
FOSTERING CLIMATE LITERACY IN TEACHING

TEACHERS' PROFESSIONAL KNOWLEDGE, CUR-
RICULAR MATERIALS AND TEACHING CONTENT
IN THE CONTEXT OF CLIMATE LITERACY

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Summary

Climate change is one of the most severe challenges of the Anthropocene. Climate education is a part of the way to meet this challenge. In education on the one hand the topic can be integrated into the overarching concept of education for sustainable development (ESD). On the other hand climate education can be integrated into science education and thus into scientific literacy (SL). A climate specific notion of SL is the concept of climate literacy that embraces knowledge about the climate system and climate change, skills to achieve and evaluate climate change specific information and communication and attitudes towards counteracting climate change. Recent reviews suggest that climate education should shift responsibility from the individual towards society, enhance political literacy and enable learners to become participatory citizens. It is unclear if climate education does currently meet the requirements outlined above.

This dissertation aims to investigate different strands of preconditions for successful climate education. At first, an adequate compilation of climate education with respect to teaching content and teachers' professional knowledge from an experts' point of view should be developed. Secondly, the current state of climate education implementation should be investigated by the means of institutional requirements and by teaching practice represented by textbooks as daily classroom material. To this end three studies were conducted: a Delphi-study (a multilevel interrogation of experts) (study 1), a curricula analysis (study 2) and a textbooks analysis (study 3).

In study 1 climate researchers, education researchers, teacher educators and teachers were interrogated in three subsequent rounds. They commonly contributed to collating teachers' necessary professional knowledge covering content knowledge (CK) and pedagogical content knowledge (PCK) in the context of climate literacy. The study results include 13 elaborated themes describing teachers' professional knowledge and at the same time provide a comprehensive outline for content coverage of climate education. In study 2 the curricula of three federal states of Germany were analysed by qualitative content analysis. For the analysis a two-dimensional analysis key was developed in order to delineate by which content and in which way climate education is implemented in the curricula. The study results indicate that climate education is most often related to the broader concept of sustainability, but also to human ways of living and least often as an explicit topic of its own right. In most cases the topic appears as obligatory teaching content, but also as overarching concepts and least often as optional suggestions for teaching. In study 3 textbooks from Germany and the United Kingdom (UK) for science subjects, geography and social studies were analysed by qualitative content analysis with a two-level category system. The content coverage by coding frequencies was similar in both countries with few exceptions. The climate system, anthropogenic climate change causes and mitigation strategies were covered most frequently, while societal discussion was mostly limited to climate conferences and adaptation strategies do hardly occur.

The dissertation indicates that the investigated strands of preconditions for climate education are rather congruent with respect to the science aspects of climate education including the climate system, causes of climate change and impacts to the natural environment. Yet, they diverge regarding the more social aspects of adaptation strategies, societal discussion and the level of indi-

vidual or societal action. While experts suggest a broad coverage of e.g. climate science, argumentation, action levels or impacts on society, the analysed curricular materials fall short on these aspects. Hence, implications for teachers' professional development as well as curricular development can be taken from the dissertation.

Zusammenfassung

Der Klimawandel ist eine der wichtigsten Herausforderungen des Anthropozäns. Klimabildung ist ein Teil des Weges, dieser Herausforderung zu begegnen. In der Bildung kann das Thema einerseits in das übergreifende Konzept der Bildung für nachhaltige Entwicklung (BNE) integriert werden. Andererseits kann die Klimabildung in die Naturwissenschaftsbildung integriert werden und damit in die *Scientific Literacy* (SL – naturwissenschaftliche Grundbildung). Eine Klimabezogener Bereich der SL ist das Konzept der *Climate Literacy*, das Wissen über das Klimasystem und den Klimawandel, Fähigkeiten, Informationen und Kommunikation über den Klimawandel zu erlangen und zu bewerten sowie Einstellungen, dem Klimawandel zu entgegenzuwirken, umfasst. Neuere Reviews legen nahe, dass Klimabildung die Verantwortung vom Individuum hin zur Gesellschaft verschieben, politische Bildung fördern und Lernende befähigen sollte zu mündigen Individuen zu werden. Es ist ungewiss, ob Klimabildung derzeit den oben genannten Anforderungen gerecht wird.

In dieser Dissertation werden verschiedene Bereiche der Voraussetzungen für erfolgreiche Klimabildung untersucht. Zunächst soll eine geeignete Zusammenstellung der Klimabildung in Hinblick auf Unterrichtsinhalte und das Professionswissen von Lehrkräften aus Expertensicht entwickelt werden. Zweitens soll der derzeitige Stand der Umsetzung der Klimabildung anhand der institutionellen Anforderungen und der Unterrichtspraxis, letztere dargestellt durch Schulbücher als gängiges Unterrichtsmaterial, untersucht werden. Zu diesem Zweck wurden drei Studien durchgeführt: eine Delphi-Studie (eine mehrstufige Befragung von Experten) (Studie 1), eine Curricula Analyse (Studie 2) und eine Schulbuchanalyse (Studie 3).

In Studie 1 wurden Klimaforschende, Bildungsforschende, Personen aus der Lehrkräftebildung und Lehrkräfte in drei aufeinander aufbauenden Runden befragt. Sie trugen gemeinsam zur Zusammenstellung des notwendigen Professionswissen von Lehrkräften im Kontext der climate literacy bei, welches *content knowledge* (CK – Fachwissen) und *pedagogical content knowledge* (PCK – fachdidaktisches Wissen) umfasst. Die Ergebnisse der Studie umfassen 13 ausgearbeitete Themen, die das Professionswissen von Lehrkräften beschreiben und bieten ebenso eine umfassende inhaltliche Ausgestaltung der Klimabildung an. In Studie 2 wurden die Curricula dreier deutscher Bundesländer mittels qualitativer Inhaltsanalyse untersucht. Für die Analyse wurde ein zweidimensionaler Analyseschlüssel entwickelt, um herauszufinden, mit welchen Inhalten und auf welche Art und Weise Klimabildung in den Curricula umgesetzt wird. Die Ergebnisse der Studie zeigen, dass Klimabildung am häufigsten im Zusammenhang mit dem übergeordneten Thema der Nachhaltigkeit, aber auch in Form der gesellschaftlichen Lebensweise und selten als explizites, eigenständiges Thema behandelt wird. In den meisten Fällen erscheint das Thema als verpflichtender Unterrichtsinhalt, aber auch als übergreifendes Konzept und am wenigsten häufig als optionale Vorschläge für den Unterricht. In Studie 3 wurden Schulbücher aus Deutschland und dem Vereinigten Königreich für naturwissenschaftliche Fächer, Geographie und Sozialkunde mittels qualitativer Inhaltsanalyse mit einem zweistufigen Kategoriensystem analysiert. Die inhaltliche Abdeckung durch Codierhäufigkeiten war in beiden Ländern bis auf wenige Ausnahmen ähnlich. Das

Klimasystem, anthropogene Klimawandelursachen und Minderungsstrategien wurden am häufigsten behandelt, während die gesellschaftliche Diskussion meist auf Klimakonferenzen beschränkt war und Anpassungsstrategien kaum vorkamen.

Die Dissertation zeigt, dass die untersuchten Bereiche der Voraussetzungen für Klimabildung in Bezug auf die naturwissenschaftlichen Aspekte der Klimabildung, einschließlich des Klimasystems, der Ursachen für den Klimawandel und der Auswirkungen auf die natürliche Umwelt, ziemlich deckungsgleich sind. Es werden jedoch in Hinblick auf die gesellschaftlicheren Aspekte der Anpassungsstrategien, der gesellschaftlichen Diskussion und der Ebenen der individuellen oder gesellschaftlichen Handlungsstrategien Unterschiede sichtbar. Während Experten eine breite Abdeckung z.B. der Klimawissenschaft, der Argumentationsfähigkeit, der Handlungsebenen oder der Auswirkungen auf die Gesellschaft vorschlagen, kommen diese Aspekte in den analysierten Curricula Materialien zu kurz. Aus der Dissertation lassen sich daher Implikationen für die Lehrkräftebildung und die Lehrplanentwicklung ableiten.

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1 Introduction

Our society including students and teachers are confronted with accelerating processes of globalisation, which means that many processes of change have global dimensions. Formal education needs to meet the changes individuals and institutions are facing (Schreiber et al., 2016). Integrative thinking about human-environmental interrelations is obligatory and should be fostered in education, since human action is the driving geofactor for the development processes on the Earth in the Anthropocene (DGfG, 2024). The Anthropocene was once proposed as a potential geological epoch due to increasing concentrations of carbon dioxide in the Earth's atmosphere as a marker of human impact (Crutzen, 2002; Steffen et al., 2007). It has recently been rejected as an era on the geological timescale though, but will still be kept up as a cultural concept (Witze, 2024). The impacts of anthropogenic global change threaten the Earth systems that form the basis for human livelihoods. Hence, education needs to foster knowledge and competencies that take into account the Planetary Boundaries (DGfG, 2024). The concept of the Planetary Boundaries has been established in 2009 due to the severe anthropogenic impacts on the Earth's systems that threaten their stability. The concept defines the Planetary Boundaries as a safe space within which no abrupt environmental change will happen that pose severe risk to humanity (Rockström et al., 2009). In 2023, an update on the framework revealed that six out of nine Planetary Boundaries are transgressed. Climate change, which is in focus of the current dissertation, is one of them (both quantifications transgressed – CO₂-concentration within the zone of increasing risk and radiative forcing within the high risk zone). Biosphere integrity is another one (Richardson et al., 2023).

Education might be one key to relate such scientific findings to societal reaction. As the ministers of education conference (KMK – Kultusminister Konferenz) (2020) states for the significance of science education, science and scientific thinking, methods, findings and applications shape society and in the meantime help to understand the world. Scientific competencies, therefore, are necessary for responsible societal participation by offering orientation and perspectives. Eventually, the subject of biology is concerned with the conservation of life and livelihoods as well as biodiversity. Biological education enhances learning about the living nature, biodiversity and humans as part of biological systems by leveraging multi-perspectivity and systems thinking (KMK, 2020). As a general reaction to the challenges of global change, the Sustainable Development Goals (SDGs) were established in 2015 (United Nations General Assembly, 2015). Education is one inherent key of the SDGs that is simultaneously a target as well as a tool for achieving the 17 goals (UNESCO, 2020). One of the severe global challenges is climate change, being mentioned above as one of the transgressed Planetary Boundaries. Climate action is, therefore, one of the 17 SDGs targeting to counteract the threats of climate change. Scientific evidence for the progress of climate change and its impacts is growing notably (IPCC, 2023) and the 1.5°C target (UNFCCC, 2015) appears to get out of range (IPCC, 2023).

One notion of scientific literacy has been put forward to foster the ability to counteract and cope with climate change by means of education: the concept of climate literacy (Azevedo & Marques, 2017; IPCC, 2023; UNESCO, 2020; USGCRP, 2009). Despite the scientific consensus on the anthropogenic causes of climate change (Cook et al., 2013), there remains a supposed controversy about the causes of climate change that puts constraints on climate educators (Leiserowitz et al., 2015;

INTRODUCTION

Niepold et al., 2007; Uherek & Schüpbach, 2008). Ledley et al. (2017) argue that the public understanding of climate change must be made congruent with the scientific findings in order to facilitate necessary societal transformation. Although awareness for climate change has been rising in society (Eurobarometer, 2021), strategies such as adaptation to climate change impacts seem to be limited by low political commitment (IPCC, 2023). Especially the interaction between science and political and social topics seems to be of relevance to enhance political commitment by science education (Kranz et al., 2022). Climate change as a socioscientific issue in science education requires embracing sociological aspects to climate education, including global inequalities and ambivalent views of science (Morris, 2014). Yet, teachers seem to face problems addressing climate change in classrooms that range from missing preparation to the lack of curricular coverage (Hestness et al., 2014; Sullivan et al., 2014; Wise, 2010). In fact, curricular inclusion would be essential for the implementation of climate change into education (Hannah & Rhubart, 2020) and in a way that allows students to connect single aspects from different subjects and content foci (Niebert, 2007). This dissertation aims to investigate the preconditions of climate education with respect to teachers' professional knowledge, curricular integration and climate literacy.

2 Theoretical background and state of research

The urgency and interdisciplinary nature of climate change lead to a particular emphasis on the conceptualisation of climate education. Climate education can be conceptualized as a part of education for sustainable development (ESD). At the same time it is being embedded in further frameworks such as scientific literacy by the climate-specific notion of climate literacy. In the following chapter (chapter 2.1), climate education is described as an element of ESD and different approaches to an ESD framework are being outlined with reference to climate education. Afterwards (chapter 2.2), the relationship of climate education to scientific literacy is defined and the framework of climate literacy that this dissertation will build on is presented. Furthermore, the current state of climate education as well as its implications will be described. The presumed preconditions for climate education in consideration for the dissertation will be outlined in chapter 2.3: (1) teachers' professional knowledge in the context of climate literacy and (2) the climate education curriculum with respect to (2-a) formal curricula and (2-b) textbooks as curricular materials. This chapter will include several sections about the current state of research considering the respective preconditions in order to open up the research gap that the dissertation will build on.

2.1 Climate change in the context of education for sustainable development

The concept of sustainability and, as a consequence the concept of ESD have developed over the past decades. First of all, the concept of sustainable development was defined within the World Commissions' report on our common future (Brundtland Report) as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland, 1987, p. 41). Its implementation was agreed on by the Agenda 21 in 1992 (United Nations, 1992). The concept of sustainability may contextualise global challenges whereas education may enable learners to cope with them (Barth, 2021). This is why ESD is more than just content aspects but transcends the learning content towards the aim of *agency*, which includes skills to acquire changes in economic, ecological and social action without only reacting to previously existing problems (de Haan, 2002). ESD was pushed forward by the UN Decade of Education for sustainable development (Buckler & Creech, 2014) and by the UNESCO Global action programme on education for sustainable development (UNESCO, 2018). In the meantime, the 17 Sustainable Development Goals (SDGs) were established by the Agenda 2030 for Sustainable Development (United Nations General Assembly, 2015). Following up the Global Action Programme on ESD, the ESD for 2030 framework aims to achieve the 17 SDGs (UNESCO, 2020). The concept once comprised an ecological, an economical and a social dimension and was recently extended by a political dimension and cultural aspects (KMK, 2024). ESD is being considered as a cross-cutting task to all subjects (Buddeberg, 2016). Therefore, overarching principles and strategies delineate ESD in education law and decrees. Furthermore, subject curricula have lately started to implement the concepts (KMK, 2024). Climate change, along with other current environmental challenges (e.g., the biodiversity crisis), adds to the urgency of societal changes that require a combined answer of environmental, social and economic issues that can be leveraged by ESD (UNESCO, 2020). The UNESCO (2020) states that ESD contributes to awareness and understanding of the SDGs and at the same time towards action which is of particular importance for necessary transformation.

Then again, ESD plays a double role with respect to the SDG framework because on the one hand, it should contribute to achieving the SDGs as a global community and on the other hand, it is its own component of the SDGs in the form of SDG 4 (*Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all*) and particularly Target 4.7 (*Education for Sustainable Development and Global Citizenship*) (UNESCO, 2020).

Elaborating on the broad frameworks of ESD related to the evolving concept and implementation of sustainable development, different scholars worked on bringing ESD into being, developing targets and principles for teaching practice. Vare & Scott (2007) conceptualize two sides of ESD: ESD 1 (“Learning for sustainable development” (Vare & Scott, 2007, p. 193)) is being depicted as transferring expert-knowledge to the learner, who then becomes guided towards what they should do. ESD 2 (“Learning as sustainable development” (Vare & Scott, 2007, p. 194)) is being depicted as a process of learning to think critically about experts’ statements and to test ideas. Both sides are viewed as complementary but not mutually exclusive to each other. Hence, ESD 2 can give meaning to ESD 1 by training the ability to think of alternatives and different ways of decision, thus to make choices towards an uncertain future. While in ESD 1 sustainability concepts are explicit and learning is implicit, in ESD 2 it is the other way around. Therefore, both concepts are needed in balance, because ESD 1 provides the subject matter to learn and think about in ESD 2 (Vare & Scott, 2007). Later on, a third concept (ESD 3) was introduced that comprises the learning of solving contradictions in order to reach a transformative process (Vare, 2014). Pettig & Ohl (2023) built on those three concepts of ESD, connecting them to different visions of future.

