcomes reflecting physical science content. This emphasis on content knowledge is inadequate to develop the necessary informed epistemic trust needed by students today to sift through the misinformation bombarding their lives today (Osborne & Allchin, 2024). It is with this in mind, that we recognize that while both TWN and MB students may be exposed to the knowledge content necessary to succeed with PISA 2025, we contend that neither curriculum document may be adequately preparing students for the entirety of PISA 2025.

Both documents had low representation of procedural and epistemic knowledge. Manitoba's document showed a higher representation of procedural knowledge than Taiwan's document. Procedural outcomes in both countries were often not connected to science content. Taiwan's document focused more on epistemic knowledge in relation to living sciences and general content knowledge than Manitoba, with Manitoba having higher representation in all other areas. Both documents were below PISA 2025 expectations. We conclude students from both countries should be prepared to answer content-knowledge questions but may be underprepared in procedural or epistemic knowledge.

Neither country had ratios reflecting the context expectations of PISA 2025. Both countries represented personal, local/national, and global contexts relatively evenly whereas PISA 2025 includes a much higher representation of local/national settings. Manitoba had more outcomes connected to each of the three contexts than Taiwan. Taiwan's document showed slight preference towards global contexts and Manitoba's document toward personal context, possibly due to the values toward community held in each context. Consequently, Manitoban students may be slightly more comfortable recognizing science in context than Taiwanese students.

Finally, PISA does not have expected distribution of science identity aspects, but Schiepe-Tiska et al. (2016) suggest equal distribution among each of the aspects; the standard deviation of science identity aspects for Manitoba was 1.1% and Taiwan was 5.2%. This suggests a relatively equal distribution of aspects in the Manitoban document but not in Taiwan's document. Taiwan's document focused on science capital, epistemic beliefs, and environmental awareness more than Manitoba. Taiwan's document emphasizes environmental awareness strongly in relation to both living (9.02% of outcomes) and earth and space (5.49% of outcomes) science; Taiwan is an island nation, and this may be because the impacts of climate change are felt more severely. Manitoba's document focused more on attitudes and dispositions than Taiwan, but very few outcomes connected to any aspect of science identity and content knowledge. We expect Taiwanese students to be more prepared in terms of science identity, particularly environmental awareness.

We conclude that both the Taiwan and Manitoba documents reflect the expected content-knowledge of PISA 2025—in many areas these expectations were exceeded—but are lacking in all other aspects. Of particular concern is the low representation of epistemic knowledge; this is representative of the literature on the inclusion of epistemic knowledge in science education (Zetterqvist & Bach, 2023). Science education prepares citizens for an increasingly uncertain world (Covitt & Anderson, 2022); thus, epistemic knowledge is of more importance than ever, and we hope that future documents will address its underrepresentation.

Conclusion

This study opens discussion about how science curriculum documents may or may not prepare students for PISA 2025. PISA, in many countries, is used to judge the quality of a nation's science education (Zetterqvist & Bach, 2023). We, like many scholars (Au, 2022), recognize the problematic nature of preparing our students for a specific assessment like PISA. However, we argue that while PISA should not be relied upon as the sole indicator of educational quality, it nonetheless offers a valuable directional guide for curriculum adjustment and improvement.

In this light, the PISA 2025 framework provides a way to systematically evaluate the appropriateness of science curriculum documents for grades 7-9 students. Ultimately, this evaluation highlights that science education has evolved beyond a mere focus on content knowledge. To truly equip students with a scientist's mindset, necessary for navigating a rapidly changing future, curricula must go beyond the OECD's competencies and deeply incorporate the nature of science.

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Dynamic Equilibrium In Science: Comparison Between The Israeli And United States Frameworks And Representations In The Standards And Textbooks

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The study examines how Dynamic Equilibrium (DE) is represented in science national standards and textbooks for high-school biology, chemistry, and physics in the US and Israel. DE, a crucial concept in understanding dynamic systems, is inconsistently represented across educational materials and students encounter difficulties learning about DE. Analysing 17 textbooks and national standards, the research combines quantitative and qualitative content analysis to assess the frequency and nature of presentation of DE-related phenomena. The study identifies 256 DE-related phenomena, comprising 14% of all phenomena that are studied in science. The primary systems approach used is System Dynamics, which focuses on stocks and rates of flow at one description level. The main representational format is verbal, and computational models are scarcely used. Differences across disciplines and between countries were found. These findings emphasize the need for powerful representations of DE to enhance students' understanding of dynamic systems and improve science education.

Keywords: Dynamic equilibrium; Science education; Systems thinking; Textbook analysis; Scientific representations; Cross-national comparison.

Introduction, Theoretical Perspectives, And Research Goal

This paper examines the concept of Dynamic Equilibrium (DE) in the US and Israeli high school science standards and textbooks, focusing on its role as a structuring concept across the natural sciences. DE is fundamental for understanding patterns in dynamic systems, describing systems that maintain stability through continuous balancing influences (Biology Dictionary, n.d.), such as homeostasis in biology, ecological systems, and chemical equilibrium. Despite its significance, DE remains a challenging concept for students, with difficulties arising from the contradiction between the system's stable appearance and the dynamic processes that maintain it (Sarıçayır et al., 2006). Students often struggle to understand stability as a dynamic process rather than static constancy, as seen in alternative concepts about chemical equilibrium (Nakhleh, 1992; Özmen, 2008) and homeostasis (Zion & Klein, 2015).

DE is analysed through systems frameworks like System Dynamics (SD; Forrester, 1961), Structure-Behavior-Function (SBF; Hmelo-Silver & Green Pfeffer, 2004), and Agent-Based Modeling (ABM; Wilensky & Rand, 2015). These frameworks focus on understanding system behavior and emergent patterns, helping students grasp the dynamic and parallel nature of equilibrium in complex systems. DE plays a key role in science education, particularly in the NGSS standards, which include Stability and Change as a crosscutting concept related to DE (NGSS, 2013). Proper instruction on DE fosters systems thinking and enhances students' understanding of complex processes across multiple levels of representation. The high school curricula in the US and Israel differ in structure. In the US, students are exposed to a wide range of subjects, with opportunities for specialization through programs like AP courses. In Israel, students specialize in one or two subjects, limiting exposure to other fields. Assessments also vary: in the US, GPA and standardized tests like the SAT or ACT are used, while in Israel, the Matriculation (Bagrut) exams focus on the chosen specialization subjects.

This study is part of a larger international project, which aims to develop better representations of DE to address the identified learning challenges. By comparing national standards and textbooks from both countries, we seek to understand how DE is structured, conceptualized, and conveyed within different educational contexts. The research excludes supplementary or external teaching materials. This research aims to compare how DE is represented in the science curricula and textbooks of the US and Israel and identify the DE-related phenomena and their representational formats. Additionally, it examines how different system frameworks are applied across subjects and countries. Through a cross-national analysis, this study seeks to uncover both expected and unexpected instances of DE in science education, with an emphasis on improving representations to enhance student comprehension of dynamic systems.

Methodology

The study analysed the content and representations related to DE in the main science textbooks and national standards of Israel and the US (Israel Ministry of Education, 2024; US NGSS, 2013; US National Research Council, 2012). A qualitative mixed-methods content analysis (Krippendorff, 2019; Schreier, 2012) categorized DE-related phenomena into seven representational formats: verbal, equation-based, graphical, tabular, photographic, illustrative, diagrams, and computational (e.g., simulations). “Phenomenon” is defined in the analysis as an object-involving occurrence, where an object (or system) undergoes a process, an event, or a state (Kaiser & Krickel, 2017). The analysis focused on the frequency of DE phenomena and the system frameworks used to describe them. This study does not encompass the entire student learning environment, acknowledging that lab work and external resources also play a role in student engagement with DE concepts.

Findings

Content Of The Curricula

An overview of the high school science curricula in the US and Israel was conducted to identify overlap and facilitate comparison. The standards and textbooks’ topics were subdivided into content-based groups, aligning them as categories. The number of phenomena in each discipline in both countries was counted (see Figure 1).

In biology, the curricula in both countries cover similar topics, with some differences in emphasis. Key topics include cellular biology, human and animal biology, and ecological systems. Both countries address cell structure, organelle functions, and processes like respiration and protein synthesis. The US emphasizes substance transport, while Israel teaches fermentation and meiosis in cell division. Both countries teach human and animal biology, including body systems, physiology, and genetics. In ecology, both curricula cover ecosystems and human impact, with the US focusing more on energy flow and succession, while Israel emphasizes human impact and ecological organization. The primary difference is that the US includes evolution and biodiversity, topics absent in Israel.

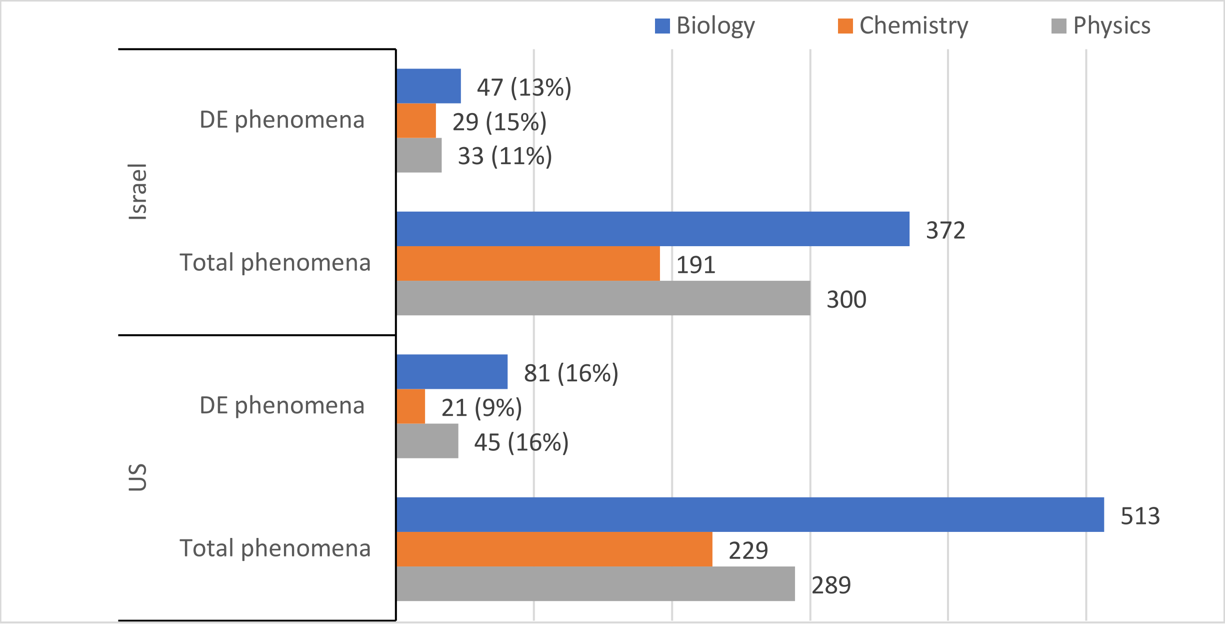
In chemistry, the curricula in both countries align closely, focusing on similar principles, though differences arise in depth or emphasis. Topics include atomic structure, chemical bonds, energy changes, food chemistry, and chemical equilibrium. Both countries address oxidation-reduction, chemical reactions, and factors affecting equilibrium. The main differences are in the level of detail or emphasis in specific areas.

In physics, both curricula cover forces and motion, energy, electricity and magnetism, and radiation and matter, with some differences. For forces and motion, Israel emphasizes Newton's laws and momentum conservation, while the US focuses on force-mass-acceleration relationships and real-world applications like collisions. Both curricula cover energy, with Israel focusing on mechanical energy and the US highlighting energy transfer and work-energy principles. In electricity and magnetism, both teach electric fields and Ohm's law, with Israel covering electromagnetic induction and the US emphasizing applications like circuits and power generation. In radiation and matter, both curricula address atomic and nuclear physics, with Israel focusing on atomic structure and quantum phenomena, while the US connects these topics to real-world applications like medical technologies. The differences lie in Israel's focus on foundational concepts and the US's emphasis on applications.

Identification And Counting Of DE-Related Phenomena

We identified phenomena embodying the principle of DE in the standards and textbooks, including those not explicitly defined as DE phenomena. The total number of phenomena and DE-related phenomena are shown by discipline (biology, chemistry, physics) for both countries (see Figure 1).

Figure 1. Frequency of All Phenomena and DE-Related Phenomena Across Disciplines (Biology, Chemistry, Physics) in the US and Israel Standards and Textbooks.

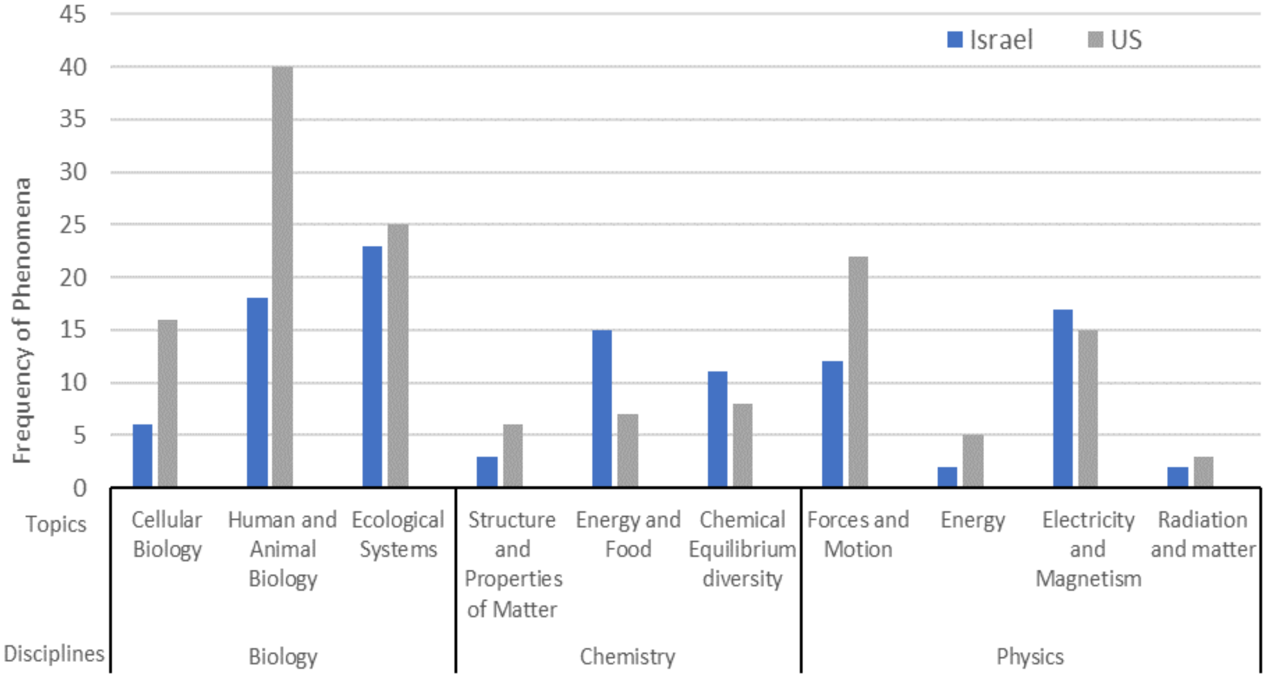


Overall, there are 256 DE-related phenomena across the three disciplines. In the US, 147 DE-related phenomena were identified, making up 14% of all phenomena. In Israel, 109 DE-related phenomena were found, representing 13% of the total. DE-related phenomena are most common in biology, followed by physics, then chemistry. In physics and chemistry, the total number of phenomena is similar between the two countries, but the US has a higher overall number of phenomena. The proportion of DE-related phenomena is greater in the US than in Israel for biology and physics, while in chemistry, Israel has a higher percentage of DE-related phenomena.

Distribution Of DE-Related Phenomena

We identified DE-related phenomena in the standards and textbooks, including those not explicitly defined as DE phenomena. Figure 2 shows the distribution by discipline and topic.The US and Israeli curricula align on half of the ten topics. However, the US includes more DE-related phenomena in forces and motion (physics) and cellular and animal biology (biology), while Israel emphasizes energy and food and chemical equilibrium (chemistry). Of the 256 phenomena examined, 11 describe chemical equilibrium, 27 address homeostasis, and 13 involve ecological systems, all traditionally linked to DE. Notably, 205 phenomena, representing 80% of DE-related phenomena and 11% of all described phenomena, depict DE processes in topics not previously defined as DE-related.

Figure 2. Distribution of DE-Related Phenomena Across Disciplines (Biology, Chemistry, Physics) and Topics in the US and Israel High School Textbooks.



DE Representations' Format

In future research, we will develop and explore new computational representations for DE. The study examined the prevalence of various representation formats in DE-related phenomena within US and Israeli textbooks, categorized as verbal, mathematical, graphical, tabular, photographic, illustrative, diagrammatic, and computational models (see Table 1).

Table 1. Format of Representations of DE-related Phenomena According to Textbooks in the US and Israel.