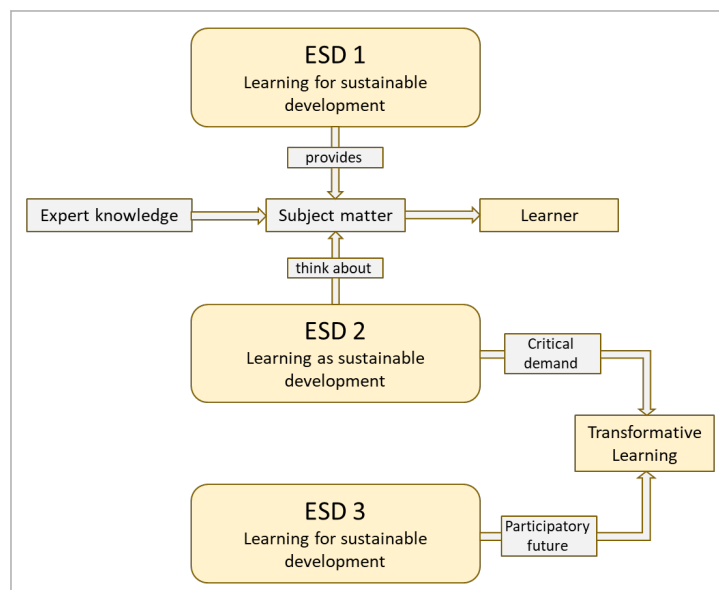


Figure 2-1: The three ESD concepts are not exclusive to each other, but closely related. This figure illustrates their interrelation according to Pettig & Ohl (2023), Vare (2014) and Vare & Scott (2007) (own graphical visualisation)

Thereby, knowledge and skills for technological innovation as well as modified ways of consumption could meet the requirements of a predictable future vision, which would acknowledge ESD 1. However, to meet the requirements of an open, ambiguous future vision, societal negotiation processes and therefore agency for participation would be needed, which acknowledge ESD 2 and

ESD 3. The authors define the concept of transformative learning as counting on ESD 2 for its critical demand and on ESD 3 for building on an open and participatory future (Pettig & Ohl, 2023). Figure 2-1 outlines the three ESD concepts.

It should be noted as well, that the question of implementation is linked to the discussion about the ESD concept outlined above. To this end, an assessment of the implementation of ESD within the German education system found that for school education, the amount of ESD inclusion recently increased, depending on the specific subjects and is often related to climate change (Holst et al., 2024). This highlights the close relation of ESD and climate education that becomes relevant for this dissertation. Moreover, large scale school assessment studies lately started to include scales into their assessment frameworks that are related to environmental issues and sustainability. As such, the Programme for International Student Assessment (PISA) study established the domain of *global competence* including the *work for sustainable development* and in 2025 the domain of *science education* will include *agency in the Anthropocene* in addition to *engagement in reasoned discourse about sustainability*. Furthermore, *environmental awareness, concern and agency* will be considered as well as *environmental impacts and climate change* (TUM, 2025b, 2025a). Similarly, the Trends in International Mathematics and Science Study (TIMSS) constructed *environmental awareness* scales based on already existing science items addressing environmental issues in 2019 (Yin & Foy, 2020) and implemented scales on *students' environmental attitudes* as well as *students' environmentally responsible behaviors* in 2023 (Reynolds & Komakhidze, 2022).

For this dissertation, the concept of ESD is relevant in general because it is considered as an overarching standard for education. Climate change might be subsumed under this task, on the one hand by formal specifications and on the other hand by teachers' choice. Thus, when sustainability or ESD is referred to, climate education is always implicit. Regarding the SDGs by the UN, climate change is one defined component of it, so climate education must be closely related to ESD. The evolving concepts of ESD become relevant because they are as true for general and different ESD topics as they are for the particular case of climate change. Thus, ESD 1, ESD 2, and ESD 3 will embrace teaching content and learning skills as well as participatory and transformative learning for an open future vision imposed by climate change. Global competencies, agency and attitudes become as relevant with respect to climate change as they are for general education for sustainable development.

2.2 Climate change in the context of science education

Climate and climate change are scientifically investigated and described in climate science. Thus, the topic encompasses key assumptions from science and therefore, has a place in science education. Within science education and science education research, the concept of scientific literacy has been put forward. DeBoer (2000) points out, that from a historical view, scientific literacy has been considered under different objectives. He outlines them as science teaching for its *cultural sake*, science teaching to be *prepared for work*, science teaching to *apply to everyday life*, science teaching to *become informed citizens*, science teaching to *understand the process of science*, science teaching to *understand science in the media*, science teaching to *describe the natural history*, science teaching to *develop appreciation for science* and science teaching to *understand the relationship between science and technology*. DeBoer argues that "Scientific literacy defines what the

public should know about science” (ibid 2000, p. 594). Scientific literacy, therefore, should encompass a wide concept of understanding science that is flexible and open, because it is generally changing in society and it is changing and developing throughout an individual’s learning biography (DeBoer, 2000). Accordingly, the concept of scientific literacy became a leading principle in science education, yet, one without a clear or uniform definition, but with varying programs (Roberts, 2010).

To this end, Roberts (2010) proposed two different visions of scientific literacy: Vision I encompasses science for its own sake with a more technical scientific focus, including scientific processes and results and it prepares students to become scientists. Vision II encompasses science as meaningful for human life with a wide and more diverse focus that prepares students to become citizens who can deal with relationships to science in everyday life. Sjöström & Eilks (2018) add on to this by bringing up Vision III, building on several other scholars. Vision III encompasses a political component of science education that includes social and ecological justice aspects, several disciplines’ views and aims to foster global citizenship. They stress the value of ESD and transformative learning for motivation in the learner and simultaneously for the fostering of a vision III kind of scientific literacy. Yet, vision III is being conceptualised slightly differently by different scholars and is currently still developing and incorporating different notions accordingly (Sjöström, 2024). Regarding the content of science teaching DeBoer (2000) states that schools and teachers should have a choice to set their own priorities since the body of knowledge that comprises scientific literacy is too undefined and flexible to be predetermined. Although, specific content is necessary to build on and to provide a basic understanding of the natural world, he recommends loosening the pressure from standards to cover certain content in order to balance the aims of teaching the other aspects of scientific literacy. However, the decision makers for any curriculum need to define what learning about science should encompass and which vision of scientific literacy this learning would follow (Roberts, 2010).

Related to the perspectives of ESD and Scientific Literacy, there are perspectives within the science education community that put an emphasis on social issues and societal transformation in science education, such as, connecting climate education to political literacy (Guerrero & Sjöström, 2024). Matters of social and ecological justice are joined to scientific literacy, which is noted as *scientific and environmental literacies* by Guerrero & Sjöström (2024). Similarly, Lee & Park (2024) put forward *Anthropocene literacy* to meet the challenges of the Anthropocene concept that prevails throughout different disciplines. Their concept relates to the nature of science and human impact on Earth. Here again, teaching is proposed to go beyond factual knowledge but to include discussion and the investigation of the discourse around the Anthropocene (Lee & Park, 2024). In a similar manner, Hodson (2003) highlights *education for citizenship* as an element of science teaching that aims to enable students to be citizens who value the current state of society and contribute to societal changes with the help of a “critical scientific and technological literacy” (Hodson, 2003, p. 654). A specific notion of scientific literacy that engages with the challenges of climate change is the concept of climate literacy (Azevedo & Marques, 2017), which will be described in the following chapter.

For this dissertation, scientific literacy is the overarching concept that comprises the particular notion of climate literacy, which will be outlined in the next section. Furthermore, the visions I to III

of scientific literacy become relevant because they open up the broader purpose of science education, which becomes particularly important in the context of climate education. In this context, the relevance for science in everyday life (vision II) and for citizenship including social and political aspects (vision III) become very meaningful. Notions such as political literacy, environmental literacy, Anthropocene literacy, or education for citizenship contribute to these notions of climate education within the framework of scientific literacy.

2.2.1 The concept of climate literacy

Within the framework of scientific literacy, climate literacy has been established with reference to climate and climate education (Azevedo & Marques, 2017; Milér & Sládek, 2011; Niepold et al., 2007). Yet, the concept was defined under different notions and has been further developed over the years by different scholars. On the one hand, there has been a rather strong emphasis on the science aspect: This includes the profound assumption that the climate system can be approached by scientific inquiry, that climate science is (as it is given by the nature of science) constantly emerging and that the scientific process is empirically validated (Niepold et al., 2007). On the other hand, there has been an emphasis on the adaptation of knowledge to situations: E.g., the development of knowledge, as well as the ability to apply one's understanding and skills to other circumstances, decisions and changing attitudes or actions (Dupigny-Giroux, 2008). Table 2-1 provides an overview over different comparable climate literacy frameworks.

The US Global Change Research Program (USGCRP) developed a guide comprising seven plus one climate literacy essential principles (CLEP), which take into account the physical science basis of climate and climate change (USGCRP, 2009). Shwom et al. (2017) added on to this by bringing up two further principles that include social and psychological contexts to the understanding and mitigation of and the adaptation to climate change. An overview over the CLEP is given by Table 2-2.

However, building on different notions and contributions to the concept of climate literacy, Azevedo & Marques (2017) emphasised three aspects of climate literacy in their review: knowledge, competences and attitudes around climate and climate science, information and communication as well as action towards adaptation and mitigation. Only recently, the USGCRP published a totally revised compilation of climate literacy principles. In this compilation the scientific side of climate and climate change is taken into consideration, as well as further disciplines and perspectives taking into account the interaction of climate, humans and societies (USGCRP, 2024). Furthermore, Janney et al. (2024) propose to emphasise agency as an outcome of climate literacy.

THEORETICAL BACKGROUND AND STATE OF RESEARCH

Table 2-1: The three central climate literacy (CL) frameworks used in this dissertation are outlined in the following table.

Climate Literacy (CL) Frameworks		
Azevedo & Marques (2017) Modelling CL according to a systematic literature review	USGCRP (2009) Development and presentation of seven + one essential principles of CL	USGCRP (2024) Advancing and presentation of eight essential principles of CL
Overarching descriptions of what CL is		
CL transcends mere knowledge and “includes attitudes, beliefs, motivational orientations, self-efficacy and values” (Azevedo & Marques, 2017, p. 9) aiming at responsible decisions as informed citizens	“CL is an understanding of your influence on climate and climate’s influence on you and society” (USGCRP, 2009, p. 4)	“CL is an understanding of how the climate system works, how human actions influence climate, how climate influences people and other parts of the Earth system” (USGCRP, 2024, p. 2)
Aspects that CL comprises considering individuals		
“ Knowledge of climate science, in its content, procedural and epistemic components” (Azevedo & Marques, 2017, p. 9)	“ [Understanding] the essential principles of Earth’s climate system” (USGCRP, 2009, p. 4)	“ [Understanding] the essential principles of Earth’s climate system and options to address human-caused climate change” (USGCRP, 2024, p. 2)
“ Competences that allow accessing, assessing relevant information [...] as well as communicate it [...]” (Azevedo & Marques, 2017, p. 9)	“ [Knowledge] of] how to assess scientifically credible information [...]” (USGCRP, 2009, p. 4) “ [Communicating] [...] in a meaningful way” (USGCRP, 2009, p. 4)	“ [Recognizing] credible information and knowing where to find it” “ [Communication] in accurate and effective ways” (USGCRP, 2024, p. 2)
“ Attitudes [...] [towards the] contribution to the conception and/or implementation of adaptation and mitigation strategies ” (Azevedo & Marques, 2017, p. 9)	“ [Ability] to make informed and responsible decisions with regard to actions that may affect climate” (USGCRP, 2009, p. 4)	“ [Ability] to make informed decisions related to climate change” (USGCRP, 2024, p. 2)

Table 2-2: The Climate Literacy Essential Principles (CLEP) as proposed by the frameworks from USGCRP (2009) (complemented with two social science principles proposed by Shwom et al. (2017)) and USGCRP (2024) are presented in the following table.

USGCRP (2009) <i>Climate Literacy Essential Principles</i>	USGCRP (2024) <i>Climate Literacy Essential Principles</i>
<p>“Guiding principle for informed climate decisions: Humans can take actions to reduce climate change and its impacts [...]</p> <ol style="list-style-type: none"> 1. The sun is the primary source of energy for Earth’s climate system [...] 2. Climate is regulated by complex interactions among components of the Earth system [...] 3. Life on Earth depends on, is shaped by, and affects climate [...] 4. Climate varies over space and time through both natural and man-made processes [...] 5. Our understanding of the climate system is improved through observations, theoretical studies, and modelling [...] 6. Human activities are impacting the climate system [...] 7. Climate change will have consequences for the Earth system and human lives” <p>(USGCRP, 2009, p. 9-16)</p>	<p>“1. How we know – Scientists understand the climate system through interdisciplinary observations and modelling</p> <ol style="list-style-type: none"> 2. Climate Change – Greenhouse gases shape Earth’s climate 3. Causes – Burning fossil fuels and other human activities are causing the planet to warm 4. Impacts – Rapid warming and other large-scale climate changes threaten human and ecological systems 5. Equity – Climate justice is possible if climate actions are equitable 6. Adaptation – Humans can adapt social, built, and natural environments to better withstand the impacts of climate change 7. Mitigation – Reducing emissions of greenhouse gases from human activities to net zero by 2050 can help limit global warming and climate change impacts 8. Hope and urgency – A liveable and sustainable future for all is possible with rapid, just, and transformational climate action” <p>(USGCRP, 2024, p. VII)</p>
<p>Shwom et al. (2017) <i>Newly proposed social science principles</i></p> <p>“Public understanding of climate change is a social and psychological phenomenon [...]</p> <p>Social contexts can enhance or constrain mitigation and adaptation [...]</p> <p>(Shwom et al., 2017, p. 379)</p>	

This dissertation builds on the conceptualization of climate literacy as provided by Azevedo & Marques (2017) regarding knowledge, skills and attitudes. Furthermore, content aspects that have been highlighted by further research are considered: the climate system and climate science, the causes, impacts and consequences of climate change as well as mitigation and adaptation strategies and means of societal and political participation and transformation (Janney et al., 2024; Shwom et al., 2017; USGCRP, 2009, 2024).

2.2.2 Current state and implications for the implementation of climate education

As outlined above, climate education is related to various interconnected broader frameworks. However, it remains unclear what climate education would look like in best-practice models. It is undisputed that climate education should be integrated into the curricula, but not clear how and where (Guerrero & Sjöström, 2024). Further research has been conducted on climate change in education in particular. Recently four reviews on climate education investigated what climate education looks like and which aspects could be defined as likely valuable for positive outcomes: (1)

Monroe (2019) retrieved successful intervention strategies, (2) Jorgenson (2019) identified possible directions of action oriented climate and energy education, (3) Bhattacharya (2021b) identified education foci as well as knowledge and conceptions and (4) Kranz et al. (2022) analysed the appearance of public action in climate education.

The reviews' key findings are outlined in the following: Monroe et al. (2019) investigated research articles that assessed climate change interventions and identified successful intervention strategies. They found two characteristics that have a positive effect on the outcomes of environmental education programmes: on the one hand, to achieve personal relevance and meaningful climate change contents and on the other hand, to achieve an engagement by learners through the programme design. Moreover, they defined aspects that help to handle the controversy around climate change topics aside of the physical basics of climate science. These are the discussion about different viewpoints, interaction with scientists and scientific process, addressing misconceptions and including school or community projects. Jorgenson et al. (2019) investigated research on environmental education with a focus on the transition of energy systems as a response to climate change. They found that education and research on climate change and energy related education mostly focused on individual behaviour in means of energy consumption and energy saving, but neglected the necessary connection to basic energy systems and their transformation by political decisions and under societal collective action. However, they make several recommendations to change the focus towards transition and collective action by considering students as participants in social networks leveraging such decisions. Bhattacharya et al. (2021b) investigated research on climate education and identified education foci as well as students' and teachers' knowledge. They found that climate education is mostly restricted to middle and secondary classes and time for teaching varies but seems to be quite short overall. Regarding contents and disciplines, they noted that the topic appears in biology, environmental science and Earth science courses above all and teaching contents focus mostly on the physical science basics of climate system and climate change as well as the impacts of climate change on the physical basics of the Earth and living. Kranz et al. (2022) investigated studies on the proportion of public and private responsibility for climate action in education. They found in their review that in climate education, emissions are often connected to the public and societal actions but mitigation action is attributed to the individual. They stress the meaning of political aspects in climate education including public sphere action and how students can be enabled to support those and promote political literacy to be part of such settings. Therefore, they propose to involve political education to foster climate literacy and they bring forward specific aspects in climate literacy education: They recommend to include all emission sectors in teaching, to include mitigation and adaptation to the same extend as physical science basis of climate change and to include climate justice in school education. Furthermore, they stress the necessity of enabling learners to act as responsible citizens in order to take social, political, and economic responsibility and thus to shift responsibilities for action more to the public sphere and with that, to involve policy education and political literacy in climate literacy education. Hence, they propose to shift the framework of climate change as a socioscientific issue to include both, science and society rather than to keep an emphasis on the physical science (Kranz et al., 2022).

In conclusion, these reviews show that the focus of current climate education is rather on the physical science side of climate change, but they stress the need for addressing and including (1) the

controversial aspects of climate change, (2) shifting responsibilities from the individual towards the public sphere, (3) enhancing political literacy, and (4) enabling students to become participating citizens. This dissertation takes these findings and recommendations into account by exploring the objectives of teaching towards climate literacy.