			Representation Format (% of N)							
Discipline	**Country**	**Phenomena (N)**	Model	Diagram	Illustration	Photograph	Table	Graph	Equations	Verbal
Biology	UA	81	18	26	48	13	1	5	6	100
	Israel	47	0	42	38	27	22	27	9	100
Chemistry	US	21	0	25	63	17	8	25	79	100
	Israel	29	3	0	11	0	24	29	34	100
Physics	US	45	0	20	76	20	4	31	73	100
	Israel	33	0	8	82	10	8	13	62	100

The study examined the prevalence of various representational formats in DE-related phenomena within US and Israeli textbooks, categorized as verbal, mathematical, graphical, tabular, photographic, illustrative, diagrammatic, and computational models. Overall, the frequency of representation formats follows the order: verbal > illustration > mathematical > diagram > graph

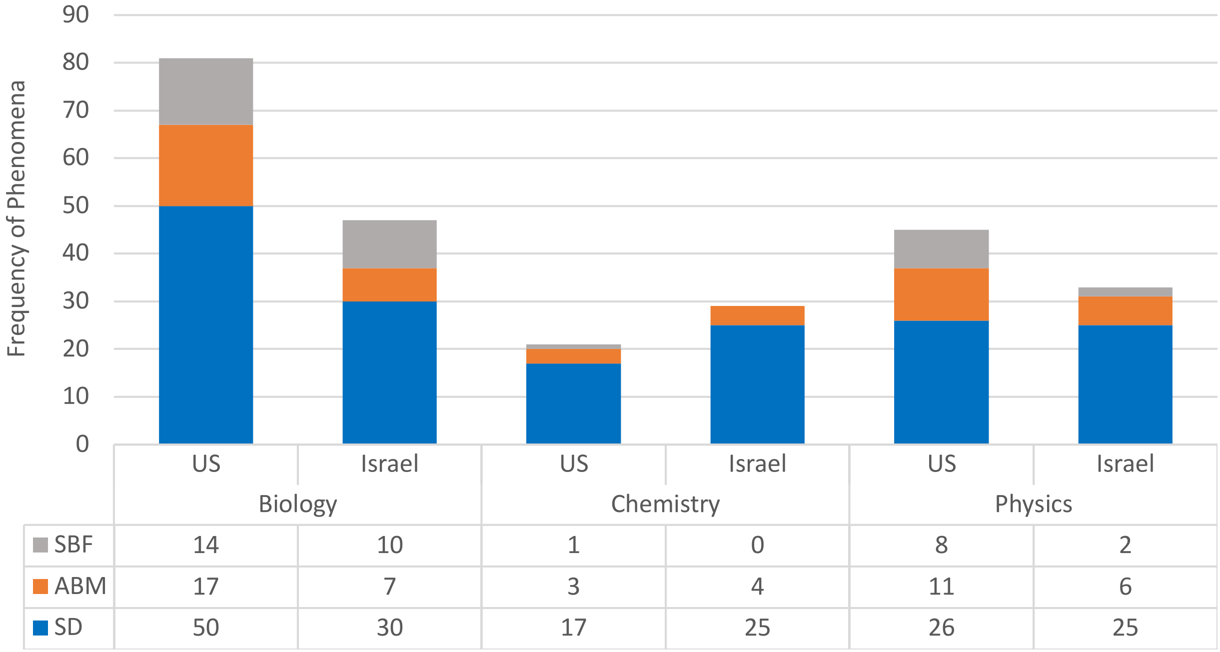
> table > computational model. Israeli biology textbooks feature six representation types in at least 20% of sections, compared to three in US textbooks. In physics, US textbooks include six types at this level, versus three in Israel.

Representations' Systems Framework

We analysed textbook explanations by systems frameworks: System Dynamics (SD), Structure-Behavior-Function (SBF), and Agent-Based Modeling (ABM). Explanations were coded using seven dimensions: behaviors and properties of components (ABM, SBF), randomness (ABM), interactions between components (ABM, SBF), functions (SBF), heterogeneity of entities (SBF), and stocks and rates (SD). These dimensions helped identify the frameworks in DE explanations (Figure 3).

SD dominates across disciplines with 173 phenomena, while ABM appears in 48 and SBF in 35. In biology, SD is most common, with ABM and SBF appearing less frequently. Chemistry is dominated by SD, with minimal ABM and almost no SBF, especially in Israel. In physics, SD is again prevalent, with ABM more frequent than SBF.

Figure 3. Frequency of System Frameworks (SD, ABM, SBF) Representing DE-related Phenomena Across Disciplines (Biology, Chemistry, Physics) and Countries.



	US	Israel	US	Israel	US	Israel
	Biology		Chemistry		Physics	
■ SBF	14	10	1	0	8	2
■ ABM	17	7	3	4	11	6
■ SD	50	30	17	25	26	25

Discussion

The research is part of an international project focused on developing representations for DE, a central idea in science that describes how stable patterns form in dynamic systems. It examines the representation of DE in high school science curricula and textbooks in the US and Israel, comparing the content across biology, chemistry, and physics. Key objectives include exploring how DE phenomena are presented and represented through various tools such as graphs, illustrations, and computational models, while analysing differences across disciplines and countries. The study also investigates the use of system approaches like System Dynamics (SD), Agent-Based Modeling (ABM), and Structure-Behavior-Function (SBF) in explaining DE phenomena. Findings reveal that DE-related phenomena make up approximately 14% of the curricula, though many are not explicitly defined as DE-related. Significant differences in the curricula were noted, such as the emphasis on evolution in US biology education versus its exclusion in Israel, influenced by social and cultural factors (Plutzer et al., 2020). Students often struggle with understanding DE due to difficulties in connecting microscopic interactions to macroscopic phenomena (Wilensky & Resnick, 1999; Friedler et al., 1987). Computational models, though scarce in current curricula, are identified as valuable tools for enhancing systemic understanding of DE. The study emphasizes the prevalence of SD for describing quantitative relationships in chemical and physical phenomena, while ABM is more suited for illustrating bottom-up interactions in biology and physics. SBF, primarily used in US biology and chemistry, connects the structure, behavior, and function of systems. The research concludes with recommendations to develop unified representations of DE that are adaptable across disciplines, enhancing consistency and comprehension. Future studies should explore DE's integration with other scientific concepts and its application to additional fields beyond biology, chemistry, and physics. This effort could expand the educational impact of DE by addressing its complexity through universal frameworks that bridge various scientific domains.

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Can Climate Literacy be taught in Special Education in Greece? Possibilities offered by science textbooks in upper high schools

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As we are already reaching the end of the first quarter of the 21st century, one would expect more progress toward addressing climate change issues, especially after almost four decades of discussions. Despite the admittedly many efforts carried out all these years, these have proven rather unsuccessful. A basic tool modern society has at its hands but does not seem to have made good use of, is the cognitive and emotional preparation of students within formal education to face this reality. Although several years have passed since climate issues entered the international debate regarding formal education, there is still an equally important field, Special Education, where no corresponding interest has been shown. A key element of education is the design of modern curricula and the selection of appropriate, up-to-date textbooks to overcome climate change challenges. That said, this study aims to investigate the presence of climate change issues in Greek Special Education high school (grades 10-12) science textbooks based on the recently updated version of the Climate Literacy Guide. Content analysis concerning textual and pictorial materials of three book series, namely Biology, Chemistry, and Physics, was used for this purpose. Results reveal that the textbooks under study contain rather inadequate and fragmented information concerning the eight essential principles and the seventy-six fundamental concepts of the Guide. The conclusions from the present study could help curriculum designers, textbook authors, and climate scientists collaborate toward the inclusion of Climate Change Education topics into national curricula.

Keywords: Climate Literacy, Special Education, High school science textbooks

Introduction

In recent decades, humanity has faced an onslaught of extreme weather events that threaten its survival, the economies of states and households, and the lives and safety of citizens. These unprecedented phenomena occur violently, have duration and intensity, and modern societies seem incapable of preventing them despite their enormous technological development. The latest report of the Intergovernmental Panel on Climate Change (IPCC, 2023) reveals that human activities, mainly through greenhouse gas emissions, have unequivocally caused global warming. This has led to widespread adverse impacts and related losses and damages to nature and people, although adaptation and mitigation strategies have progressed across all sectors and regions. The United Nations Framework Convention on Climate Change is the first official tool of international law that recognises the problem of climate change and its interconnection with anthropogenic greenhouse gas emissions. However, almost four decades after the signing of this and other respective agreements, global greenhouse gas emissions are still rising rapidly.

In this respect, the need for global climate change education was already reflected in the early ’90s (Henderson & Holman, 1993). However, it was realised only at the end of the first decade of the new century with references to socio-constructivist approaches, conceptual change, and experiential learning (Pruneau et al., 2003), and later with the Agenda 2030 Framework, while key terms such as adaptation and mitigation also begun to associate with climate change education (e.g., Pruneau et al., 2010). According to Anderson (2010), climate change education seeks to teach an understanding of the causes and consequences of climate change, its impact, and appropriate responses; it further fosters attitudes and motivations to make informed decisions and take responsible action.

This is the time when discussions about the necessity of creating a climate-literate citizenry led to a framework based on the experience of a similar effort (the Ocean Literacy campaign) that preceded a few years earlier. This framework, called Climate Literacy, originally consisted of 7 basic principles, supported by a set of 39 fundamental concepts (USGCRP, 2009) and was thoroughly updated based on current research in September 2024, now portraying 8 principles (Table 1) and 76 concepts (USGCRP, 2024). Climate Literacy is defined as the *understanding of how the climate system works, how human actions influence climate, and how climate influences people and other parts of the Earth system* (USGCRP, 2024). UNESCO (2009) describes this framework as an attempt to help people understand the effects of global warming while encouraging the change in attitudes and behaviour needed to take action on climate change.

Table 1. The Essential Principles of the Climate Literacy Guide.

Principle #1	**[How we know]**	Scientists understand the climate system through interdisciplinary observations and modelling
Principle #2	**[Climate change]**	Greenhouse gases shape Earth’s climate
Principle #3	**[Causes]**	Burning fossil fuels and other human activities are causing the planet to warm
Principle #4	**[Impacts]**	Rapid warming and other large-scale climate changes threaten human and ecological systems
Principle #5	**[Equity]**	Climate justice is possible if climate actions are equitable
Principle #6	**[Adaptation]**	Humans can adapt social, built, and natural environments to better withstand the impacts of climate change
Principle #7	**[Mitigation]**	Reducing emissions of greenhouse gases from human activities to net zero by 2050 can help limit global warming and climate change impacts
Principle #8	**[Hope & Urgency]**	A liveable and sustainable future for all is possible with rapid, just, and transformational climate action

Although several years have already passed since climate issues entered the international debate and, therefore, became a topic of interest within the boundaries of formal general education, a corresponding interest focusing on Special Education does not seem to have been a similar concern for the experts of the field. UNESCO defines Special Education as the one designed to *facilitate learning by individuals who, for a wide variety of reasons, require additional support and adaptive pedagogical methods to participate and meet learning objectives in an education programme* (UIS, 2012). Even though significant research has been published concerning Special Education and science and/or environmental education, to our knowledge no respective research has been conducted regarding Special Education and climate issues in particular. A key element of education is the design of modern curricula and the selection of appropriate, up-to-date textbooks to overcome climate change challenges. This becomes even more imperative when addressing scientific issues within the framework of Special Education. Tracana et al. (2008) have reported that textbook analysis is an important parameter in implementing national educational objectives at the school level. Therefore, this study attempts to investigate the presence of the Climate Literacy basic principles and fundamental concepts according to the corresponding Guide in Greek Special Education high school science textbooks.

Materials and Methods

The corpus under study comprised three series of reading books, namely *Physics*, *Chemistry*, and *Biology* (Figure 1), all corresponding to compulsory courses in Greek upper high school grades 10-12 (15-18 years old), used in Special Education. Content analysis was selected based on both textual and pictorial material from the corresponding school manuals to evaluate the presence of climate science issues according to the Climate Literacy Guide. With regard to the presence of climate sciences issues, both the manifest and latent content were examined, referring to both visible and underlying components of each passage of the text (e.g., Downe-Wamboldt, 1992). The unit of analysis and the construction of categories were also considered. Concerning the former, the "theme" was chosen as, according to Krippendorff (2004), thematic excerpts are rich in information and preferable to other kinds of distinctions; in terms of the latter, a deductive coding scheme (Stemler, 2001) was followed, as the 8 essential principles and 76 fundamental concepts of the recently updated Guide (USGCRP, 2024) constituted the categorical context for the respective analyses. In addition to the above, the validity and reliability of the procedure were also ensured.

Figure 1. The Special Education upper high school science textbooks under study.

Results

The present study revealed that although all Climate Literacy principles (CLps) are presented in Special Education upper high school science textbooks, twenty-six of the total seventy-six supporting concepts are lacking (Figure 2), while the existing ones are not entirely addressed, according to the corresponding Guide. Climate Literacy principle 2 referring to the greenhouse gases that shape Earth's climate, CLp 3 regarding the causes, CLp4 providing valuable information about the impact, and CLp7 concerning mitigation strategies are adequately covered in terms of the number of concepts for which information is displayed, and the number of references to these principles reflected in all textbooks (Figure 2). On the contrary, CLp1 referring to the fact that scientists understand the climate system through interdisciplinary observations and modeling, and CLp6 regarding adaptation strategies, seem to be the least representative both in terms of the number of concepts covered and number of references that appear in all science textbooks (Figure 2). In Figure 3 we can easily detect that almost the same Climate Literacy fundamental concepts are recorded in all three studied textbook series, although we observe a remarkable quantitative difference between the Chemistry textbooks on one hand and Physics and Biology textbooks on the other. More specifically, the textbook with the most relevant information, Chemistry, appears with 8 principles, 48 concepts, and 528 references in total, followed by Biology (8 principles, 30 concepts, and 115 references), and finally Physics (7 principles, 33 concepts, and 55 references) (Figure 4). With regard to the grade level, grade 11 appears to be the richest in information with 8 principles, 48 concepts, and 344 references, followed by grade 10 and grade 12 (Figure 4).

Figure 2. Total number of Climate Literacy fundamental concepts in Special Education upper high school science textbooks.

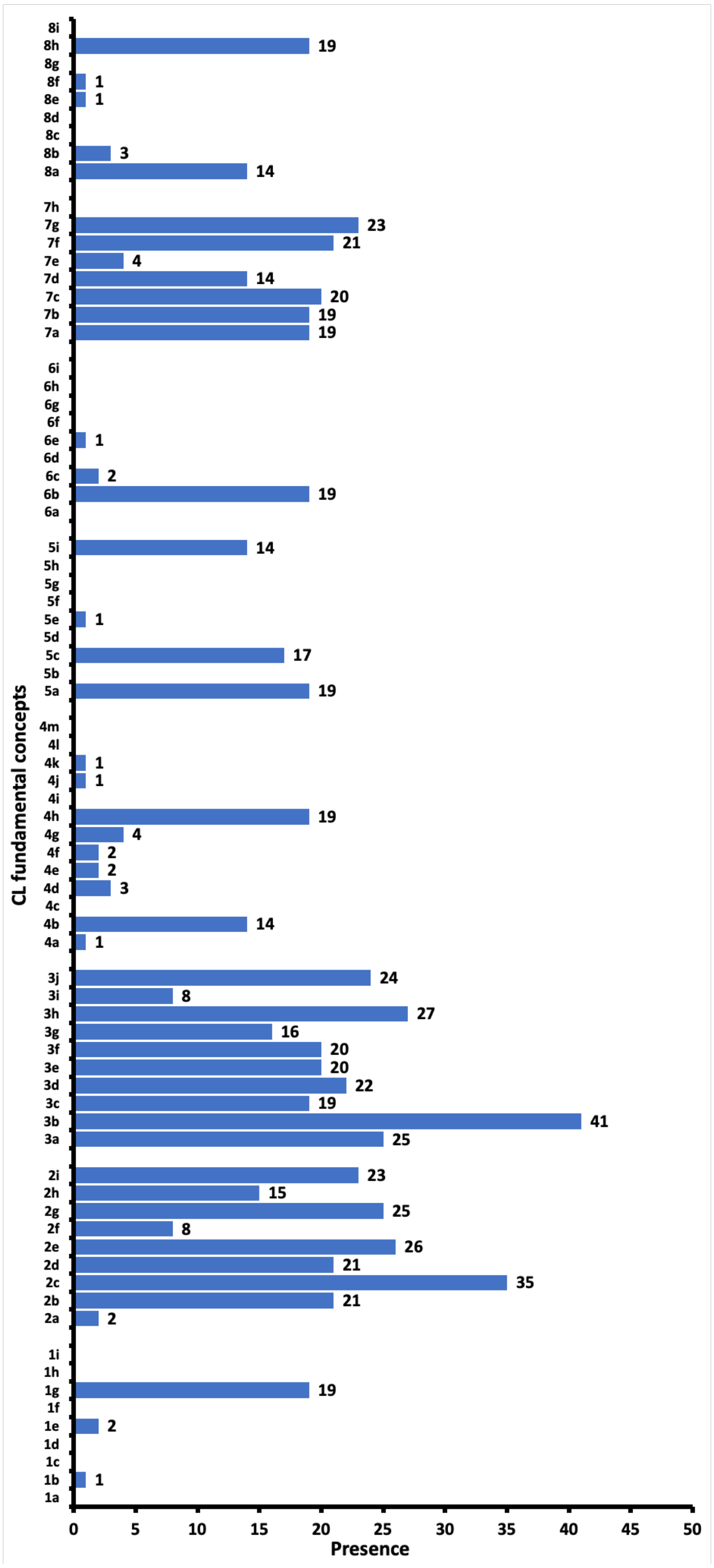


Figure 3. Total number of Climate Literacy fundamental concepts per science textbook.