2.3 Preconditions for climate education

Although climate education is necessary not only on school level but transcending generations (Guerrero & Sjöström, 2024), students who still develop their worldviews are a major target group (Stevenson et al., 2014). Guerrero & Sjöström (2024) emphasize the importance of teachers' skepticism and preparation for climate education as well as the need to highlight climate education among school curricula as main issues from the literature. Students' conceptions regarding climate change (Shepardson et al., 2009) and learning difficulties with regard to possible action (Tolppanen et al., 2022) have been investigated and show areas of potential improvement in climate education. In order to leverage climate literacy, it has been argued that education needs to achieve more than scientific literacy, integrate different disciplines and take social aspects into account as well (Ledley et al., 2017). Janney et al. (2024) state that according to the literature, two aspects hold teaching about climate change back from addressing all necessary aspects of climate literacy: (1) they criticize the lack of connection between climate change knowledge and practice, e.g., in the transfer from theoretical classroom teaching to personal interests and action and (2) the isolation of, e.g., policy education and climate education that fail to make the beneficial connections between both topics. Furthermore, they criticize the limited interdisciplinary character of climate education, which plays into the isolation of subjects and the restriction of climate change topics to science classes, neglecting the interdisciplinary and social aspects. Science teachers in particular seem to have difficulties including political, social and economic aspects of climate literacy in their teaching (Herman et al., 2017). Still, teachers themselves would appreciate an interdisciplinary approach to climate literacy education (Howard-Jones et al., 2021; Johnson et al., 2008).

Zeidler & Newton (2017) describe how to arrange climate education within a socioscientific issues framework. They argue that socioscientific reasoning and perspective taking are necessary skills that should be applied in climate education in order to foster students' development as competent members of society. Thus, they propose to expand climate education beyond pure scientific knowledge and to consider not only effects that climate change has on society and vice versa, but also the effects that climate change mitigation strategies might have on different members of society (Zeidler & Newton, 2017). However, the question which subjects should be responsible for climate literacy education is often answered only with geography or earth science although many teachers as well as scholars argue for an extension of this framework (Dupigny-Giroux, 2010; Hestness et al., 2014). The aspects outlined above also speak in favour of not only transcending the single subjects, but also to relate the science and the social side to one another.

In order to meet the challenges of climate education as there are teachers' preparation, the interdisciplinary character of the topic and the necessary connection between scientific, political and social aspects, different strands of preconditions for successful climate education need to be considered: Teachers' professional knowledge as well as the curriculum with respect to climate education should be in focus in the following subchapters.

2.3.1 The relevance of teachers' professional knowledge in climate education

Teachers are the ones responsible for fostering climate literacy among students. They elucidate the complex scientific concepts and specific terminology in order to make them accessible for students (Dupigny-Giroux, 2010). To start with, teachers' professional knowledge, is a prerequisite for teaching practice. This knowledge can be split up into different knowledge facets that have been conceptualised, defined and developed by different scholars in the past. Shulman (1986) suggested three aspects in the first place, namely (1) subject matter content knowledge, (2) pedagogical content knowledge, and (3) curricular knowledge. In a subsequent study, he split up teachers' professional knowledge into a total of seven categories, but still retained content knowledge (CK), curriculum knowledge (CuK) and pedagogical content knowledge (PCK) among others, while particularly emphasising the importance of PCK (Shulman, 1987).

However, CK is continuously considered as one clearly differentiated knowledge facet by others who work on the conceptualisation of teachers professional knowledge (Baumert & Kunter, 2006; Grossman, 1990; Tamir, 1988). Teachers' CK is being described as knowledge of the structure of disciplinary concepts and facts as well as knowledge of how the currently accepted state of facts came about. It is also described as knowledge about the substantive and syntactic structure of the subject (Grossman, 1990; Shulman, 1986; Tamir, 1988). Thus, teachers' content knowledge includes different facets than that of an expert in the subject (Shulman, 1986). Furthermore, knowledge about the respective centralized or decentralized significance of certain topics in the orchestration of the subject is important for teachers with respect to accentuation in curricular organisation (Shulman, 1986). Hence, teachers' content knowledge needs to extend beyond the subject matter that is being taught at school, but still differs from academic subject matter knowledge. It must be a deep and thorough knowledge and comprehension of the subject matter relevant for the school curriculum (Baumert et al., 2013).

Pedagogical (content) knowledge and the curricular aspect, in contrast, are conceptualized and developed differently. An explicit difference is being made between general pedagogical knowledge (PK) and PCK (Baumert & Kunter, 2006; Grossman, 1990; Tamir, 1988). CuK, for instance, is sometimes put separately (Shulman, 1986; Tamir, 1988) and considered by others as part of PCK (Grossman, 1990; Magnusson et al., 1999; Park & Oliver, 2008). CuK is described as the general orchestration of a subject and its topics (*vertical curriculum knowledge* (Shulman, 1986)) or the position of one subject's topics among the topics of other subjects (*lateral curriculum knowledge*) (Shulman, 1986)). Moreover, it is described as the general goals and objectives of a subject and how those are reflected within the topics of a subject (Magnusson et al., 1999). Equivalently, there is the notion of CuK including the specific curricular materials suitable for the different subjects and their topics as well as appropriate alternatives (Magnusson et al., 1999; Shulman, 1986). Furthermore, CuK and decisions are informed by the syllabus, and curricula inform the planning and operation of teaching as well as its outcomes (Tamir, 1988). Regardless of the question whether CuK is considered as separate or part of it, PCK is of high interest in education research and its conceptualisation is particularly diverse and difficult (Park & Oliver, 2008). As Park and Oliver (2008) already stated, however, most conceptualisations commonly include two aspects of PCK: (1) instructional strategies (e.g., "the ways of representing and formulating [...] comprehensible to others" (Shulman, 1986, p. 9), "instructional strategies" (Grossman, 1990, p. 5;

Magnusson et al., 1999, p. 97), “and representations” (Park & Oliver, 2008, p. 264), or “explanatory knowledge” and “knowledge of [...] tasks” (Baumert et al., 2013, p. 29)) and (2) students’ conceptions (e.g., “what makes the learning of topics easy or difficult [...] conceptions and preconceptions that students bring with them [...]” (Shulman 1986), “students understanding [...]” (Grossman, 1990, p. 5; Magnusson et al., 1999, p. 97; Park & Oliver, 2008, p. 264), or “students [...] thinking” (Baumert et al., 2013, p. 29)).

In 2012 a PCK summit was held by a group of science education researchers. The resulting PCK consensus model (CM), provided a broader picture of teachers’ professional knowledge including PCK, but PCK remained somewhat dissolved and unclear within the model (Hume et al., 2019). Thus, on a second PCK summit a refined CM (RCM) was agreed on in 2016. The model distinguishes three realms of PCK, namely (1) enacted PCK, used and developed by teachers’ planning of and reflecting on teaching, (2) personal PCK, informed by teachers’ own experience and by others’ contributions and (3) collective PCK (cPCK), which is the PCK that the former literature outlined above is about (Hume et al., 2019). In this conceptualisation, cPCK can be applied to a subject or a topic scale, for instance. Following the examples given by Hume et al. (2019), this conceptualisation appears to incorporate students’ conceptions as well as instructional strategies. However, here curricular knowledge is conceptualised once more outside of PCK along with CK and other knowledge facets (Hume et al., 2019). As CK is related to particular subjects and their related topics, PCK is also related to the same specific content of subjects and their topic (van Driel et al., 1998). As several scholars have pointed out, both knowledge facets are to be differentiated from each other (Baumert et al., 2013; van Driel et al., 1998), yet, CK seems to be a precondition for the development of PCK (Baumert et al., 2013) whilst PCK enforces the conversion of CK into teaching practice (Magnusson et al., 1999).

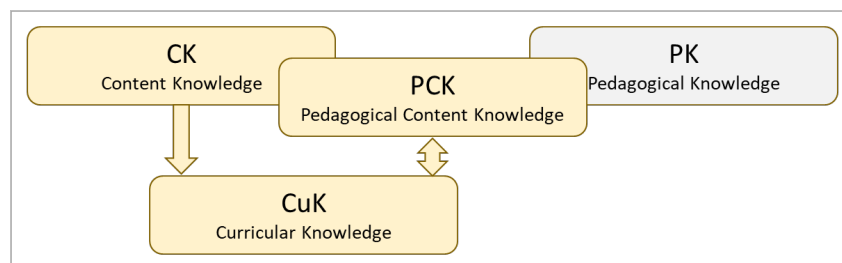


Figure 2-2: The dissertation builds on a conceptualisation of teachers' professional knowledge as illustrated by this figure and takes into account the three highlighted knowledge facets of CK, PCK and CuK (own graphical visualisation).

Mahler et al. (2017) found that while PCK has an influence on students’ learning outcomes, CK and CuK as well seem to have an indirect effect via PCK. They assume that especially PCK and CuK are interrelated, although initially considered to be separate in their study. For the content area of climate change, these knowledge facets can be considered as topic specific but transcending the borders of single subjects due to the interdisciplinary nature of climate change. Regarding such an interdisciplinary notion of teachers’ professional knowledge facets, Reinke (2017) conceptualised an ESD-oriented notion of teachers’ professional knowledge building upon the work by Kunter et al. (2011). In this conceptualisation, CK comprises general and academic knowledge as well as concepts and structures of sustainability, whereas PCK comprises instructional strategies and tasks,

students' conceptions and their contexts, as well as action orientation and opinion skills. This dissertation also focusses on CK and PCK, but will consider CuK with respect to the particular focus of curricular integration of climate education as illustrated in Figure 2-2.

This dissertation builds on such an interdisciplinary topic-specific notion of teachers' professional knowledge for climate literacy while taking into account the content-specific knowledge facets of CK and PCK. However, CuK is considered as a further facet that is of particular interest with regard to the interdisciplinary nature of climate literacy that traditional curricula and syllabi can hardly comply with. Hence, CK and PCK will be considered as a precondition for teachers' ability to foster climate literacy. Furthermore, the allocation of climate change content to subjects and the specific content of climate education will be in focus.

2.3.2 Teachers' professional knowledge in the context of climate literacy – state of the art and research gap

There are different aspects of teachers' professional knowledge that play a role in research on climate education and climate literacy. One aspect is the willingness and preparedness of teachers to teach about climate change. Several studies found that teachers feel insufficiently prepared for climate literacy education. They found that teachers miss CK as well as teaching strategies on the one hand and that they perceive the topic as controversial on the other hand, which is why they lack confidence in teaching it in an adequate manner (Berger et al., 2015; Boon, 2016; Johnson et al., 2008; Sullivan et al., 2014).

In order to shed light on the question if the self-perception of teachers considering their knowledge is correct, studies have been conducted that tested teachers' knowledge on topics related to climate literacy. There are studies that show a positive vision of teachers' knowledge, especially regarding climate change and its causes, but even these found a lack of knowledge regarding impacts or solutions of climate change (Anyanwu et al., 2015; McNeal et al., 2014). But in general, deficiencies in content knowledge (e.g., confusing weather and climate, different greenhouse gases) as well as existing misconceptions (e.g., regarding the greenhouse effect, confusing climate change and ozone depletion) among teachers were revealed throughout different studies, even though knowledge about anthropogenic causes and related mitigation strategies was evident (Eze et al., 2022; Nyarko & Petcovic, 2021; Papadimitriou, 2004; Ratinen, 2013). Knowledge gaps concerning climate change content knowledge as well as teaching strategies seem to lead to low awareness towards climate change among teachers (Competente, 2019), which hinders the inclusion of the topic in teaching in general. The outlined knowledge gaps raise the question of how and from where teachers gain their climate literacy related knowledge. According to research, the internet and (social) media are among the main resources that teachers report as foundation of their knowledge acquisition (Berger et al., 2015; Boon, 2016; Competente, 2019; Wise, 2010). Yet, professional development programmes as well as government resources, textbooks, the IPCC reports and documentaries among others were mentioned as further information sources (Puttick & Talks, 2022). Accordingly, research shows that professional development programs on climate literacy education enhanced teachers' CK (Berger et al., 2015; Ekborg & Areskoug, 2012; Favier et al., 2021). However, professional development programmes need to meet various challenges regarding valid climate change related knowledge aspects, transdisciplinary teaching, systems thinking, attitudes and self-efficacy as well as varying curriculum standards

(Beach, 2023). Hence, teacher education needs to integrate subjects across curricula (Demant-Poort & Berger, 2021). It is necessary to educate teachers themselves in a way that includes not only the scientific but also the societal and political sides of the topic in focus which means political CK and PCK (Kranz et al., 2022). At the current time, teachers who lack adequate scientific knowledge on climate change have problems including climate change into their teaching and teachers who are well equipped with scientific knowledge have problems of including social or emotional sides of climate change into their teaching (Beasy et al., 2023).

With respect to CuK, the curriculum plays an important role in the orchestration of teaching content as well as the subject integration mentioned above. Thus, the climate education curriculum is in focus in the following chapters.

The reported knowledge gaps, the existing misconceptions, the perceived unpreparedness and the fact that teachers rely on internet resources for their own preparation emphasise the need for the professional development of teachers concerning climate literacy education. Professional knowledge of climate change and climate science are continuously evolving since the topic itself is of current relevance and development. Teacher education and professional development programmes need to meet these challenges. Therefore, it is necessary to figure out which specific CK- and PCK aspects are relevant for climate literacy education. Such aspects would merge scientific and social dimensions and allow teachers to develop the ability to foster climate literacy embedded in science education as well as in ESD. This includes background knowledge aspects as well as strategies of teaching needed to engage in climate education.

2.3.3 The climate education curriculum

The inclusion of climate change in the official education standards issued by governmental institutions enhances the possibility that teachers spend (more) time of their teaching on the topic (Hannah & Rhubart, 2020). Yet, the perception of teachers that climate education is not congruent with the standards or curriculum hinders them to include the topic into their teaching (Wise, 2010). Furthermore, climate change might be perceived as subordinate to more traditional subject specific topics (Feierabend et al., 2011). While policymakers, teacher educators and teachers all agree that climate education needs to be included in curricula in a way that involves every subject, they also recognise that at the current time, climate change is not implemented explicitly enough in different countries' curricula (Ben Zvi Assaraf et al., 2024). Because curricula and curricular materials hold such a significance, a focal point of this dissertation will be to examine the role and current state of such curricula and curricular materials for the inclusion of climate education in teaching.

2.3.4 The relevance of curricula in research and climate education

According to Tamir (1988), teachers have to make decisions regarding syllabus and curricula on different levels for the implementation of teaching, which emphasises the relevance of curricula for climate literacy education. Research on and the conceptualisation of the curricula is outlined in the following chapter.

When considering the professional knowledge facets as well as subject matter content in research literature, a differentiation between (1) subject-specific and general content-specific or between (2) academic subject matter content and curricular content of school subjects has not necessarily

been made (Bromme, 1995). Hence, school subjects are no small edition of academic subjects, but they provide the relation of academic subjects and research for everyday life and solutions. Particular topics are being included in school subject content if teachers and curriculum designers consider them as relevant for learners' development of skills towards current and future realities (Klafki, 1995). Research on curricula and their development gained interest with the implementation of national education standards (*Nationale Bildungsstandards*) in Germany (Bernholt & Parchmann, 2021). National education standards have been issued for mathematics, German, languages and science subjects by the KMK. For other subjects, e.g., geography, they were issued by subject research groups and associations (DGfG, 2020, 2024; Köller, 2018). Regarding the term *curriculum*, one has to differentiate between the curriculum that implements what should be taught versus the curriculum that implements what is being taught – textbooks are one example to get an insight into the latter. The term of the planned curriculum refers to the curriculum provided by official frameworks (later also referred to as formal curriculum) on the one hand and textbooks on the other hand. Finally the enacted curriculum becomes vivid in the classroom by the teacher (Gehrke et al., 1992). The curriculum can be defined as describing frameworks for the general goals of teaching and learning, such as national curricula, that provide a basis for teachers to decide what to teach. When referring to the curriculum as describing the content that should be taught, the term usually describes general frameworks from administration or policy. Some researchers however, use the term when describing materials directly used by teachers to design their lessons (Stein et al., 2007) – e.g., textbooks or similar such as Remillard (2005) does. Others use the term curriculum materials for the latter (Davis et al., 2016). Remillard & Heck (2014) introduced a visual model of curriculum policy, design and enactment. They differentiate the official and the operational curriculum. The first is being designed and implemented by authorities and includes curricular guidelines with aims and objectives, assessment contents and the designated curriculum which comes in the form of, e.g., instructional materials that are selected and approved by authorities. The latter comprises what is *intended* by teachers in the classroom as well as what actually happens during teaching (*enactment* process) during the interaction with students. Hence, instructional materials are informed by the official curriculum and in turn, they inform the operational curriculum (Remillard & Heck, 2014). This conceptualisation, as the dissertation will build on it, is illustrated in Figure 2-3.

In this dissertation, the term *curriculum* is used for frameworks describing what should be taught by official authorities (official curriculum), while instructional materials are either explicitly named as *textbooks* or referred to by *curricular materials* combining them with the official curriculum.