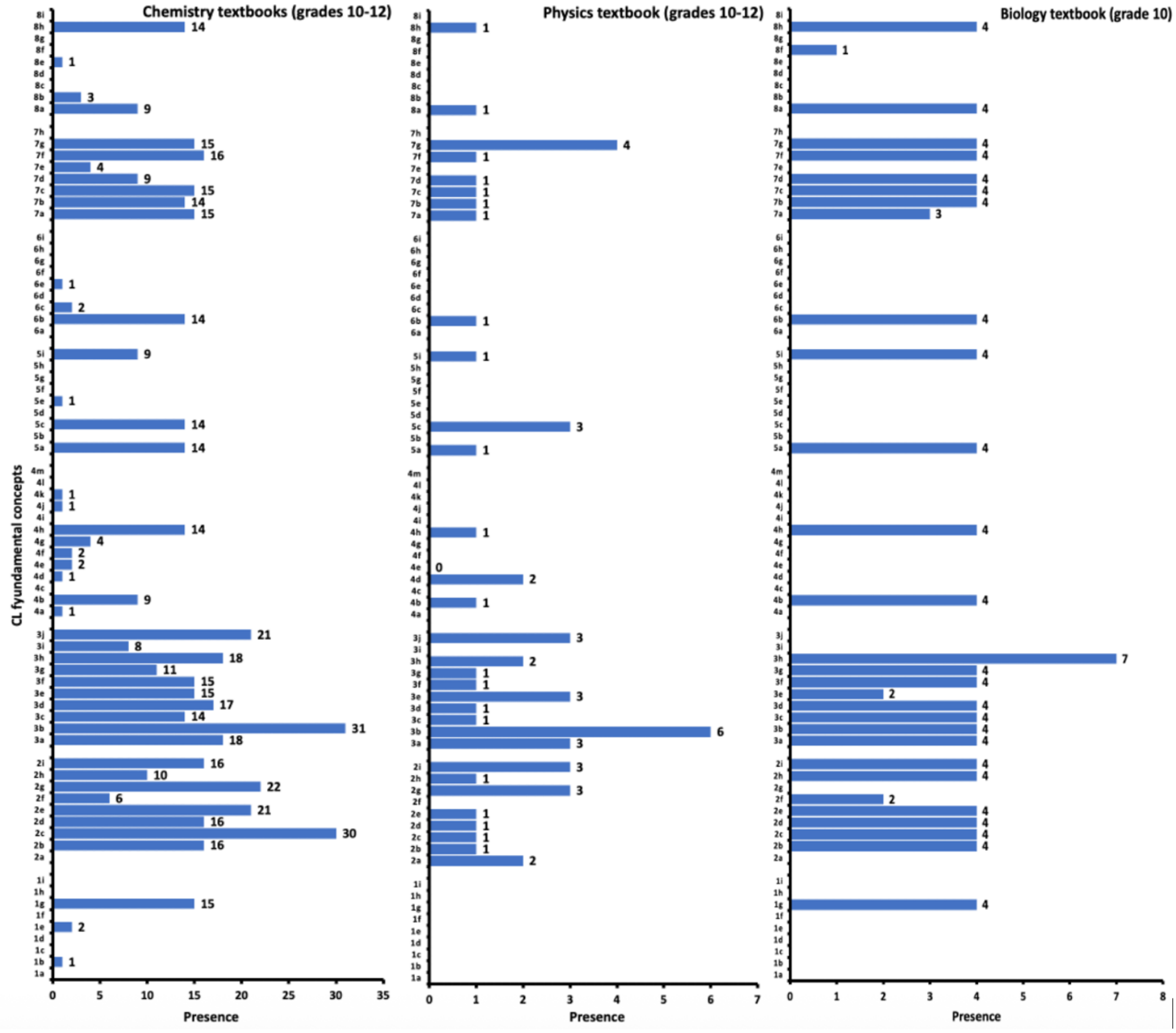
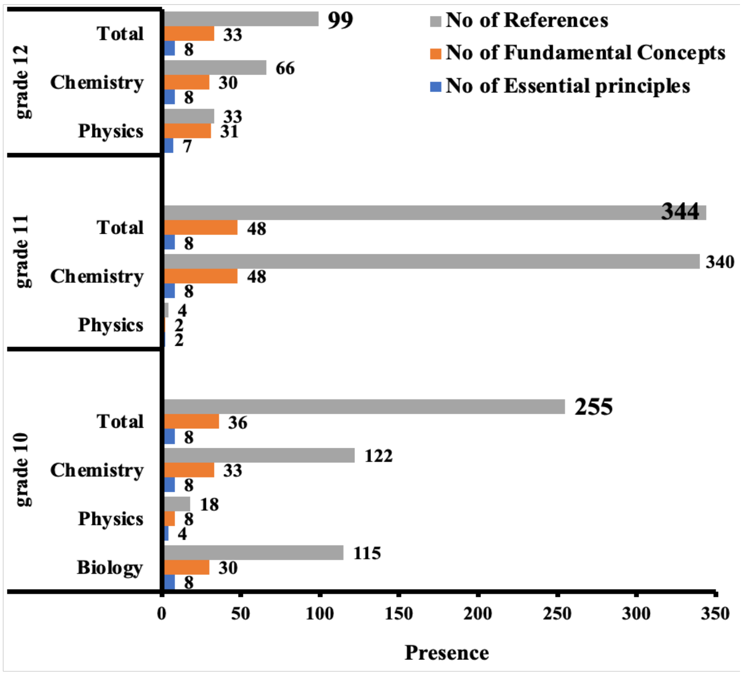


Figure 4. Number of Climate Literacy basic principles, fundamental concepts, and references per grade and science textbook.



Discussion

Content analysis of Greek science textbooks' textual and pictorial material revealed that although all eight essential principles and some aspects of many fundamental concepts of the recently updated Climate Literacy Guide (USGCRP, 2024) are mentioned in the Special Education upper high school (grades 10-12), nevertheless these are only partially covered, making the relevant information rather superficial and fragmentary. Most principles and concepts are found in Chemistry, while grade 11 appears well-stocked in pertinent information. Important issues such as, among others, the distinction between climate and weather, climate variability, exposure of marginalized and low-income populations to climate hazards and associated health problems, climate impact on businesses, governments, and economies, necessary shifts in institutions, behaviours, and values, the demand of huge financial investments in new technologies, infrastructure, and education are missing, making climate change education rather unpromising for upper high school students enrolled in Special Education settings. Furthermore, the existing information seems to be rather inappropriately presented, as the degree of difficulty exceeds the cognitive capabilities of students with special needs.

Although research on climate change education has thrived over the last 15 years, to our knowledge, relevant issues are not currently included in national curricula or school textbooks. As a result, we cannot reliably assess the impact of the Climate Literacy framework on formal education systems worldwide. Moreover, it appears that no scientific interest at all exists in making climate change education more inclusive by incorporating it into Special Education. It seems that either this innovative framework has not been properly communicated, particularly to policymakers, or we have not fully grasped the critical need to introduce this knowledge to modern society. As the USGCRP (2009) elegantly states, only "*a climate literate person understands the essential principles of Earth's climate system, knows how to assess scientifically credible information about climate, communicates about climate and climate change in a meaningful way, and is able to make informed and responsible decisions regarding actions that may affect climate*."

The latest IPCC report (IPCC, 2023) is undeniably clear about the causes of climate change and the anticipated consequences if adaptation and mitigation measures are not implemented immediately. Drawing inspiration from a recent book by Gates (2021), we must achieve something monumental; we need numerous groundbreaking discoveries in science and engineering, we need to reach consensus where it currently does not exist, and we need to design government policies that will accelerate a transition that would not happen otherwise. None of these will be accomplished if we do not make climate change education an integral part of our national education systems, and the Climate Literacy Guide can serve as a solid foundation for student awareness in formal education.

In conclusion, the above mapping could help curriculum designers, textbook writers, classroom teachers, and climate scientists successfully integrate Climate Literacy issues into current educational systems.

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EUROPEAN SCIENCE EDUCATION RESEARCH ASSOCIATION ESERA 2025 Copenhagen

The Science Curriculum as a Vehicle for Climate Change Education: A Cross-Country Project

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Climate Change Education (CCE) is an increasing focus of global curriculum advocacy, as countries come to terms with the future threats posed by the Anthropocene polycrisis and the need for an informed citizenry that can make critically informed and responsible decisions. Given the crucial role of science in monitoring and responding to Anthropogenic Climate Change, the Sciences are of crucial importance to CCE, yet to date education systems have been slow in taking this up. The recent OECD PISA 2025 Science Framework places fresh emphasis on students' critical evaluation of evidence to make informed decisions in relation to socio-ecological challenges, advocating a focus on student decision making, action, and agency. This symposium represents selected explorations in a cross-country project focused on enacting CCE within Science curricula consistent with these ideas. The three explorations map out the potential to productively include CCE in these subjects, through 1) a cross-country survey of teachers' knowledge, practice, and confidence of CCE, 2) a cross-country analysis of the structure and amount of ACC content in middle years textbooks in the science disciplines, and 3) co-design research with a primary school science specialist exploring how best to infuse CCE into a traditional science curriculum across multiple topics. The set of three explorations identify systemic constraints on the infusion of CCE, but provide confidence that the conditions exist with teachers, students, and education system commitments and resources for expansion of science curricula to contribute to CCE.

Keywords: Climate Change Education, Teacher learning, Curriculum

Introduction

We are living in an epoch of human induced Climate Change (CC) (Lee et al., 2023), the 4th industrial revolution (Schwab, 2016), and the 6th mass extinction (Dirzo et al, 2014) - the Anthropocene (Lewis & Maslin, 2015). There are urgent calls for education to focus on developing students' knowledge and agency with respect to the global socio-ecological challenges of CC These issues have been well represented in the fields of *Environmental Education* (EE) and *Education for Sustainable Development* (ESD) for decades, and as the cross-curriculum priorities in a number of countries. Currently, increasing urgency in the scale and global nature of impacts have encouraged the formulation of CCE that better represents the climate science, societal impetus, and social impacts and that integrates more directly with school disciplinary subjects. CCE is different from either EE or ESD (Monroe et al., 2019; White et al., 2024) in referring to key content and concepts associated with the complex interactions of climate science and the social systems that have generated unprecedented and significant impact on all Earth systems (OECD, 2019).

Calls for the development of a systematic CC Education (Academy of Social Sciences in Australia [ASSA], 2023) have slowly been taken up by most systems (Dawson et al., 2022; Roussel et al., 2020), reprising challenges in incorporating Education for Sustainability (EfS) as a core commitment (ASSA, 2023). CCE, while related to EfS, brings new elements of science into focus, as well as enhancing temporal and global spatial dimensions concerned with interconnected Earth systems. In contemporary scientific research and development, CC related initiatives are increasingly important, identifying interruptions to Earth systems; investigating the interconnections between global systems to build increasingly complex climate models; monitoring temperature and the effects of global temperature rise; designing climate mitigation approaches; developing technologies for the transition to low carbon energy systems; and understanding climate related events (Lee et al., 2023).

The OECD PISA 2025 Science Framework (OECD, 2023) is a transformative document in expanding the remit of science education to prepare students not only to explain and engage in the traditional knowledge building practices of science, but to develop the competency to *research, evaluate and use scientific information for decision making and action*. The strong environmental science agenda has been introduced into the Science Framework, informed by the companion document 'Agency in the Anthropocene' (White et al., 2023; 2024), to further interpret and expand the competencies such that 15-year-olds should be able to:

1. Explain the impact of human interactions with Earth's systems.

2. Make informed decisions to act based on evaluation of diverse sources of evidence and application of creative and systems thinking to regenerate and sustain the environment.

3. Demonstrate hope and respect for diverse perspectives in seeking solutions to socio-ecological crises.

Thus, what has been mainstream in EE and EfS has now been recognised within the science framework as an important aspect of a mainstream science education, going beyond explanation, interpretation and engagement in core science practices to consider science knowledge and practice related to the socio-ecological challenges of the Anthropocene (White et al, 2024).

This paper describes the developing research agenda of a cross-country research project 'Enacting Climate Change Education (ECCE) through representing Scientists' Practice' (ECCE, 2025) that responds to the agenda enabled by the OECD PISA Science Framework 2025. ECCE involved science education researchers from Australia, Finland and Taiwan co-designing teaching and learning sequences that infuse CCE with teachers and with scientists' input into the science curriculum. An emphasis on student knowledge, dispositions and decision making and action leading to student agency as envisaged in 'Agency in the Anthropocene' was the priority. The explorations described are structured to explore the possibilities and potential pathways for the much needed substantial infusion of ACC into the science curriculum (Dawson et al., 2022). The set of three explorations represent preliminary scoping work for the project, which investigate: 1) teacher engagement with ACC; 2) textbook representation of ACC across the three countries, and 3) an Australian example of a Design Based Research approach with teachers to explore the possibility of infusion of CCE into a full year's science curriculum.

Exploration 1: Teacher Knowledge, Practice, And Confidence In CCE: A Cross-Country Comparative Analysis

In any major curriculum reform agenda, teachers are key. This is particularly the case with contexts such as climate science where the complexity of interacting Earth systems are impacted by social priorities and practices resulting in socio-ecological challenges. Not only is the science contemporary and situated, but essential to addressing socio-ecological related crises are the complicated relationships between human behaviour, technologies and environmental degradation. Teachers of science thus need to extend their science knowledge by drawing on contemporary research, but also complex socio-ecological dynamics underpinning. Thus, teachers, and teacher professional learning is critical to enacting a CCE curriculum in science (Tytler & Freebody, 2023).

Methodology

A Qualtrics online survey was administered to secondary school teachers of Science and Humanities, invited through online invitations through teacher organisation in each country. The questions were translated into the three languages and cross checked by the team. Participant numbers were 67 in Australia, 68 in Finland, and 86 in Taiwan. Survey participants were mostly secondary teachers, mostly teaching science.

The survey consisted of 23 questions of mixed type, focusing on the following aspects of teachers' experience with CCE: knowledge of CC phenomena; perceptions and confidence in relation to CCE; the nature of their CCE practice in terms of the degree of embeddedness, nature of focus; resources and engagement with climate scientists; degree of support; reasons for teaching/not teaching CCE; the nature of outcomes that should drive CCE; the urgency of including CCE in the curriculum.

Analysis

The reliability of the questions was tested using Cronbach's alpha. The results revealed that most of the questions showed high reliabilities (alpha > .90), excluding two questions. Questions with a single sub-item or "yes or no" questions were excluded from calculating Cronbach's alpha. Analysis of the data mainly used descriptive statistics, but cross-country comparisons involved an ANOVA analysis to identify significant differences in response patterns. Extended responses were thematically analysed and verified by team discussion.

Results

Attention to CCE: The responses to the question 'Is CCE embedded in your teaching' yielded a distinct hierarchy in 'yes' responses: Taiwan 86%; Finland 98% and Australia 67%. This reflected curriculum histories in the three countries, with Taiwan including CCE since 2018 and Australia only since 2022 in a limited way. This hierarchy was reflected in many of the question responses.

Knowledge of CCE: Despite the difference in practice, teachers across the three countries expressed strong knowledge of 'the scientific explanations for CC', 'the role of human impacts of CC, and 'the impacts of CC on the environment and on humans', with mean scores in each case above 4.2 on a 5-point scale. Knowledge of 'approaches to CC mitigation at the personal and societal level' were equally strong for Finnish and Taiwanese teachers but significantly lower for Australia (p=0.004). Knowledge of 'the way individuals and societies must adapt everyday practices' was strong for Taiwan, but significantly lower for Finland and Australia (p=0.0001). The picture of teacher knowledge is thus strong overall, but with significant gaps in responses to CC reflecting curriculum histories.

Confidence in aspects of teaching CC: Teachers across all countries expressed confidence (mostly 4 on the 5-point scale) about a variety of aspects of teaching CC, generally without significant differences, including: 'I welcome learners' questions about C'; 'Although this is a complex topic, I feel prepared to teach it'; 'I know how to effectively address learners' misconceptions related to CC' (slightly lower score); 'I am able to use local and global examples to teach about CC.'

Knowledge of key terms and phenomena: In an exploration of teachers' understanding of terms related to CC (e.g., tipping points, net zero), teachers from the three countries generally expressed confidence in their knowledge of these terms. There were some differences with Australian teachers, for instance, showing significantly lower confidence in understanding ‘Circular economy’ than Finnish and Taiwanese teachers.

Outcomes of teaching CC: We asked what the main outcomes were when including CCE in science or humanities. Teachers’ responses were diverse, but the key focus was empowering students to make appropriate agentic choices and to act accordingly. Teachers emphasised the urgency of teaching about the climate crises but discussed the importance of hope and positive attitudes. The significance of developing scientific literacy in students was highlighted. One teacher focussed her students proactively: “Agency, voice, the feeling that they can do something about it and making students active contributors in community science.”