Considering the target area of this dissertation, the highest level of curriculum design in Germany is the level of national education standards. National education standards are a national instrument transcending the federal states of Germany. They frame requirements for teaching and learning at school by drafting desirable students' learning outcomes and subject-specific or interdisciplinary basis qualifications. They are a reference for teachers' professional agency (KMK, 2004b). As such, they are content standards that define the performance output of students, formulated as competencies. Thus, they are separated from curricula that outline specific subject content (Köller, 2018).

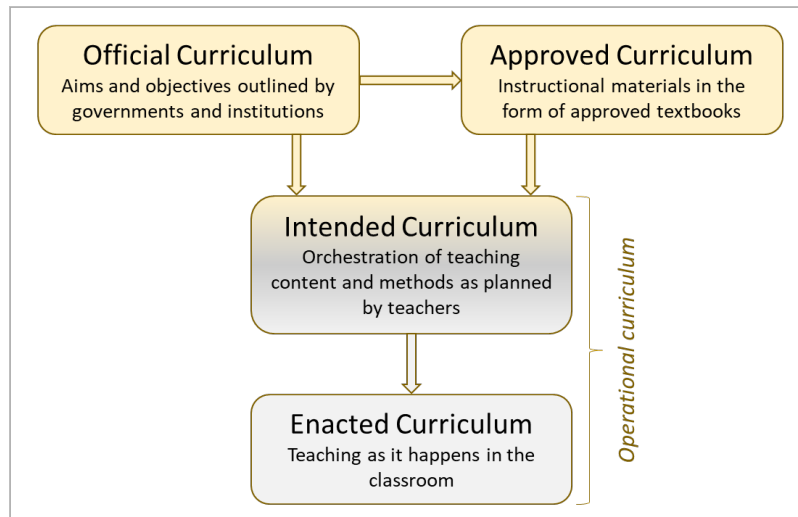


Figure 2-3: Different levels of curriculum are described by different authors. In this dissertation, a conception of the official curriculum and the curricular role of textbooks are used according to Remillard & Heck (2014) (own graphical visualisation)

The specific implementation of these curricular standards is up to schools and teachers (Gassmann, 2013). National education standards are the target level of teaching and learning. This means they provide the pursued results in the form of a curricular guideline by describing general goals of education, central objectives and concepts of subjects as well as basic competencies. Official curricula, however, list contents and learning goals in a systematic and temporal structure including implications for teaching practice and methodology, thus providing a way towards reaching the overarching aims of the national education standards (KMK, 2004b). Hence, national education standards are implemented by means of official curricula, which themselves need to be developed by taking into account the objectives provided by national education standards (KMK, 2010). Official curricula arrange the different subjects by providing a framework of content orientation as well as structural and temporal organisation of teaching (Oelkers & Reusser, 2008). As such, standards (output-oriented) define objectives and competencies as output categories, while official curricula (input-oriented) define content and subjects and their directions towards those competencies (KMK, 2010; Oelkers & Reusser, 2008).

This dissertation refers to the input-oriented official curricula designed and issued by the federal states (Bundesländer) of Germany. They represent the official or formal curriculum and therefore provide the first level of implementing climate education into teaching. The official curricula of specific federal states are in the focus of the dissertation. These curricula documents are structured by (1) introductory chapters which describe general objectives of education and of the specific subjects as well as by (2) content-related chapters that include standards, competencies, content and learning goals in chronological sequences.

2.3.5 The relevance of textbooks in research and climate education

While the official curriculum is implemented through curriculum frameworks and standards it can also be seen as represented in textbooks (Stein et al., 2007). National education standards must not only be taken into account for the development of curricula, but also for designing and editing textbooks. The interrelationship between both, curricula and textbooks, is of severe importance for the objectives of education policy (KMK, 2010) and both seem to play a pivotal role in the

implementation of national education standards into practice (Oelkers & Reusser, 2008). Hence, the specific education policy perspective has to pass different stages until it can result in classroom teaching, for example through curriculum standards, textbooks and teachers themselves (Roberts, 2010). Referring to textbooks in particular, political motives can play a role in their presentation and prioritisation of content (Bruillard, 2022), since they fulfil the implementation of curricular standards into practice with the liability of their official authorisation (Oberle & Tatje, 2017). With this reference to officially authorised curricula, textbooks reflect the perspective of the political and professional authorities who decide on what is to be taught at school at the given time (Heyneman, 2006). The opinions and agendas of these authorities are compounded by the perspectives of authors, editors, reviewers and publishers, who bring together their values and interests during the production process of textbooks (DiGiuseppe, 2014).

Regarding the specific subjects, textbooks frame how the academic discipline is presented to the public by their role in facilitating teaching and students' learning (Sidaway & Hall, 2018). Therefore, they can be seen as remnants that show how scientific findings, theories, practices and ideas are presented to the readers. The public, in the form of students, is obliged to use textbooks (in contrast to other publications for the public) and the textbooks are considered as having a certain authority to students as they are approved by states, schools and teachers (Shapiro, 2012). In research, textbooks can be seen as an approximation of the implementation of a specific content ("discipline" (Bruillard, 2022, p. 11)) into teaching by providing the optimal role out of the subject matter into practice. This is because textbooks are considered as most relevant instruments for teaching and learning (Bruillard, 2022). Teachers even seem to rely on textbooks rather than on official curricula in some cases and use textbooks as their most relevant instrument for teaching (Oelkers & Reusser, 2008). Textbooks enhance the understanding of subject matter by providing text processed for learning through specific forms of presentation and structuring of the specific subject matter (Heyneman, 2006). As an example, Oberle & Tatje (2017) found that a vast majority of politics teachers that they questioned use the textbook for the planning of teaching units and of single lessons as well as a main instrument within their lessons. Therefore, in order to understand the implementation of the official curriculum into teaching in the form of the enacted curriculum, teaching resources such as textbooks play a role for its arrangement by teachers and that role needs to be understood (Remillard, 2005). Since students' learning is merely influenced by the enacted curriculum, which brings the planned arrangement of topics into practice, textbooks as instruments for instruction do play an important role for learning as well (Remillard & Heck, 2014).

Although the specific application of textbooks within the enacted curriculum might differ between situations, their investigation provides a preliminary view into teaching practice or what teaching practice might be like. Thus, this dissertation considers textbooks as a basis for teaching practice and draws conclusions from contents and representation within textbooks towards the current implementation of climate change in classroom teaching.

2.3.6 Implementation of climate education in curricula and curricular materials – state of the art and research gap

The implementation of climate education into the curriculum follows different ways according to comparisons of different countries. Building on previous work, Eilam (2022) elaborated a structure

in which these different ways can be arranged. Broadly speaking, there can be (1) a cross-curriculum approach that integrates climate education within different subjects in different possible ways (subsumed under sustainability, within one or few subjects, or within many subjects) or (2) a non-subject approach that situates climate education in a separate place of the curriculum (Eilam, 2022). Figure 2-4 illustrates this structure.

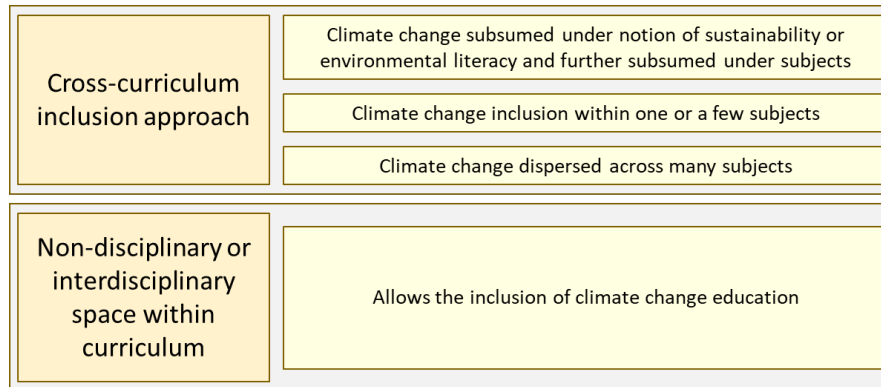


Figure 2-4: Climate education may be implemented in the curriculum by different structures following different subjects and/or overarching topics as well as in a separate way according to Eilam (2022) (own graphical visualisation)

Different studies on the inclusion of climate education within official curricula documents show that the topic is being implemented in science and earth science subjects (particularly geography) but there are also a few example that show connections to climate education within social studies subject. In Australia (Colliver, 2017) and in Canada climate education was found in both subject areas (science and social studies), yet, in Canada, the focus of the topic within the different subjects appeared to be very diverse throughout the provinces (Field et al., 2023). Similarly, in Singapore both subject areas showed connections to climate education, but they varied throughout the different subjects regarding different content foci (e.g., the atmosphere, energy resources) and elaborateness (Chang & Pascua, 2017). Another study that took into account the curricula of different countries found very different levels of elaborateness as well: While specified teaching units on climate change were identified in Ontario (Canada) and Indonesia, climate education was added on to the overarching topic of ESD in Israel and it appeared to be obliged to teachers how to realise climate education in Finland (Dawson et al., 2022).

The studies outlined above investigated manageable numbers of curricula in a content-related way. The case of Germany, however, comes with the particularity of federalism, which leads to an immense number of different curricula for various school types and subjects. Siegmund et al. (2021) solved this by conducting a lexical content analysis that provided insight into the abundance and distribution of different key words from the context of climate education. They also found the topic to be included in geography and science subjects. Yet, even this extensive study leaves open in which way and related to which topics climate education is embedded in German curricula.

Adding on to formal curricula, textbooks as an important resource for teachers as planning and teaching instruments have been in the focus of international research on the inclusion and implementation of climate education. Most of the studies considered textbooks for geography and in some cases, science textbooks. Yet, the subject focus does not seem to be consistently related to content foci. As such, the scientific basics of climate change as global warming and the greenhouse

effect are included in many of the investigated textbooks. Furthermore, the anthropogenic causes for, as well as the consequences of, climate change are included in many studies throughout various countries (e.g., Ethiopia, Colombia, Spain, Germany, Romania, and Mexico) (e.g. Bagoly-Simó, 2013; Bonilla & Quesada, 2024; Dalelo, 2011; Morote & Hernández-Hernández, 2023) and similarly in a study that took into account visual representations within textbooks (Schauss et al., 2024). Scholars report that the topic is being treated inconsistently within different countries (Bagoly-Simó, 2013) or find the topic inadequately addressed within the investigated textbooks (Bonilla & Quesada, 2024; Morote & Hernández-Hernández, 2023). Notwithstanding, there is evidence from a study conducted in The United States that the topic of climate change has evolved within textbooks from the 1970s until recently, considering the amount of textbooks pages covered as well as an enhanced topical focus (Ansari & Landin, 2022). Apart from this, there are also studies that found broader coverage of climate change. In those cases, apart from causes and consequences of climate change, solutions such as action strategies or international collaboration were thematised as well. The latter holds true for studies from the Czech Republic, Poland, Germany, the UK, Norway and South Africa (Baarova & Hibszer, 2022; Moelter-Reich et al., 2023; Morris, 2014; Trædal et al., 2022). Still, there are some critical voices regarding the representation of misconceptions within textbooks that were identified by studies from the United States and the UK. Another challenge is provided by textbooks from the United States that still represent the anthropogenic causes of climate change with a certain measure of scientific uncertainty (Meehan et al., 2018; Román & Busch, 2016).

This dissertation takes into account both official curricula and textbooks as part of the curriculum. Official curricula are considered as one important building block on the way to the implementation of climate education. The implementation starts with the expert knowledge of the field of climate and education research comes across the professional knowledge of teachers, including the curricula related component of CuK and leads towards actual teaching. Therefore, the dissertation aims to add on to the existing research on the implementation of climate education within formal curricula in Germany. Therefore, it investigates in which way, related to which topics and with what focus and depth of content climate education is embedded in German curricula. Due to the broad range of curricula according to the federal structure of the education system, a selection of curricula had to be made for the sample of the study. Therefore, the dissertation sheds light on a few exemplary curricula but provides deep inside into the qualitative inclusion of climate education in Germany.

Textbooks are considered as the basis for teaching practice on the way from the official curriculum to the intended and enacted curriculum in the classroom. The textbook studies outlined above mainly focused on one subject (geography or science), apart from single exceptions considering, e.g., science and social studies. When comparing the different results, it appears to be impossible to make out structural differences between the subjects nor the investigated countries. Differences in content coverage seem to exist, yet it remains unclear whether they rely on the focus, on different subject traditions, national preferences, the time of publication, or a combination of those. Hence, this dissertation aims to investigate textbooks from different subjects, especially including both sides – science and social studies – to make out possible differences between subject approaches. Furthermore, textbooks from two different countries were taken into account to shed light on the question whether there are severe differences between them. Due to the very

small sample of only two countries, comparability should be sure enough, which is why Germany and the UK as two countries with a European background were chosen.

Both formal curricula and textbooks as curricular materials are considered as interrelated and complementary, two sides of the same coin. They lead the way for the implementation of climate education into teaching enactment in the classroom. The question, what kind of implementation is currently achieved according to the proposed structure by Eilam (2022), remains open. It is also unclear how the interdisciplinary nature of climate education is being met by the different subjects, especially with regard to the dichotomy of science and society.

3 Aim and overview of the conducted studies

When looking at the current research and practice of climate education, different strands of preconditions for successful climate education become evident: the orchestration of climate education throughout a school biography, the specific teaching content and subject matter, the specific knowledge (CK and PCK) that teachers need to have and the alignment of theoretical requirements and current teaching practice.

The dissertation aims to approach these preconditions by (1) investigating the requirements of an adequate climate literacy education with respect to teaching content and teachers' knowledge on the theoretical side from an experts' point of view, (2) revealing the existing requirements of climate education from an institutional point of view and (3) approximating the current practice of teaching as represented by profound daily classroom materials in the form of textbooks.

The outline of this dissertation, therefore, follows an interconnected pathway starting from theoretical expertise about what *should be taught* in the context of climate literacy education. The dissertation then investigates what *needs to be taught* in the context of institutional curricula arrangements and what is *actually being taught* according to school textbooks with mono- and interdisciplinary subject foci.

To achieve the aims outlined above, this dissertation aims to answer the following overarching research questions:

(1) Preparatory research questions

- *What do teachers need to know and what should be included in teaching in the context of climate literacy?*
- *How is climate education being included by institutional requirements (curricula) and teaching materials (textbooks) considering different subjects especially regarding natural sciences and social studies?*

(2) Concluding research question

- *How does the current state of climate education by curricular inclusion and teaching implementation compare to the required climate education towards climate literacy as proposed by experts?*

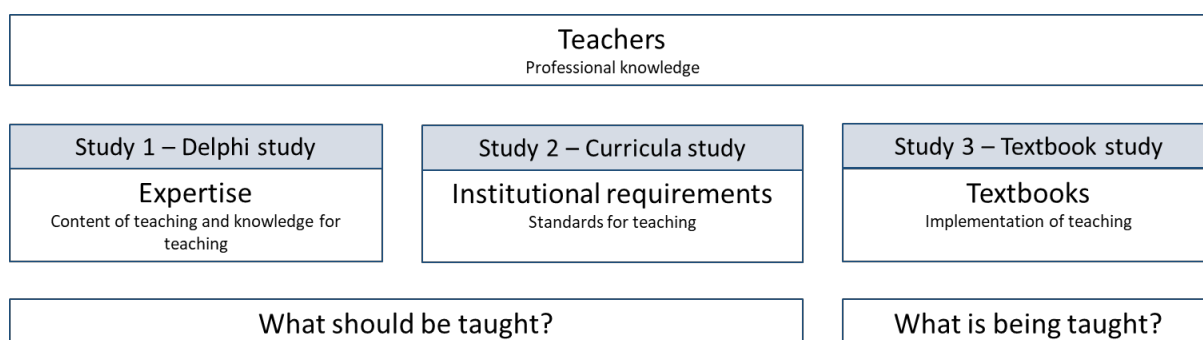


Figure 3-1: The dissertation investigates expert perspectives on climate literacy education, the state of climate education according to curricular guidelines and teaching practice by the means of curricular materials under the outline of teachers' professional knowledge. This figure illustrates the outline of the conducted studies of the dissertation.

3.1 Rationale of the conducted studies

Study 1: Implementing climate literacy in schools – what to teach our teachers?

The concept of climate literacy connects to aspects of different subjects and requires to consider them from a multidisciplinary perspective rather than isolated as the common orchestration of subject curricula suggests. Thus, the specific teaching content as well as the (content and pedagogical content) knowledge of teachers independent of specific subject curricula are of interest. Study one, therefore, aimed to identify and compile the necessary aspects of scientific background knowledge as well as knowledge on (mis-)conceptions and teaching strategies needed in order to foster climate literacy. Of further interest was the question if and how those aspects are allocated in specific subject disciplines. Because the study set the basis for further research and teaching concepts in climate literacy, the aim was to build on a broad and profound expertise. Hence, the study was designed as a Delphi-study, a multilevel interrogation of experts in the field. The experts involved in the study were from climate science, education research and educational practice (teacher educators and teachers). They were interrogated in three subsequent rounds. During the process of the study, the experts were asked to bring up their own ideas for relevant knowledge and furthermore, to rate and modify their suggestions against the background of group decisions. Up to 64 participants were involved in the study (round 1: n=44, round 2: n=64, round 3: n=45).

Study 2: *Curriculare Einbindung der Klimabildung – wie ist der Stand und wo soll es hingehen?* (= Curricular inclusion of climate education – what is the status quo and where should we go?)

Although, as mentioned above, climate literacy is as a concept detached from the structure of specific subjects, the organization of education in common school systems follows a conventional division into such subjects. Therefore, the second study adds on to the first study by providing a perspective from the subject side, investigating the status quo of climate education aspects within current school curricula. Moreover, the study provides an insight into what is currently required from teachers to include in their teaching. This is the second baseline for climate education, because teachers are obliged to follow these institutional requirements and need to build their teaching on them. The study investigated the amount and specification of how climate education is being included in the curricula of Germany. Since Germany is a federal republic and the school system and curricula organization are structured according to the different federal states, the study focussed on the curricula of three different federal states providing curricula with a low, medium and high abundance of climate education references. The level of abundance was determined by a pre-keyword-analysis. In order to meet the multidisciplinary perspective of climate literacy, different science subjects as well as social subjects and integrative subjects from both fields were in focus. Curricula for secondary education (*Sekundarstufe I and II*) were investigated, comprising 99 curricula documents from three federal states. Due to the high specificity, diverse structure and alignment of curricula in the federal state of Germany, the decision was to focus only on Germany in this study. This focus allowed a broader insight into the German curricula rather than only a small exemplary sample of, e.g., one federal state to tie up to an international comparison.

Study 3: A fragmented endeavour – Climate education contents in natural science, geography, and social sciences textbooks

Following up the two previous studies that outlined what teachers should know and what should be taught from an experts' point of view (study 1) and from an institutional point of view (study 2), the third study aims to figure out what is actually being taught. As an approximation to what current classroom practice looks like, a comprehensive textbook analysis was conducted. Classroom teaching is known to be informed by textbooks structure and content, thus they were considered an adequate object of investigation for this purpose. The content presented in the textbooks is specific, illustrated and reprocessed for classroom teaching compared to the requirements from curricula. Again, in order to meet the multidisciplinary nature of climate literacy and climate change against the background of subject oriented school structure, textbooks from science and social subjects were chosen and integrative subjects were included as a useful add-on that might point onto an interdisciplinary pathway. This study took into account textbooks from two different countries, in order to assure an international connectivity. Therefore, textbooks from Germany that were institutionally approved for as many federal states as possible and furthermore, textbooks from the UK were chosen for a two-country comparison. The sample consisted of 14 English and 22 German textbooks. The difference in sample size mainly resulted from the fact that German lower secondary level textbooks were often split up into at least two volumes.

3.2 Overview of the conducted studies

Study 1	
<i>Title</i>	Implementing climate literacy in schools – what to teach our teachers?
<i>Authors</i>	Anna-Kathryn Leve, Hanno Michel & Ute Harms
<i>Published</i>	2023
<i>Journal and Volume</i>	Climatic Change 176
<i>DOI</i>	https://doi.org/10.1007/s10584-023-03607-z
<i>Personal contribution</i>	The study was designed by myself. Ute Harms and Hanno Michel contributed to the study conception and design. Material preparation, data collection, and analysis were performed by myself. The study was supervised by Ute Harms. The first draft of the manuscript was written by myself. Ute Harms and Hanno Michel revised previous versions of the manuscript. All authors read and approved the final manuscript.
<i>Abstract</i>	Climate literacy (CL) comprises knowledge, skills, and attitudes that enable individuals to counteract the global threat of anthropogenic climate change. Teachers' knowledge and pedagogy are main predictors of students' learning outcomes, but teachers are insufficiently prepared in the interdisciplinary field of CL. In a multilevel interrogation of experts in the fields of climate science, education research, and school, we derived 13 delineated themes describing necessary knowledge concerning the scientific background of climate change as well as pedagogy and teaching strategies. These themes indicate that teachers need a broad basis of understanding the climate system, climate science, causes of, impacts of, and dealing with climate change as well as the ability to convey this interdisciplinary content into teaching, by making the

Study 1

	topic personally relevant and strengthening students' role as change agents. The findings underline the need to promote interdisciplinary ways of teaching towards CL and provide a baseline for the development of future teacher preparation.
<i>Research Questions</i>	<ul style="list-style-type: none"> – What aspects of scientific background knowledge do teachers need to foster students' CL and how are those aspects allocated in different disciplines (<i>content knowledge</i>)? – What aspects of knowledge do teachers need to foster CL with an emphasis on (mis-)conceptions and teaching strategies (<i>pedagogical content knowledge</i>)?
<i>Design</i>	Delphi Study
<i>Methods</i>	<ul style="list-style-type: none"> – Delphi method: an iterative interrogation of experts in three subsequent rounds – Expert panel: climate researchers, educational researchers, teacher educators and teachers – Study area: Germany, Austria, Switzerland – Survey period: February – October 2021
<i>Instruments</i>	<p>Three self-designed online surveys</p> <ul style="list-style-type: none"> – <u>Interrogation round 1</u>: 5 open ended questions aiming to gather suggestions concerning (1) basic knowledge about climate and climate change including human interference, (2) pre- and misconceptions, and (3) exemplary teaching strategies – <u>Interrogation round 2</u>: 20 closed questions aiming to rate 20 themes that emerged from round 1, 42 open ended questions aiming to collect justifications for ratings, suggestions for changes and suggestions for merging/splitting any themes – <u>Interrogation round 3</u>: 13 closed questions aiming to rate 13 revised themes that emerged from round 2, 14 open ended questions aiming to collect comments on themes and suggestions for merging/splitting any themes
<i>Sample</i>	<ul style="list-style-type: none"> – <u>Interrogation round 1</u>: n=44 participating experts (11 CR, 11 ER, 12 TE, 9 TC, 1 unspecified)* – <u>Interrogation round 2</u>: n=64 participating experts (18 CR, 14 ER, 15 TE, 16 TC)* – <u>Interrogation round 3</u>: n=45 participating experts (11 CR, 13 ER, 10 TE, 11 TC)* <p>*CR = climate researchers, ER = education researchers, TE = teacher educators, TC = teachers</p>
<i>Main results</i>	<p>Themes describing teachers' professional knowledge in the context of climate literacy</p> <ul style="list-style-type: none"> – <i>CK-specific</i>: <ul style="list-style-type: none"> – Climate history and natural climate fluctuation – Components and functioning of the climate system – Climate science and dealing with information – Relation to other societal/global problems – Causes of anthropogenic climate change – Impacts of anthropogenic climate change

Study 1

- Dealing with climate change
- *PCK-specific*
 - Interdisciplinary structure of climate education and curricular integration
 - Pre- and misconceptions
 - Dealing with willingness and capacity to act
 - Formation of opinion and argumentation integrated into climate education
 - Self-reference: living environments and options to act
 - Teaching: strategies and illustration

Study 2

<i>Title</i>	<p>Curriculare Einbindung der Klimabildung – wie ist der Stand und wo soll es hingehen?</p> <p>(= <i>Curricular inclusion of climate education – what is the status quo and where should we go?</i>)</p>
<i>Authors</i>	Anna-Kathryn Leve, Carola Garrecht & Ute Harms
<i>Published</i>	2025
<i>Journal and Volume</i>	Zeitschrift für die Didaktik der Naturwissenschaften (ZfDN)
<i>DOI</i>	https://doi.org/10.1007/s40573-025-00178-7
<i>Personal contribution</i>	The study was designed by myself. Ute Harms and Carola Garrecht contributed to the research design. The preparation of research material, data analysis and evaluation were conducted by myself. The study was supervised by Ute Harms. The first draft of the manuscript was written by myself. Ute Harms and Carola Garrecht thoroughly revised previous versions of the manuscript. All authors read and approved the final manuscript.
<i>Abstract</i>	It is one of today's unquestioned challenges to take action towards climate change as a society. Education can be a key contribution to meet this challenge. The analysis of German curricula can show to what extent the content of school education would come up to this role. The present study provides an insight into how climate education is currently being implemented in German curricula of science and social studies for secondary education in a sample of three federal states (Bremen, Saarland, Mecklenburg-Vorpommern). They show two patterns: on the one hand that climate change is addressed through cross-cutting themes such as Sustainability but on the other hand that it is also described explicitly as a specific topic of its own right. In both cases there are cross-curriculum references as well as mandatory topics. Foci are to be found in Science subjects and in Geography, but there are also references to climate change that can be found in further social subjects. It is not visible within the current curricula documents if and how a connection between the subjects is being made.

Study 2

<i>Research Questions</i>	<ul style="list-style-type: none"> – How specific, how obligatory and related to which topics is climate education being implemented in current German curricula for public schools? – Which differences are to be found with regard to topics and to the profound implementation of climate change between subjects and school types within the selected federal states?
<i>Design</i>	Curricula analysis based on qualitative content analysis
<i>Methods</i>	<ul style="list-style-type: none"> – Pre-analysis: quantitative analysis of the curricula for biology, geography and integrative subjects from all German federal states with regard to the abundance of climate change related terms – Main-analysis: quantitative analysis of the curricula for science and social science subjects of three selected federal states with low (Hansestadt Bremen), medium (Mecklenburg-Vorpommern) and high (Saarland) abundance of climate change related terms with regard to climate change related contexts
<i>Instruments</i>	<p>Deductively self-developed two-dimensional analysis key for the qualitative content analysis:</p> <ul style="list-style-type: none"> – Dimension a: content related categories <ul style="list-style-type: none"> – a-1: sustainability, global change, Anthropocene and society – a-2: explicit mentioning/thematisation of climate change – a-3: way of living and action – Dimension b: Categories for the implementation of content <ul style="list-style-type: none"> – b-1: overarching concept – b-2: obligatory content and competencies – b-3: hints and suggestions for teaching
<i>Sample</i>	<p>Curricula of science and social science subjects for secondary level I and II in public schools within three federal states</p> <ul style="list-style-type: none"> – Hansestadt Bremen: <ul style="list-style-type: none"> – Secondary level I (science: 1, social: 1, integrative: 1), – Secondary level II (science: 3, social: 5) – Mecklenburg-Vorpommern: <ul style="list-style-type: none"> – Secondary level I (science: 8, social: 9, integrative: 4), – Secondary level II (science: 3, social: 3) – Saarland: <ul style="list-style-type: none"> – Secondary level I (science: 9, social: 14, integrative: 8), – Secondary level II (science: 10, social: 12)
<i>Main results</i>	<p>Dimension a: Frequencies of coding:</p> <p>a-1: sustainability, global change, Anthropocene and society > a-3: way of living and action > a-2: explicit mentioning/thematisation of climate change</p> <p>Dimension b: Frequencies of coding:</p> <p>b-2: obligatory content and competencies > b-1: overarching concepts > b-3: hints and suggestions for teaching</p>

Study 2	
	<ul style="list-style-type: none"> – References to <i>sustainability</i> focus on: ecosystems, sustainable action and use of resources – Specific references to <i>climate change</i> focus on: the greenhouse effect, carbon cycle, Earth's radiation budget, impacts of climate change and climate protection – References to <i>ways of living</i> focus on: energy resources, causes of climate change and way of action
Study 3	
<i>Title</i>	A fragmented endeavour – Climate education contents in natural science, geography, and social sciences textbooks
<i>Authors</i>	Anna-Kathryn Leve, Carola Garrecht & Ute Harms
<i>Status of manuscript</i>	Resubmitted after 2 nd major revisions
<i>Journal and Volume</i>	Science & Education
<i>Personal contribution</i>	The study was designed by myself. Ute Harms and Carola Garrecht contributed to the study conception and design. Material preparation, data collection and analysis were performed by myself. The first draft of the manuscript was written by myself, while Carola Garrecht and Ute Harms thoroughly revised previous versions of the manuscript. All authors read and approved the final manuscript.
<i>Abstract</i>	Climate change is one of today's most urgent global challenges. School education is an important key to preparing future generations to meet its impacts. Climate education can help students develop the knowledge, skills, and attitudes, i.e. climate literacy, necessary to elaborate approaches for mitigating climate change and for adapting to the climate to come. Due to the interdisciplinarity of the phenomenon 'climate change' and its impacts, it can be assumed that climate education takes place in natural science as well as in the social sciences' subjects. To gain a deeper insight into current climate education in schools, we conducted a comprehensive textbook analysis with textbooks for secondary education from science subjects, geography and social studies from the UK and Germany. In both countries, we found a wide range of climate education topics within geography textbooks and textbooks with a particular focus on energy content within the natural science subjects of chemistry and physics, but less coverage of climate education in biology and social studies. Overall, basic knowledge about the climate system and the greenhouse effect, anthropogenic causes and mitigation strategies are most

Study 3

	strongly represented. For the development of a comprehensive climate education, however, societal transformation and adaptation strategies should be more addressed.
<i>Research Questions</i>	<ul style="list-style-type: none"> – To which extent is climate education being addressed in natural science and social studies textbooks in secondary education in the UK and in Germany? – What are the main focus topics of climate education in natural science and social studies textbooks in secondary education in the UK and in Germany? – In which ways do textbooks for natural science or for social studies address climate education differently?
<i>Design</i>	Textbook analysis based on qualitative content analysis
<i>Methods</i>	Qualitative content analysis of textbooks for mandatory secondary education from Germany and UK including textbooks for science, social sciences and integrative subjects.
<i>Instruments</i>	<p>Deductively self-developed two level*¹ category system*²</p> <ul style="list-style-type: none"> – Climate system (<i>space and time, components and processed</i>) – Climate change (<i>natural, anthropogenic</i>) – Impacts (<i>natural environment, ecosystems/biosphere, human society</i>) – Ways to deal with climate change (<i>values/norms/discussion, adaptation, mitigation</i>) – Sustainable development, ESD, sustainability concepts <p style="text-align: right;">*¹level 2 displayed in italics *²based on (2023)</p>
<i>Sample</i>	<p>Textbooks for science, geography and social science subjects from the UK and Germany</p> <ul style="list-style-type: none"> – UK: science: 6, social: 2, integrative: 6 – Germany: science: 9, social: 8, integrative: 5
<i>Main results</i>	<p>The distribution of categories is similar in both countries</p> <p><i>Exceptions:</i></p> <ul style="list-style-type: none"> – Space and time GER > UK – Sustainability GER > UK – Impacts to the natural environment UK > GER <p>Most frequent codings:</p> <ul style="list-style-type: none"> – The <i>climate system</i> (including <i>climate change</i>), – <i>Anthropogenic causes</i> – <i>Mitigation</i> <p>The following topics are in focus:</p> <p>The greenhouse effect and its enhancement, anthropogenic causes of climate change, energy resources (fossil and renewable)</p>

Study 3

Noteworthy:

- *Mitigation* often refers to energy resources
- *Values, norms discussion* often refer to climate conferences and the Paris agreement
- *Adaptation* strategies do hardly occur

4 Study 1:

Implementing climate literacy in schools — what to teach our teachers?¹

Abstract:

Climate Literacy (CL) comprises knowledge, skills, and attitudes that enable individuals to counteract the global threat of anthropogenic climate change. Teachers' knowledge and pedagogy are main predictors of students' learning outcomes, but teachers are insufficiently prepared in the interdisciplinary field of CL. In a multilevel interrogation of experts in the fields of climate science, education research, and school we derived 13 delineated themes describing necessary knowledge concerning the scientific background of climate change as well as pedagogy and teaching strategies. These themes indicate that teachers need a broad basis of understanding the climate system, climate science, causes of, impacts of, and dealing with climate change as well as the ability to convey this interdisciplinary content into teaching, by making the topic personally relevant and strengthening students' role as change agents. The findings underline the need to promote interdisciplinary ways of teaching towards CL and provide a baseline for the development of future teacher preparation.

Keywords: Climate Literacy, teacher education, climate change, teaching strategies

¹ This is the peer-reviewed version of the following article: Leve, A.-K., Michel, H., Harms, U. (2023). Implementing climate literacy in schools — what to teach our teachers? *Climatic Change*. 176:134. The final print version of this article is available at: <https://doi.org/10.1007/s10584-023-03607-z>.

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4.1 Introduction

With each passing year, there is growing scientific evidence regarding anthropogenic climate change and its impacts (IPCC 2021). Despite rising awareness throughout society (Leiserowitz et al. 2015; Eurobarometer 2021), a perceived uncertainty about the topic remains and the assumption that scientific findings about climate change are controversial and doubtful is prevailing (Niepold et al. 2007; Uherek and Schüpbach 2008; Leiserowitz et al. 2015). In order to address the challenges of climate change by means of individual and collective action, sophisticated education plays a pivotal role by promoting scientific findings without paralyzing students and thus enabling subsequent action (Milér and Sládek 2011; Ledley et al. 2017; Crandon et al. 2022).