Resources: Teachers’ responses indicated the use of a range of formal and informal resources that include textbooks, online materials, news articles, videos (specifically YouTube), social media and documentaries. Some teachers gave specific examples of websites and resources, others stated broad categories. The Australian teachers were significantly less confident in finding reliable resources for teaching about CC” ($F = 5.9635$, $p = 0.0030$).

Discussion

The survey uncovered patterns in both strength of response across countries, and difference between countries on particular aspects of CCE. Overall, the results are very encouraging in terms of supporting the agenda of widening the scope of the science curriculum in line with the PISA 2025 Science Framework (OECD, 2023) and its companion Agency in the Anthropocene document (White et al., 2023). Teachers generally expressed confidence, not only in their own knowledge in teaching the various dimensions of CC Science, but in engaging with students’ perceptions and misconceptions about CC. In terms of outcomes of CCE, they focused on empowering students and on the development of student agency in making responsible decisions concerning climate related challenges.

The findings provide confidence that teachers are generally knowledgeable about and committed to a CCE agenda that focusses on student understandings, attitudes and actions. Teachers’ preparedness to probe and negotiate with student perspectives and open discussions that attend to student voice is encouraging for establishing a curriculum agenda in science in line with advocacy of activities and content found in the CCE literature (Monroe et al., 2019; White et al., 2023; Academy of Social Sciences in Australia, 2023).

We interpret the difference between patterns of responses between the three countries through a lens of curriculum politics and national political landscapes. In general, the confidence of teachers, and particularly their access to resources, was strongest in Taiwan and weakest for Australian teachers. In Taiwan, Anthropogenic CC has been included in the core Science and Geography curricula since 2018, and textbooks are officially endorsed only if they reflect this (Taiwan Ministry of Education, 2018). In contrast, Australia only included CC in its curriculum in 2022, with inaction before that determined by a decade of CC Denial politics influenced by fossil fuel interests (Crowley, 2021). Nevertheless, Australian teachers are only recently entering this curriculum space, and their confidence and commitments are encouraging. Finland’s in-between position is related to considerable support by the Finnish government promoting ecologically sustainable practices and strengthening learners' climate knowledge and skills (Hilldén et al., 2022).

Exploration 2: Representations Of Anthropogenic CC In Science Textbooks: A Cross-Country Comparative Analysis

In recognition of the importance that resources play in supporting Science teachers to embrace new topics, particularly those representing contemporary science and socio-ecological challenges associated with ACC, we analysed Science and Geography textbooks across the three countries; Australia, Finland and Taiwan. The analysis was framed to ascertain the proportion of the total curriculum in these subjects devoted to CCE, interpreted through the space devoted to ACC topics in each subject as a percentage of total textbook page area.

The research questions for this exploration are: 1) What is the percentage of textbook space devoted to anthropogenic CC in the core Science and Geography subjects across the secondary schooling years, and across subjects, in the three countries? 2) What different themes are represented concerning ACC, and what are their patterns of representation in the different subjects? 3) What can we learn, from this cross-country comparison, about the different ways ACC can be addressed through different subjects and topics? An account of the methodology and findings can be found in Tytler et al. (2025).

Methods

We used the Comparative Case Study (CCS) approach by Bartlett and Vavrus (2016), designed to examine varying contexts and scales. In comparing CCE content in lower secondary school textbooks from three countries, it allowed us to explore how each country addresses CC in their textbooks, considering both similarities and distinct features. We situated the analysis within the particular curricular contexts of each country, and also the wider policy landscape, to generate multidimensional insights into national distinctiveness and shared patterns in CCE across the three countries.

We developed a Framework consisting of a set of code categories and codes that was refined over a series of meetings and a substantive coding exercise by the Taiwanese team. A coding scheme was developed and refined through further comparative discussion. The flowchart of coding steps is shown in Tytler et al. (2025). The relevant inter-rater reliability exceeded 0.75 in each case.

The unit of analysis was a sentence or coherent section of the text, including figures and tables, related to ACC. For each such unit, the percentage of page area relating to particular codes was measured to the nearest 10%, and a running total collected to calculate the percentage of total text area devoted to ACC, and of that, the % area dedicated to each code.

The major coding categories, each of which consisted of multiple codes, were:

- Science and technology ideas (SI)
- Nature of science (NOS)
- Human-environment interactions relevant to CC (H/E)
- CC impacts on humans (CCI)
- Response to CC and environmental threats (SR)
- Principles around sustainable human environments and CC (SHE)
- Suggested activities (Act)

Within each of these categories were a set of distinct codes. The analysis identified the percentage of curriculum space for each of the Sciences, and Geography, dedicated to ACC, and within that the breakdown of coding categories and codes. The results represent a proxy measure of the extent of CCE embedded in each country’s Science curriculum.

Information about the curriculum context for each country, including the relationship of textbook design to the formal curriculum, the degree of autonomy allowed for writers and teachers, and the broader CCE policy context, allowed interpretation of findings in terms of curriculum policy.

Findings

The percentage area of text related to anthropogenic CC across the Science and Geography curricula varied between the countries: 2.7% in Taiwan, 1.5% in Finland, and 0.7% in Australia. We identified the following contextual factors affecting these numbers: The explicit inclusion of ACC topics in the Taiwanese curriculum since 2018; the close association of textbooks with the formal curriculum in Taiwan supported by ratification processes; the autonomy of textbook writers, schools and teachers in Finland and Australia with respect to interpreting the curriculum; the existence of significant policy initiatives in Finland supported by resources for CCE inclusion in the curriculum compared to lack of tangible support for a 'Sustainability' cross-curriculum priority in Australia; the existence in Australia over the crucial 10 years prior to 2019 of significant CC denial politics spilling into curriculum 'culture wars'.

In terms of details of CCE representation, analysis showed significant differences in patterns by year level, indicating no agreed progression model for CCE.

Representation in different subjects: There are similarities but also significant differences in representation of CCE across the Science disciplines. The bulk of ACC content is covered by Earth Science and Geography. In Finland, Earth Science is part of the Geography curriculum. There is substantial representation of CCE in each Biology, Chemistry and Physics in at least one country, but considerable variation across the countries. Percentage distribution of anthropogenic CC content by subject discipline can be found as Figure 5 in Tytler et al. (2025). Thus, a case can be made that ACC content can be productively included in each of the disciplines, but this has not been uniformly taken up.

Patterns of code categories across the three countries: The bulk of textbook CCE presence in each country is the SI (Science and Technology Ideas) category representing 32-47% of ACC space. The Nature of Science (NOS) and Principles around Sustainable Human Development (SHE) codes are disappointingly small, particularly given the emphasis on NOS in contemporary science literacy advocacy. Variations from which we can learn include country differences in representation of CCI, SR and HE. Percentage representation of each of the major code categories is depicted as Figure 6 in Tytler et al. (2025).

The analysis reveals patterns in the representation of CCE in Science curricula which are significant for understanding curriculum enactments in this fast-changing field.

The positioning of ACC in the curriculum: The extent of CCE representation is related to the extent of explicit inclusion of ACC topics in the formal Science curriculum, with cross-curricular, interdisciplinary approaches leading to lower levels of representation. However, strong policy initiatives and resourcing are impacting positively in Finland, indicating a degree of political will that is missing in Australia that has compromised curriculum action.

The role of Science disciplinary subjects: Most CCE work is undertaken by Earth Science and Geography, between these accounting for over 60% of ACC content in each country. There was, however, smaller but significant ACC content in each of the Science disciplines that can point a way to greater representation of ACC in Science as advocated by the PISA 2025 Framework.