To achieve this, the concept of scientific literacy has been put forward, which covers the understanding of natural systems and their functioning as well as an understanding of the nature of science (DeBoer 2000) and which, besides knowledge, includes skills such as the assessment of information and decision-making (Dupigny-Giroux 2008). For climate change, a context-specific notion of scientific literacy – climate literacy (CL) – was defined (Niepold et al. 2007; Azevedo and Marques 2017) which this study is based on because it relates to a theoretically well-founded framework in education research. Although further, broader definitions do exist, the OECD has adopted the same conceptualization (OECD 2022). As such, CL comprises (1) content knowledge of climate and climate change, (2) skills needed to assess, interpret and communicate (scientific) information, and (3) attitudes that result in climate-friendly behavior (Azevedo and Marques 2017). Hence, education plays a significant role in promoting CL (Lee et al. 2015; Simpson et al. 2021) and students are a highly relevant target group to sensitize for the challenges of climate change, for they are still developing their worldviews (Stevenson et al. 2014). Studies show that students lack knowledge and hold misconceptions about climate change (Shepardson et al. 2009) and have difficulties regarding knowledge on action or willingness to act (Tolppanen et al. 2022).

Thus, teachers play a pivotal role in connecting students to the matter of climate, climate change, and thus CL (Dupigny-Giroux 2010). Therefore, teachers need to translate complex concepts and specialized terminology – which are likely to form obstacles to understanding the issues correctly (Dupigny-Giroux 2010) – into the context of school subject matter. Furthermore, in order to implement CL in a way that leverages the necessary changes in society, the focus may not only be on scientific and technological aspects but also on societal and ethical dimensions (USGCRP 2009; Azevedo and Marques 2017; Shwom et al. 2017).

Yet, the inclusion of political, social and economic aspects in CL education seems to be of difficulty for secondary science teachers (Herman et al. 2017). One possibility to overcome this challenge is an interdisciplinary approach to CL education which was appreciated by secondary teachers according to Johnson et al. (2008) and primary and secondary teachers according to Howard-Jones et al. (2021). Nevertheless, Wise (2010) reports that CL education was included in earth-science curricula in her sample whilst teachers in other subjects include the topic in informal ways, and Howard-Jones et al. (2021) also see a focus in science and geography. Thus, although willing to teach interdisciplinary climate change, pre-service teachers would need more knowledge throughout different subjects (Demant-Poort and Berger 2021) and they would need to be in agreement about (1) what content and (2) where in the curriculum of (3) which subject (e.g., chemistry) to teach (Feierabend et al. 2011). Apart from the interdisciplinary challenge, teachers' attitudes and

further barriers towards teaching climate change have been investigated. Competente (2019) reports low awareness towards climate change in pre-service teachers due to missing content knowledge and teaching strategies, whereas Liu et al. (2015) and Jeong et al. (2021) could improve pre-service teachers' climate change awareness by their interventions. In fact missing content knowledge and teaching strategies along with a perceived scientific controversy in the topic regarding climate change were often mentioned as barriers that make teachers feel underprepared for CL education according to several studies (e.g., Johnson et al. 2008; Sullivan et al. 2014; Berger et al. 2015; Boon 2016). In line with teachers' perceptions of their own knowledge, research has been conducted, testing teachers' general knowledge in the field of CL education. Several studies found that teachers have incomplete content knowledge (e.g., of the greenhouse effect) and hold misconceptions (e.g., about presumptive relations between climate change and ozone depletion or pollution) (Papadimitriou 2004; Ratinen 2013; Nyarko and Petcovic 2021; Eze et al. 2022). However, McNeal et al. (2014) report that they investigated an informed group of secondary teachers who showed a good knowledge basis but still had some uncertainties about causes and impacts of climate change, which is partially in line with Anyanwu et al. (2015) who report that a group of high school geography teachers they tested understood the causes and processes of climate change better than impacts and solutions and still held misconceptions. Regarding the resources that (pre-service) teachers gained their knowledge from, several investigations revealed that the internet and (social) media play a significant role, indicating that learning from professional development programs is of minor significance (Wise 2010; Berger et al. 2015; Boon 2016; Competente 2019). Still, research on such professional development courses for CL education (e.g., including climate change adaptation, the greenhouse effect, climate change as a socioscientific issue, and pedagogy) reveals that those courses do help to improve teachers' knowledge (Ekborg and Areskoug 2012; Berger et al. 2015; Favier et al. 2021).

The studies outlined above were conducted mainly in Europe and the USA, although Ghana, Nigeria, South Africa, Australia, the Philippines and Puerto Rico are also represented, and with (pre-service) teachers from either primary or secondary or both levels who cover many subjects with a strong emphasis on science. Given the fact that teachers from such diverse backgrounds feel poorly prepared, hold misconceptions and gain their knowledge from internet sources according to the challenges outlined above, the question arises, what exactly teachers need to know to be firmly prepared. It has been acknowledged in the lessons learned from the professional development program by Johnson et al. (2008) and in the literature review by Hestness et al. (2014) that there are manifold requirements towards such programs. Yet, it remains still fragmented and vague and not empirically compiled what specific knowledge aspects teachers need for CL education and in which way these are specific to certain subjects and students' age levels. This includes knowledge of the content and scientific background of the topic of climate change (e.g., the climate system; the greenhouse effect), which means a level of knowledge that goes well beyond the level being taught at school, but that is still not the same knowledge as that of research scientists (Baumert et al. 2013). This is particularly important but challenging with respect to the constantly developing field of climate science as continuously analyzed and documented by the Intergovernmental Panel on Climate Change (IPCC) (IPCC 2021) and at the same time, puts constraints on teachers that could prevent them from participating in climate related professional development programs (Ennes et al. 2021). Additionally, teachers need to know how to teach the relevant

content knowledge to students (e.g., knowledge about students' conceptions; instructional strategies) (Shulman 1987; Baumert et al. 2013; Großschedl et al. 2015). These two areas of teachers' professional knowledge are of significant relevance for students' learning outcomes (Mahler et al. 2017) which is why they are in focus of this study.

We aim to compile and empirically support those aspects of scientific background knowledge that teachers need to foster students' CL and how those aspects are allocated in different disciplines. Furthermore, we aim to compile and empirically support those aspects of knowledge that teachers need to foster CL with an emphasis on (mis-)conceptions and teaching strategies. First of all we do so without referring to specific subjects or age levels of students. Our compilation of knowledge aspects should help to provide a basis for the support and equipment of teachers that could be adapted to their individual needs of knowledge according to subject and their students' age levels. For this, we used a panel composed of experts from the fields of climate science, education research, and educational practice applying a Delphi method. We interrogated the expert panel in three subsequent rounds asking them to bring up ideas for relevant knowledge aspects and to rate and modify their collective suggestions. We aim to identify those knowledge aspects that we could find consensus for among the expert panel regarding their relevance for CL teaching.

4.2 Methods

The research questions in this study were addressed using the Delphi method, an iterative interrogation of experts in the field of study in premising rounds (Linstone and Turoff 1975). The Delphi technique is a group communication process that aims to find consensus or opinion stability when empirical findings are missing. Due to anonymous interaction of the panelists, group consensus is allowed to form without single group members becoming dominant (Osborne et al. 2003). The Delphi technique often starts with an open, qualitative round providing the basis for the subsequent rounds that become more quantitative and include rating techniques (Powell 2003).

4.2.1 The Expert Panel

For our research interest, we involved climate researchers, educational researchers, teacher educators, and teachers, who were considered as all relevant participant groups in the field of climate education bringing together expertise from the scientific background and from education expertise and practice. Experts were recruited following two expert level criteria: (1) Government research or educational institutions and consortia were chosen that put an emphasis on the field of research on climate, climate change or climate education/sustainability education (e.g. working groups, research consortia, formal education institutions). (2) People were chosen who hold a high position or a responsible role. Invited experts were offered the possibility to recommend colleagues from their institution as further experts to us. Regarding the subject backgrounds of our expert panel about half of the experts had a science-only background and about half had a background in science and further subjects or other than science (e.g. social studies, interdisciplinary subjects). The study was administered to an expert panel from the German-speaking area of Austria, Switzerland, and Germany. In all three countries, teacher education for the most part takes place at higher education institutions or universities with different amounts of mandatory practical training at schools. A large panel of experts was aimed at, thus up to 175 experts were invited with a feedback quota of about 30 %. The resulting number of participants was considered as

sufficient, particularly since most answers were quite detailed which was preferred over numerous shallow answers. Furthermore, the subsequent rounds offered the opportunity for additional participants to contribute to our interim results as outlined below. Experts were invited via e-mail and all Delphi rounds were conducted using online questionnaires in German. The study and research questions are framed by the international research around CL. Yet, the study was implemented in German only to avoid limitations to experts who might be less familiar with English. The Delphi study was conducted in three subsequent rounds from February until October 2021.

The experts' answers towards CL-related knowledge aspects from the interrogation rounds (1 to 3) were analyzed between the rounds and fed back to the expert panel. By these feedback loops, the experts could modify their collective answers and rate and rerate what knowledge aspects are being considered as relevant for teachers by the whole expert panel. We followed a procedure similar to but not precisely the same as described by Osborne et al. (2003). In our study, the knowledge aspects were represented as themes including a heading and a description text. Themes evolved throughout the subsequent interrogation-rounds of the study (cf. Figure 4-1) by achieving consensus among the expert panel about which themes are being considered as relevant knowledge for teachers. The three Delphi rounds are described in detail in the following section.

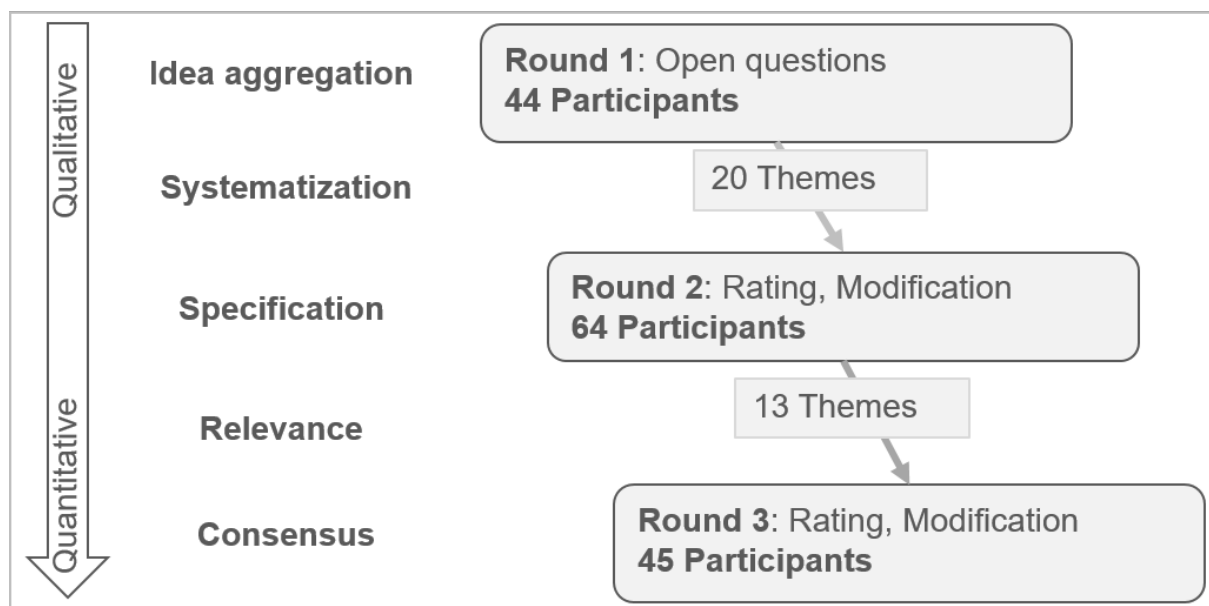


Figure 4-1: Schematic diagram of the Delphi-method process. The first round of the interrogation had qualitative character, the subsequent interrogation rounds became more quantitative, including rating techniques.

4.2.2 Delphi Round 1 and qualitative content analysis

The first round aimed at gathering ideas, suggestions, and experience from the expert panel. In order to meet the research interests, questions were prompted that asked for (1) basic knowledge about climate and climate change including human interference, (2) pre- and misconceptions, and (3) exemplary teaching strategies. Additionally, experts were asked to rate their subjective competence in these three sections on a 4-point Likert scale from 'not competent' to 'very competent'.

STUDY 1

In total 129 experts were invited to round 1, 44 of whom participated. All four groups were reasonably equally represented (climate researchers (11), education researchers (11), teacher educators (12), teachers (9), not specified (1)).

The experts' answers from Delphi round 1 were analyzed using a deductive-inductive approach of qualitative content analysis (Mayring 2014; Kuckartz 2019) using a content analysis software (MAXQDA 2020). Primary coding was conducted by the first author of this article. The development of the coding scheme and primary coding was done within the answer-section to each question, thus, codes were assigned to smaller thematically related text segments within each answer-section. For the intercoding of 20% of the material, each answer-section was treated as one coding unit. A good inter-coder-reliability was achieved ($Kappa = 0.75$). The resulting 20 themes cover content- and teaching-related knowledge. In preparation of the second Delphi round, descriptions reflecting all 20 themes were written based upon the expert answers.

4.2.3 Delphi Round 2, qualitative and quantitative analysis

In the second Delphi round, the expert panel was asked to rate the 20 themes according to their relevance for the education of teachers to foster CL on a seven-point Likert scale from 1 (not relevant) to 7 (very relevant). Experts were asked to justify their rating, to make suggestions for changes, and to state whether they would merge, split, or add any themes. For the second (and third) round, the pool of experts who were invited was enlarged to 175 following the same experts-criteria as indicated above. In total, 64 experts participated in round 2 (climate researchers (18), education researchers (14), teacher educators (15), teachers (16), not specified (1)). 26 of the participating experts were the same as in round 1, 38 were new participants.

The answers were analyzed quantitatively and qualitatively. Means, standard deviations, and frequency distributions of the experts' ratings were calculated. Experts' feedback on overlaps between themes was analyzed by frequency. Themes were merged when at least two experts saw overlaps and further comments indicated missing distinction from other themes. No indications for splits were expressed by the experts. Experts' reasons for their ratings and on possible changes were analyzed for suggested additions, reductions or corrections, comments towards the structure, focus, and complexity of themes as well as interrelations with other themes and target group specificity. The descriptions of themes were revised accordingly. 13 themes remained covering content- and teaching-related knowledge.

4.2.4 Delphi Round 3 and statistical analysis

The third Delphi round asked the expert panel to rerate the revised themes under consideration of the panels' ratings from round 2 and to comment on them. To this end, the frequency distributions of Likert-scale-ratings and the means for all former themes were presented. Eventually, they were asked if they would merge or split any themes. In total, 45 experts participated in round 3 (climate researchers (11), education researchers (13), teacher educators (10), teachers (11)). 15 of the participants were the same as in round 1 and 2, 30 were the same as in round 1 or 2, there were no new participants.

The experts' answers from Delphi round 3 were analyzed analogous to round 2. According to this feedback, the themes were revised by further additions and adjustments of wording. No indications for merging or splitting any themes were expressed.

As to compare the central tendency of ratings between expert groups for the final themes in round 3, a Kruskal-Wallis test (non-parametric for ordinal scaled data) was conducted ($p < .05$) and a Dunn-Bonferroni post-hoc test was used to identify the particular expert groups between which significant differences occurred (adj. $p < .05$).

Statistical analyses were done using the statistic computing language and environment R (R Core Team 2020), including the following packages: dplyr (Wickham et al. 2021), mosaic (Pruim et al. 2017), ggplot2 (Wickham 2016), FSA (Ogle et al. 2021).

4.3 Results

Themes that are considered as relevant knowledge for teachers have been identified by achieving consensus among the expert panel throughout the subsequent interrogation-rounds of the study. Hence, consensus as a measure in this study indicates which knowledge aspects originally brought up during round 1 were subsequently highly rated among the expert panel and how they evolved during the subsequent rounds. Defining consensus by means of a predefined majority within the expert panel is common, even though the critical share to build a majority varies among different authors (Osborne et al. 2003; von der Gracht 2012; Deeken et al. 2020). Following the more conservative two-thirds-rule, consensus for rating themes as important (≥ 4 on the Likert-scale) was reached for 17 out of 20 themes in round 2 and for all remaining 13 themes in round 3.

Since the study was conducted in German all of the results presented here have been translated thoroughly into English. Yet, slight inaccuracies resulting from the translation cannot be absolutely excluded. The titles of themes that originally emerged from round 1, their ratings, and their evolvement between round 2 and 3 are displayed in Table 4-1. Ratings of themes from round 3 are displayed by expert groups in Table 4-2. The final themes (headings and description texts) as resulting from the study are provided in the supplementary material in English, translated from the original German results (refer to the supplementary materials).