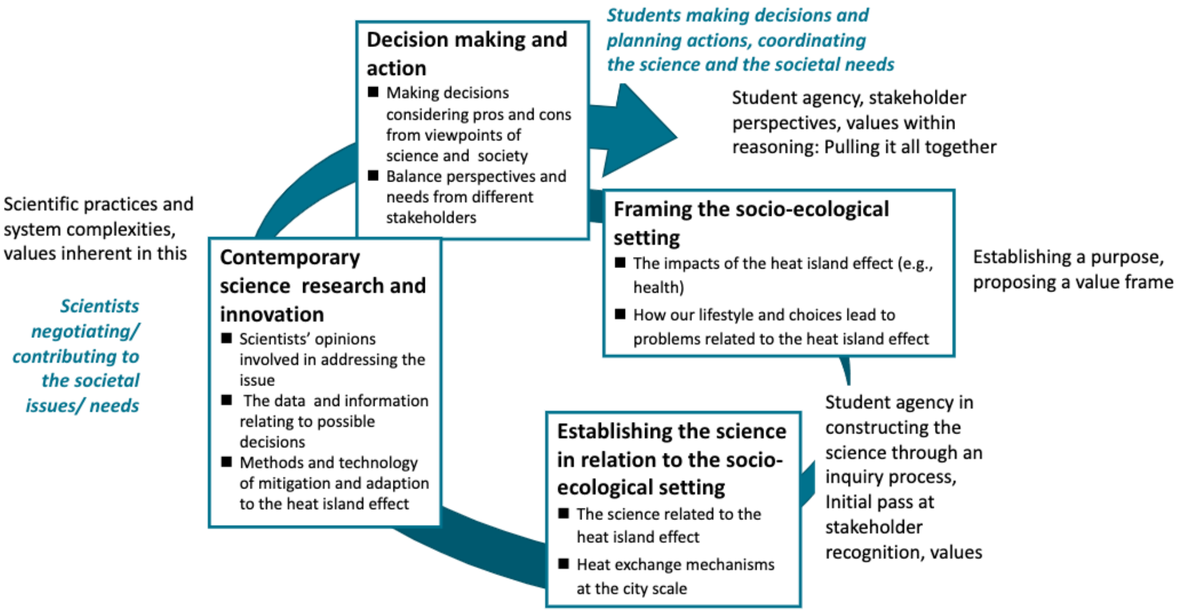
Widening the science curriculum to include socio-ecological challenges: Current research and curriculum advocacy in CCE focuses not only on knowledge and attitudes but on decision making and responsible action (OECD, 2023; Monroe et al., 2019). We argue that if the Science disciplines are to be an important part of CCE, they need to include not only knowledge of systems and effects, but also human-environment interactions around socio-ecological challenges. Patterns of codes show each of these are included in at least some of the texts, giving confidence that Science writers accept this challenge. These cross-country differences present an opportunity to further explore what effective representation of CCE themes might include, as a contribution to advancing our understanding of the dimensions of a quality CCE-rich disciplinary curriculum (Tytler et al., 2025).

Project 3: Developing A Co-Design Model For Infusing CCE Into The Science Curriculum

The central intent of the ECCE project is to work with teachers to develop approaches to infusing CCE into the science curriculum to foster student agency.

Drawing on the experience of the researchers from the three partner countries (Australia, Finland and Taiwan), we developed a learning sequence design model (Figure 1) that leads from a socio-ecological challenge through establishing the required science knowledge, representation of current research, and finally to student consideration of decision making and action in relation to the challenge.

Figure 1: Learning sequence design model with illustrative examples referring to a simulation module on the heat island socio-ecological challenge in Taipei.



While the nature of co-design processes across the countries varies, each of the learning sequences is evaluated against student outcomes in terms of: knowledge (science of CC and human causes, processes for dealing with ACC and impacts); values (eco-justice, hope and resilience); decision-making and action (design approaches, commitment to acting, self-efficacy, engage with civic processes). In drafting sequences, strategies designed to support student agency are prioritised, which involves privileging student idea generation, decision making and action.

This exploration focuses on a particular co-design partnership with a specialist Year 5-6 science teacher in Australia, involving the entire year's science curriculum to infuse ACC related content while attending to the core science curriculum requirements. The research questions we addressed were: 1) What are the affordances and challenges of infusing CCE into the science curriculum? 2) What is the experience of a primary teacher of science, of co-designing CCE- focused curriculum sequences? 3) What student outcomes can be discerned from a year-long CCE infused science curriculum?

Methodology

In the project we utilise Design Based Research (Plomp & Nieveen, 2013) with a strong co-design approach, to generate draft classroom sequences that are negotiated with the teacher, and then iteratively refined both during the sequence and across sequences. Design research reflects a pragmatist epistemology by which theory development is grounded in interrogation of practice (Cobb et al., 2003).

To develop the draft Year 5-6 sequences, the research team drew on scientific expertise regarding, for instance, energy transition research, bushfire disaster expertise, and research into bees and environmental threats. For each topic the team consulted with the teacher concerning ACC links.

Evaluation of the sequences during the design cycle drew on: interviews with the teacher and students following each sequence; pre-and post-sequence written assessments; field notes and video capture of classroom interactions; capture of student work samples; and notes taken during planning and review sessions within the team and with the teacher.

Results

We discuss the results in the order of the research questions: the experience of infusing CCE into science curricular topics; the experience of the teacher in emphasising ACC; and student outcomes from interview and survey data.

Infusing CCE into the science curriculum: For the different science topics represented in the Victorian (Australia) curriculum the school follows, the possibility of infusing CCE varied considerably. However, it proved possible to use ACC as a significant context for teaching science content within each of the eight sequences we worked with across the two-year levels. Table 1 provides examples of some of the inclusions of CCE into these science topics, together with activities designed to support student decision making and agency.

Table 1: Examples of CCE infusion into traditional science topics

Science topic	CCE content based in science research	Activities focused on student agency
Energy transformation	The nature of transformations in renewable energy sources and electrification in the energy transition. Hydrogen energy research, electrolysis and social licence.	Development of scenario around fuel cell conversion of a local bus line. Future energy scenario building.
Astronomy	Earth as a Cinderella planet and the greenhouse effect. Investigation of satellite climate monitoring data.	Students investigating patterns in online satellite data.
Biodiversity	Sequence on bees, informed by bee research expertise, and focusing on hive collapse threats and biodiversity loss.	Role play focused on socially acute question of managing varroa mite spread.
Light and vision	Electromagnetic spectrum and infrared. Use of infrared cameras to identify heat loss points in school buildings.	Development of design proposals to the school to improve energy efficiency.

The experience of the teacher in co-designing sequences: The teacher, Maja, is a science specialist leading three classes each of Years 5 and 6 for science, for a one-hour lesson each week.

The repeat classes allowed us to informally discuss a lesson prior to the repeat. Our negotiations with Maja often concerned clarifying the science or providing background to the relevant socio-ecological issues, while she provided advice on how to frame activities, and on structure and timing. Maja has a strong sense of how to engage students in discussion and was increasingly confident with and dedicated to both emphasising students having a voice on the science and socio-ecological issue, and in interacting with each other in developing explanations and arguing for positions. Her advice was particularly strong on matters of students discussing decisions and actions that could influence school policy.

Student outcomes: Student focus group interviews were held at the end of each sequence and a review interview at the end of the year. Students generally were very positive about the science they were doing, engaged with science ideas, and expressed a commitment to the need to act on CC and sustainability more generally. Assessment results at the end of each sequence generally showed strong growth in knowledge of science concepts. In an end of year survey, over 80% expressed confidence to explain key features of ACC, and a clear distinction between climate and weather.

One question on the survey distinguished between interest and importance of three types of activity: design activities denoting action; doing practical activities; learning about science phenomena; and learning about implications of CC for the future. Each was given a score from 0 (not at all interesting/important) to 3 (very interesting/important).

The results show a uniform level of ‘interesting’ for these activities, but the ‘importance’ level is strikingly higher for learning about implications of CC for the future (2.7) and design activities denoting action (2.5) compared to learning content or doing practical activities (1.5-2.2). If this finding is repeated more generally, it has significant implications for the expansion of the science curriculum to include student decision making and action, and consideration of socio-ecological challenges as advocated in the OECD PISA Science Framework 2025 (OECD, 2023).

Discussion And Conclusion

These three explorations were part of the initial phase of the ECCE cross country project. Research is ongoing concerning the development of learning sequences and approaches to CCE that foreground critical understandings, systems thinking and student agency related to climate impacted futures and regenerative learning. The incorporation of contemporary science research in a co-design process is central to the project.

The explorations described in this paper demonstrate the viability of introducing education system responses to CC challenges. The first exploration demonstrates teacher confidence in climate science and in developing pedagogies related to not only science knowledge but also focused on affective and perceptual outcomes and student agency. The second exploration identifies substantive differences in the amount of CCE content in the three countries which are related to curriculum policy and contextual system influences but demonstrates that this rich array of CCE ideas are represented across the Science disciplines and Geography in at least some countries, providing confidence that CCE can be productively and richly represented in the science curriculum. The research identified particular roles for the different disciplines in representing CCE, and the analysis promises to yield useful data to inform the design of a systematic approach to CCE in the sciences.

The third exploration identifies a variety of ways CCE can be included in diverse science topics to provide substantive engagement with learning and agency. Teacher commitments and positive student outcomes demonstrate that the science curriculum can be enriched through infusion of CCE in ways that benefit both teachers and students. The exploration also demonstrates the power of a co-design approach to CCE that involves contemporary scientists and their research, teachers, and in some cases students. We continue to refine our understandings and approaches, drawing on insights based in our cross-national collaboration to sharpen understandings of the contextual factors that frame possibilities of innovation in this CCE.

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