Table 4-1 Themes that emerged from the Delphi rounds after the analysis of round 1 and their ratings (rating scale 1 (not important) to 7 (very important)) in round 2 and round 3 (themes ranged left are according to their final wording, indented themes were merged or changed in wording between round 2 and round 3)

Theme titles	Round 2			Round 3		
	Mean	Mode	SD	Mean	Mode	SD
Knowledge of scientific background and content:						
Climate history and natural climate fluctuation	5.84	6	1.25	6.20	6	0.63
Components and functioning of the climate system				6.53	7	0.69
<i>formerly:</i> Components and functioning of the climate system	5.80	7	1.34			
<i>and</i> Climate as a system	5.55	6	1.39			
Climate science and dealing with information				6.33	7	0.8
<i>formerly:</i> Climate science, information, and media	5.98	7	1.29			

STUDY 1

Theme titles	Round 2			Round 3		
	Mean	Mode	SD	Mean	Mode	SD
<i>and</i> : Denial of climate change, skepticism against climate science	5.56	7	1.62			
<i>and</i> : Genesis and status of scientific knowledge	5.00	7	1.66			
Relation to other societal/global problems	5.54	6	1.34	6.02	6	0.94
Causes of anthropogenic climate change	6.27	7	1.13	6.69	7	0.63
Impacts of anthropogenic climate change	6.15	7	1.24	6.53	7	0.84
Dealing with climate change				6.58	7	0.62
<i>formerly</i> : Mitigation- and adaptation strategies	5.92	7	1.35			
<i>and</i> : Societal changes and processes	5.83	7	1.20			
Interdisciplinary structure of climate education and curricular integration				6.28	7	0.98
<i>formerly</i> : Interdisciplinary content and fields of specific subjects	5.77	7	1.59			
<i>and</i> : Thematic structure of climate education and curricular integration	5.73	7	1.70			
Knowledge about how to foster CL in teaching:						
Pre- and misconceptions				5.82	6	1.04
<i>formerly</i> : Misjudgments	5.59	7	1.52			
<i>and</i> : False or simplified concepts	5.25	7	1.70			
<i>and</i> : Visualization and further development of students' conceptions	5.39	6	1.57			
Dealing with willingness and capacity to act (<i>formerly wording</i> : Perceived obstacles to willingness to act)	5.52	7	1.48	6.16	7	0.88
Formation of opinion and argumentation integrated into climate education (<i>formerly wording</i> : Formation of opinion and argumentation)	5.63	7	1.51	5.76	7	1.21
Self-reference: living environments and options to act	5.85	7	1.59	6.19	7	1.26
Teaching: strategies and illustration	6.12	7	0.98	6.31	7	0.9

4.3.1 Variance of Group Ratings

Significant differences in ratings between expert groups ($p < .05$) were revealed by a Kruskal-Wallis test for four out of 13 themes: *Components and functioning of the climate system* ($\chi^2=15.25$, $df=3$, $p=0.002$); *Impacts of anthropogenic climate change* ($\chi^2=8.19$, $df=3$, $p=0.04$); *Pre- and misconceptions* ($\chi^2=8.52$, $df=3$, $p=0.04$); *Self-reference: living environments and options to act* ($\chi^2=11.95$, $df=3$, $p=0.008$). A Dunn-Bonferroni post-hoc test revealed that for *Components and functioning of the*

climate system the differences were between the group of climate scientists and teachers (adj. $p=0.01$) as well as between climate scientists and teacher educators (adj. $p=0.008$).

Table 4-2 Means and standard deviations by expert groups for all themes of round 3 (rating scale 1 (not important) to 7 (very important)).

Theme	Mean ± SD Expert groups				Mean ± SD
	Education researchers	Climate researchers	Teachers	Teacher educators	
Knowledge of scientific background and content					
Climate history and natural climate fluctuation	6.23±0.73	6.36±0.67	6.09±0.7	6.10±0.32	6.20±0.63
Components and functioning of the climate system	6.77±0.44	7.00*±0	6.18*±0.75	6.10±0.88	6.53±0.69
Climate science and dealing with information	6.46±0.78	6.36±0.5	6.09±1.04	6.40±0.84	6.33±0.8
Relation to other societal and global problems	6.31±0.95	5.64±1.21	6.00±0.63	6.10±0.88	6.02±0.94
Causes of anthropogenic climate change	6.69±0.63	6.73±0.47	6.82±0.4	6.50±0.97	6.69±0.63
Impacts of anthropogenic climate change	6.62±0.87	6.00±1	6.73±0.65	6.80±0.63	6.53(*)±0.84
Dealing with climate change	6.62±0.65	6.73±0.47	6.55±0.69	6.40±0.7	6.58±0.62
Knowledge about how to foster CL in teaching					
Interdisciplinary structure of climate education and curricular integration	6.25±1.06	6.00±1.26	6.64±0.67	6.22±0.83	6.28±0.98
Pre- and misconceptions	6.31±0.95	5.40±1.07	5.36±0.92	6.10±0.99	5.82(*)±1.04
Dealing with willingness and capacity to act	6.23±0.60	5.55±1.13	6.64±0.5	6.20±0.92	6.16±0.88
Formation of opinion and argumentation integrated into climate education	6.00±1.53	5.73±0.79	5.82±0.98	5.40±1.43	5.76±1.21
Self-reference: living environments and options to act	6.46*±1.13	5.18*±1.72	6.60±0.7	6.56±0.53	6.19±1.26
Teaching: strategies and illustration	6.08±1.04	5.91±1.04	6.55±0.69	6.80±0.42	6.31±0.9

* significant differences of ratings were found for the respective theme between the indicated expert groups according to the Dunn-Bonferroni post hoc test

(*)significant differences of ratings were indicated for the respective theme by Kruskal-Wallis Test, but not verified by Dunn-Bonferroni post hoc test

Furthermore, it revealed that for *Self-reference: living environments and options to act* differences were between climate researchers and education researchers (adj. $p=0.02$) as well as between climate researchers and teachers (adj. $p=0.03$). Significant differences between groups for *Impacts of anthropogenic climate change* and *Pre- and misconceptions* were not verified by the post-hoc test (adj. $p > .05$). Thus, regarding the respective measures of central tendency, climate scientists

rated one content-related theme (*Components and functioning of the climate system*) as significantly more relevant than teachers and teacher educators did, whereas education researchers and teachers rated one teaching-related theme (*Self-reference: living environments and options to act*) as significantly more relevant than climate researchers did.

In round 3 only two themes show mean ratings <6 across all groups: *Pre- and misconceptions* and *Formation of opinion and argumentation*. These two, as well as *Self-reference: living environments and options to act*, show high standard deviations >1. Teaching-related themes were overall rated with less relevance (mean <6, except for one theme) by climate researchers and show a higher variance (standard deviation >1 for all but one theme). Moreover, all teaching-related themes except for *Pre- and misconceptions* and *Dealing with willingness and capacity to act* show high standard deviations of >1 within the group of education researchers. Thus, teaching-related themes are rated more controversially than content-related themes especially with respect to different expert groups.

4.4 Coverage of the final themes and overall discussion

The study aimed at answering the question what knowledge teachers need to support students in the development of CL with regard to knowledge of scientific background and content related to climate change as well as knowledge of how to convey this into teaching. As results of our Delphi method, 13 overarching themes evolved (see Table 4-2). Experts might have spent less time suggesting ways to merge or split themes in the third round than they had before but increasing relevance levels in the ratings of the themes indicate that throughout the iterative process of the Delphi rounds, the themes have become increasingly precise, distinct, and phrased in ways that allowed experts to agree to the themes with larger consensus and with increasing relevance levels. The significant differences between group ratings revealed by the Kruskal-Wallis test indicate that climate researchers seem to rate content-related themes higher and teaching-related themes lower than the other expert groups do. This pattern can also be observed as a tendency in descriptive (non-significant) differences in mean ratings but not very pronounced. Hence, there could have been a growing understanding of teaching-related issues by climate researchers or of content related issues by educators that attributed to higher ratings and increased consensus.

The seven content-related themes comprise climate history, the climate system, climate science, causes of, impacts of, and ways to deal with climate change as well as relationships of climate change to other global challenges. The six teaching-related themes cover students' conceptions, broad approaches towards climate change in the classroom such as argumentation, action, and personal relevance, specific methods, and they stress the interdisciplinary character of the topic. The themes with the highest mean ratings (>6.5) are related to the *climate system*, *causes of*, *impacts of*, and *ways to deal with climate change*. These aspects are reflected in the *Climate Literacy: Essential Principles* (CLEP), a detailed elaboration of aspects of CL published by the U.S. Global Change Research Program (USGCRP) – although structured differently. Also reflected in the CLEP is the theme *Climate history and natural climate fluctuation*. The focus in the CLEP is strongly on physical and biological aspects of climate and climate change (USGCRP 2009), whereas the present study also considers social and economic aspects as they need to be integrated in a system-wide approach (Shepardson et al. 2011b) and thus addresses the need for teachers to include political, social and economic aspects of climate change (Herman et al. 2017). Furthermore, since

the study was meant to consider the specific knowledge of teachers and, thus, knowledge especially relevant for teaching, this framing needs to be considered as well.

Hestness et al. (2014) take this into account in their literature review and stress the need for teachers to handle complex knowledge of climate change although coming from different disciplinary backgrounds. Hence, aspects of the climate system as reflected in the theme *Components and functioning of the climate system* are reported as basic knowledge that needs to be recognized in its complexity and in a correct way by teachers, especially those who teach science (Wise 2010; Ekborg and Areskoug 2012; Hestness et al. 2014; Hannah and Rhubart 2020; Howard-Jones et al. 2021). Further involved with the social side of climate education is the theme *Dealing with climate change* that reflects different levels of action to mitigate climate change and to adapt to its impacts. Experts commented on both individual and societal measures, and while some stated that individual action will not solve the problem, others stressed the necessity to include options that students can take themselves. The teaching-related themes of *Dealing with willingness and capacity to act* and *Self-reference: living environments and options to act* pertain to the same levels of individual and structural action. These findings open up opportunities for teachers to include CL education beyond science and earth science subjects, but also stress the need to prepare teachers with a profound scientific knowledge basis. However, teachers need to be enabled to guide students towards action competence and agency (Crandon et al. 2022) of which appropriate career choices could be part of, and instruction should include occasions for the reflection and discussion of values and worldviews (Libarkin et al. 2018).

In this sense, approaches including the local allocation of climate change and personal significance in order to enhance relevance of the topic (Johnson et al. 2008; Kirk et al. 2014) – such as experiencing climate-change-related weather events can raise awareness (Lee et al. 2015; Hoffmann et al. 2022) – are reflected in these themes. Students seem to have difficulties connecting climate change (solutions) and their own lives (Shepardson et al. 2011b), but decreasing psychological distance leads to higher concern towards climate change (Busch and Ayala Chávez 2022). Overall, this might eventually lead to the evocation of counteracting climate change. The experts discussed measures of individual action for counteracting eco anxiety and enabling students to draw positive solutions for the problem, in line with Johnson et al. (2008). The right way to deal with climate change in society is not defined yet. Some students themselves think education to be important, while others value instant school striking higher (Lee et al. 2022) and also teachers do seem to be unsure about the adequate path (Liu et al. 2015) which imposes unease on the question how to handle the societal debate about the topic (Uherek and Schüpbach 2008). However, our themes outline suggestions of how to approach these issues in classes. Climate change being perceived as a controversial topic in the media and by teachers requires preparation and strategies to handle the topic in class (Hestness et al. 2014). Therefore, the integration of *Opinion formation and argumentation* has been implemented in this study giving teachers opportunities to handle the perceived controversy. People are confronted with information about climate and climate change in everyday news media, where imbalanced impressions of the scientific consensus about anthropogenic climate change might be promoted and the perceived controversy of the topic is cultivated by a lack of understanding of the nature of climate science (Niepold et al. 2007). This is reflected in the theme of *Climate science and dealing with information* where the need for awareness of the evolving status of knowledge is addressed as well as the handling of information sources and

uncertainties. Teachers seem to have difficulties with the scientific process as such and with handling controversies about perceived uncertainties in classes (Johnson et al. 2008; Liu et al. 2015). Related to other research (Johnson et al. 2008; Hestness et al. 2014) experts stressed the necessity for teachers to know about the scientific process themselves, the ability to scrutinize information and sources in order to counteract positions of climate change denial due to perceived absence of scientific consensus providing a profound basis for the development of teachers' professional development.

Regarding the interdisciplinary nature of climate education, experts have emphasized the need for connecting different school subjects with the topic – which would provide different perspectives – in the theme *Interdisciplinary structure of climate education and curricular integration*. Some, however, opined that science should be the central discipline of focus. For the time being, the practice of allocating climate education in science curricula rather than in social disciplines prevails, although the latter has gained relevance in education research recently (Dupigny-Giroux 2010; Shwom et al. 2017). Comments from the expert panel underlined the need for such interdisciplinary education but pointed at constraints of overscheduled separated disciplinary curricula, missing opportunities for interdisciplinary exchange, and limited amount of time. While some suggested assigning specific knowledge aspects to single subjects, others advocated for dissolving the current separation of subjects in general. Especially experts (including teachers) coming from non-scientific disciplines were calling for approaches towards the topic that were not only focused on the physical and natural basics. In general, teachers seem to be open to include the topic in their classes, independent from their disciplines (Johnson et al. 2008) but seem to have problems with the missing explicit coverage within disciplinary curricula and standards (Sullivan et al. 2014), and they miss preparation (Demant-Poort and Berger 2021). Thus, climate education is rather being included subordinate to classical (e.g., chemistry) topics or postponed to upper secondary classes (Feierabend et al. 2011). The study results, however, could lead to new integrated approaches of curricula, inter-subject collaborations, and team-teaching.

As central aspects of teachers' knowledge, we asked particularly for common pre- and misconceptions. Experts named well-known examples of *Pre- and misconceptions* that can be found throughout the literature (McCaffrey and Buhr 2008; Shepardson et al. 2011a; McCuin et al. 2014) and that may be triggered by school books (Shepardson et al. 2011b). Accordingly, they mentioned simplified concepts, biased proportions of variables or the relocation of the problem elsewhere, and the overgeneralization of environmental problems such as pollution (Papadimitriou 2004; Lambert et al. 2012) which even merits an own theme, *Relation to other societal or global problems*, in the present study. Since misconceptions among teachers do occur (Papadimitriou 2004; Hestness et al. 2014; Anyanwu et al. 2015; Ratinen 2013), this is a highly relevant part of teacher professionalization regarding climate education and our results pinpoint the relevant concepts that teachers need to overcome. The promotion of the scientific background knowledge is a basis to prevent teachers from holding misconceptions (Sullivan et al. 2014), which the present study contributes to providing profound description of knowledge aspects that can be transferred into the professional development of teachers.

Eventually, for teachers to be enabled to take CL into their teaching they need to be equipped with skills, tools, and techniques for managing the topic in classrooms (Holthuis et al. 2014). The

theme *Teaching: strategies and illustration* brings together particular methods and classroom activities that focus on illustration, practice-orientation, personal involvement, and changing perspectives. Thus, inquiry-based science education, hands-on work with data, role plays, and the application to personal livelihoods and environments are reflected as they are found throughout the literature (Johnson et al. 2008; Dupigny-Giroux 2010; Hestness et al. 2014; Kirk et al. 2014; Sullivan et al. 2014) but are compiled and supported by experts' consensus in our results.

Throughout several themes, experts pointed to the need for teachers to be able to adapt the aspects of CL reflected in the themes to different target groups, especially regarding the age of students. So far, teachers must do this by experience and may be hindered by curricula for schools and for teacher education that allocate complex issues to upper secondary classes and leave out adequate preparation for primary or lower secondary educators (Uherek and Schüpbach 2008). Here, more work needs to be done in the elaboration of new concepts regarding curricula, school development, and teachers' collaboration which the present study's results could be a valuable starting point for.

4.5 Conclusion

Using a Delphi method with an expert panel, we identified specific aspects of what teachers need to know with regard to the scientific background and content related to climate change in order to convey this into teaching. We could derive 13 clearly delineated themes, seven of which contain content knowledge that goes some way beyond the strong focus of scientific aspects and additionally takes social sciences into account. Furthermore, six themes outline how to support students with their role in society beyond the limitation of single disciplines. The 13 themes provide – to our knowledge – the first compilation of the basic knowledge aspects for teachers aiming at teaching for CL that moreover has been validated by experts in the field in a multilevel process. However, the question remains to what extent teachers from different subject backgrounds and for different school levels or age groups need the whole range of this knowledge compilation or in which ways it could and should be adapted to individual focus groups depending on their respective scientific preparation. Furthermore, as our experts came from three different countries that bring together different backgrounds in teacher training and teachers' professional development (PD), this is something that needs to be taken into account as well. Yet, the results of our Delphi study prepare the ground for adaptations on different levels of the educational system to integrate CL into education: They can serve as (a) guideline for school curriculum development; and (b) a starting point for developing respective teacher preparation and professional development courses in order to enable teachers to address CL in classrooms from a broad multidisciplinary basis. One relevant outcome is that CL should be approached as transcending science and geoscience classes in trans- and interdisciplinary ways. This, in our opinion, is a challenge that needs to be overcome by transforming traditional school curricula on the basis of respective research. In order to develop teacher preparation, future research should also focus on how teacher PD is organized in different countries looking for best practice models. Longitudinal studies that investigate teachers' PD with respect to CL as well as the learning outcomes of their students could help to understand the impacts of teacher education on students' CL.

4.6 Declarations

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Competing interests:

The authors have no relevant financial or non-financial interests to disclose.

Author contributions:

The study was designed by Kathryn Leve. Ute Harms and Hanno Michel contributed to the study conception and design. Material preparation, data collection, and analysis were performed by Kathryn Leve. The study was supervised by Ute Harms. The first draft of the manuscript was written by Kathryn Leve. Ute Harms and Hanno Michel revised previous versions of the manuscript. All authors read and approved the final manuscript.

Data Availability:

The datasets generated during the current study are not publicly available due to participants in this study consenting to their data being stored securely at IPN. They did not consent to their data being shared publicly.

Ethical approval:

Ethical approval for this study was granted by the IPN Ethics commission in January 2021. The authors declare that they have adhered to all ethical regulations.

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4.8 Supplementary Materials

The supplementary material compiles the 13 final themes describing relevant knowledge of scientific background and teaching strategies that teachers need to foster climate literacy as they resulted from the Delphi study. Each theme consists of a heading followed by a description text that has been written following the expert panel's suggestions, revisions and approval.

Climate history and natural climate fluctuation

The dimension of anthropogenic climate change during the last >100 years (since the beginning of industrialisation) can be classified based on the historic observation of climate history. This can be opposed to sceptical positions. Thereby, the comparison of the long timescales of natural climate history and the extremely short timescales of the anthropogenic changes can be regarded as helpful. The extent and the depth of the thematisation should be adaptable depending on the capacity of time, and on the target group: A basic illustration could be: Time series, which represent the development of the CO₂-concentration and the trend of the global mean temperature. A deepening illustration could be: Causes for natural climate fluctuations and their order of magnitude, as well as the effects of climate fluctuations in earth's history on vegetation and wildlife.

Climate models can be used in the classroom to conduct comparing simulations with and without anthropogenic emissions, in order to illustrate that 98% of the temperature increase since 1850 was caused by humans (cf. 6th IPCC-report). The understanding of time series can be difficult, though. Therefore, it is important to foster an interest in the coherences and to prevent the development of an ideology. A connection to personally meaningful coherences to improve the understanding is helpful for that.

Components and functioning of the climate system

The understanding of what climate is, what distinguishes it from weather, and that it is a matter of an overall system consisting of several subsystems is fundamental. Depending on the focus subject of the teacher, different focuses (based on the listing below) should be set.

A systemic understanding regarding the interaction between the earth's spheres and further components of the climate system is important. Thereby, the systems thinking is fostered, and the important control variables of the climate system can be understood. The complexity regarding possible actions becomes visible. Depending on the teachers' focus subject they involve: Cause-effect-interactions and cause-effect-chains, non-linearity, feedback loops (e.g. ice-albedo-feedback loop), tipping points (e.g. melting of permafrost soil and methane- release).

Teachers should not recoil from the complexity, but they should develop the ability to calmly approach complex questions and to convey this capability to students. Such abilities are applicable to other complex contexts. The ability to make a good choice and to convey the coherences in an easily accessible manner to different target groups is significant.

Properties of the climate system are:

- the structure and the composition of the atmosphere
- the earth's radiation budget and the role of solar irradiation

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- the greenhouse effect, the role of greenhouse gases, the importance of the greenhouse effect for the living conditions on earth, the anthropogenic intensification of the greenhouse effect
- the exchange of air masses, winds, the atmospheric circulation
- the role of aerosols in the atmosphere
- the ocean currents, the role of the ocean as a thermal- and carbon storage system
- the global water cycle
- the importance of clouds and ice-covered surfaces
- the climate zones of the earth
- the biochemical cycles and especially the carbon cycle, but also nitrogen- and phosphate cycles in relevance to the vegetation
- natural carbon sinks, also terrestrial ones
- the photosynthesis, the cellular respiration and the interplay of climate and vegetation, the resulting ecozones of the earth
- the bio-geophysical effects of land use changes

Climate science and dealing with information

Scientific findings contain insecurities and uncertainties, but they represent reliable findings that have been validated through the scientific process. An understanding of the emergence of scientific climate-knowledge (about measurement-methods, climate archives, climate models and scenarios) helps to understand it and to deal with certain and uncertain knowledge. The contents of the IPCC-report (report of the Intergovernmental Panel on Climate Change) represent the current state of knowledge.

This understanding of knowledge counteracts the denial of the current anthropogenic climate change by training a critical view on the approach to information. This way, wrong presentations can be distinguished from scientifically tenable positions and they can be responded to.

Teacher education for climate literacy is supposed to make the current state of knowledge accessible for teachers and impart techniques and argumentation to recognise and deal with climate change deniers (also critical-constructive dealing with social media and digital geo-media).

Relation to other societal and global problems

To understand the great significance of the currently ongoing climate change, it should be related to and differentiated from other problem areas such as resource consumption, biodiversity loss, poverty, migration, population growth, as well as air-, water-, and soil pollution. Thus, an understanding for global relations and influence factors is fostered and the principle of climate justice can be understood. Since learners often overgeneralize climate change with other environmental problems (e.g. plastic waste), one should in a differentiated way elaborate on the aspect, that other problem areas can indeed be connected with climate change, but still have other causes.

Reasons for anthropogenic climate change

Teaching about the causes of climate change should be about the anthropogenic reinforcement of the natural greenhouse effect and the consequences resulting from interactions within the climate system.

Focussing on the reasons and sources of the rising concentration of the greenhouse gases leads to the individual activities of individual people but also to macrosocial and political dimensions, where the main sources of greenhouse gases are to be found.

Particularly relevant societal areas are:

- use of fossil fuels for the supply with heat, electricity, and for mobility
- the operating principle of combustion processes of fossil fuels
- the linkage to activities such as traveling, leisure, living, communication
- the linkage to political dimensions such as subsidies for the carbon- and car industry
- population growth, leading to a higher amount of emissions
- food- and retail chains
- anthropogenic imprint on natural surfaces
- land use and especially agriculture, fertilisation, and livestock farming
- deforestation
- the destruction of ecosystems, that function as significant sinks for greenhouse gases

The impacts of anthropogenic climate change

Basically, it is important to understand that climate change causes consequences for terrestrial and aquatic ecosystems, as well as economic and social impacts. An understanding of the interactions between changes in nature and the life of humans requires questions about the qualitative significance of the environment, biodiversity, and cohabitation.

The impacts of climate change come with uncertainties and no linearity so that the effects of a 1.5°C or a 2°C warming are different. The handling of consequences and uncertainties should be positively oriented to prevent triggering a feeling of powerlessness. Furthermore, local positive developments as well as positive effects of adequate action can be underlined.

Examples of specific effects can serve as a basis to go deeper into focal points.

Changes of the nature-spatial circumstances of the earth:

- an increasing average temperature as well as further local temperature increases
- the melting of ice sheets and glaciers
- sea level rise
- changes of precipitation patterns
- changes of the salinity of sea water, changes of ocean currents
- erosion and desertification
- extreme weather event such as heatwaves, drought, heavy rains, floods, local fire

Effects to the biosphere:

- damage to ecosystems
- acidification of the seas

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- interactions of vegetation/soils/climate
- species extinction and biodiversity loss
- changes in distribution patterns of vegetation and wildlife
- the effect of CO₂-fertilization to vegetation

Effects to human society:

- changes in the availability of freshwater resources (bad harvests, drinking water shortage), changes in ground water levels
- regions with an improving access to fresh water: improved conditions for agriculture and drinking-water supply
- floods in coastal areas, river floods
- impacts to peoples' health
- uninhabitability of areas
- conflicts, warlike disputes
- (refugee) migration
- economical impacts

Dealing with climate change

In order to encounter climate change, the mitigation of the causes and effects as well as the adaptation to the effects should be distinguished. When teaching about these strategies, it is important to distinguish between structural (political, global/regional) strategies and individual options for action. The possibilities and limitations of the action range of individuals and respectively different states (industrial states, insular states, global south) require complex political decision-making processes. Thereby, students should be seen as agents, who can initiate a transformative change. Therefore, legal matters (environmental law, human right) like for instance the role of legislation in dealing with climate questions or questions of justice can be considered, as well.

Different migration- or adaptation strategies can lead to dilemma-situations, such as the individual restriction in favour of the society, and inconsistencies. Furthermore, there are uncertainties regarding different climate change scenarios. Therefore, an ambiguity tolerance is important.

Teachers should be able to mediate a differentiated picture of who has potential influence and how students can find themselves in it. Specific aspects can serve as a basis to go deeper into subject-specific focal points:

Reduction of the causes/effects through the reduction of anthropogenic greenhouse gases

- international agreements
- governmental measures, sustainability strategies regarding sectors like forestry/ agriculture, mobility, food supply
- climate engineering
- change of transport and mobility
- the path of industrial transformation
- post-growth concepts
- individual options for action regarding the CO₂-emissions, consumption, one's own health as motivation

- two-sided point of view: Consequences of increasing carbon tax e.g., for companies, price development
- renewable energies (including operating principle) and energy revolution, societal acceptance of technologies
- creation of carbon sinks, such as reforestation
- transformation of the production and marketing to degrowth/greengrowth, recycling economy
- future job descriptions
- net-zero goals, negative-emissions, carbon-offsetting

Adaptation strategies:

- greenery, shadowing
- constructional changes (energy efficiency)
- city-planning/ urban development and “how to build”: less sealing, other material than stone and concrete
- urbanisation in surrounding areas versus “city of short ways”
- flood protection
- settlement policy
- future job descriptions
- education for resilience

Interdisciplinary structure of climate education and curricular integration

Climate literacy is basically a cross-sectional task that is too complex for only one of the existing subjects. It is particularly important to connect natural-, economic-, and social- science, as well as liberal arts to a subject-connecting or even an interdisciplinary approach. This is especially relevant regarding a societal transformation towards climate protection. Media competence has to be considered with regard to the reporting about climate change, and the discussion of plausible climate scenarios under various societal conditions need to be discussed. Subject-specific foundations can be mediated from the perspective of different subjects and then be put together in an interdisciplinary manner. At school, an interface for the linkage of diverse professional topics in councils would be helpful.

The structuring of the topic for different ages of learning groups by adapting complex issues is crucial. Teachers should be able to adapt complex issues according to different age groups. For them to have an overview kind of knowledge about different subject-specific focal points would facilitate the interdisciplinary work. Regarding teacher education, school concepts such as the Whole-School-Approach (school-overarching climate-curriculum, which keeps reviving climate education in and besides the subjects) could be mediated and developed.

The interviewed experts assigned focal point of climate education to the following subjects:

Geography (physical): components of the earth system and the climate system, the earth’s spheres and integration of nature-spatial basics and the societal areas, systemic understanding, climate history, climate zones, consequences of human actions, natural carbon sinks (soils, forests, moor, oceans), ecosystem services

Physics: the earth's radiation budget, radiation, reflexivity of different surfaces, energy policy, atmospheric dynamics, climate models, physical states of water, IR-spectra of the greenhouse gases, functioning principle of photovoltaic systems and wind turbines, currents, exchange processes on surfaces (radiation, latent and perceptible warmth), heat-storage in mediums with different densities, the isolating effect of materials

Chemistry: the earth's radiation budget, ozone hole/ozone formation, air pollution, hydrocarbons, combustion processes, greenhouse gases, water solubility of the greenhouse gases, weathering of carbon acid, biogeochemical cycles, natural carbon sinks, gas to particle conversion, wet-state-chemistry (atmosphere as a chemical reactor)

Biology: photosynthesis, CO₂ during the evolution, ecosystems and biodiversity, distribution of the species and shift of habitats, significance for humans and the human health, biogeochemical cycles, natural carbon sinks (soils, forests, moors, oceans), nature conservation, ecosystem services, significance of humans in cultural systems

Ethics/religion/philosophy/social studies: climate justice, climate and living circumstances, appreciation of the earth, options for action, energy policy

Politics/economy/sociology/geography (human): (refugee) migration, economic consequences, costs of the CO₂-prevention, individual behaviour and climate efficacy, international climate agreements, energy policy, willingness of people to design areas climate-friendly, significance of humans in cultural systems, juridical aspects (environmental law, human right), the role of legislation in dealing with climate issues

History: the absence of the summer of 1816 as an example for climatic effects on the society, medieval interglacial period, early effects of human actions on climate, cultural history and technical progress, industrialisation, history of the discovery and politics of the anthropogenic reinforcement of the greenhouse effect (from Arrhenius to Hasselmann to Paris Agreement)

Nutrition classes: reduction of the consumption of food of animal origin

Arts and music: artistic approaches to connect to living reality

German/languages: finding sources, significance of climate change for indigenous people, dystopias and short stories

Mathematics/computer science: modelling, calculations with data, statistics and the opportunity of a desired statement through the choice of a suitable method – also in a graphical presentation

Pre- and misconceptions

The interviewed experts named assumptions, which do not consider how multi-layered and complex the problem is (e.g. the assumption that climate change happens somewhere else), as common preconceptions. Furthermore, they mentioned preconceptions that demonstrate distorted proportionalities of causes, effects, and actions (e.g. allegedly harmless slight changes of the CO₂-concentration). Also, misconceptions were named, which involve simplified or incorrect concepts of phenomena involving climate and climate change (e.g. confusion of weather/climate).

Teachers should know these conceptions, how they are formed (e.g. illustration in schoolbooks), and how to deal with them (e.g. conspiracy theories). In class, they can be used as starting points to further develop them towards scientific conceptions.

The interviewed experts named the following examples of specific pre- and misconceptions:

- misinterpretations of single events as proof or contrary indicators of climate change
- ignoring the occurred impacts at other locations of the earth
- no impacts of climate change, because the CO₂-concentration in the atmosphere is considered as low, or the temperature rise of 2°C is considered as being only slight
- underestimation of the dismantling period of CO₂ in the atmosphere
- climate change is not being located in Central Europe
- missing link with own actions or attribution of great relevance of single actions
- allegedly easy technological solutions
- disaster scenarios or the concept that there are exclusively negative effects
- confusion of weather and climate
- considering the ozone hole as the cause of climate change
- conception of the atmosphere as a closed layer, like a greenhouse
- perception that climate change is destroying life on earth even though it just drastically changes the circumstances
- alleged difference between natural (good) and anthropogenic (bad) CO₂
- lack of comprehension of physical concepts of heat or radiation, interaction with the earth's surface and atmosphere
- lack of comprehension of the complexity of the climate system

Dealing with willingness and capacity to act

The step from knowledge to action should be part of teaching. Here, the focus is on individual responsibility as well as on obstacles regarding one's own willingness to act, such as a lacking self-efficacy, insufficient willingness for a renunciation or changes of habits, and repression strategies. On the other hand, objective boundaries of self-efficacy (poverty, power relations, rebound effect, social and physical risks of the action) must be considered.

Teachers should be able to support students to develop their own feeling of responsibility and to perceive themselves as agents to also prevent the feeling of powerlessness.

Formation of an opinion and argumentation integrated into climate education

Different perspectives and argumentation strategies play a role in the societal and political debate about climate change. By including the controversy of the topic and the scientific process as well as immanent uncertainties, the valuation of scientific and non-scientific perspectives can be practiced. Teachers should be able to foster the (interdisciplinary and) specialist appraisal as a relevant topic of climate education and they should enable students to develop an own opinion regarding for instance solution approaches, and to become responsible and mature in regard to dealing with information and illustrations.

Self-reference: living environments and options to act

During climate education, teachers should create references to the living environments of learners through different approaches. Climate can be perceived as something local by taking up specific local/regional events, or by linking global phenomena to local circumstances. Involving own examples and own activity orientations in class increases the motivation and helps to understand complex processes. The well-being of students (counteracting their anxieties, eco-anxiety) should be furthered by reinforcing students in their role as consumers, but also as citizens, e.g. through own projects such as city cycling, school gardening, or activities/exhibitions at school that they come up themselves. A societal framing should take place to rank own means of actions in so far, what individuals can achieve on their own and what society would be able to collectively actuate.

Teaching: Strategies and illustration

The interviewed experts mentioned a variety of different methods and approaches that are of particular significance regarding in climate education. Therefore, illustration, practical relevance, consternation, and changes of perspectives are crucial.

The following methods and approaches were mentioned by interviewed experts as particularly appropriate for the context of climate education.

Metacognitive elements: starting from a specific content, then thinking about systemic aspects, then generalising these/transfer them on other contents

Project work: in different manners, supplementing or as a mandatory program; oriented towards specific close to school examples such as the own solar panels on the roof or individually conducted research processes within inquiry-based science education approaches

Data work: comprehension of issues, hands on calculations, analysing, graphic editing (diagrams); as a result of that and with according tools simulations or modelling can be individually performed to illustrate the work of climate science

Game theoretical exercises: with simulated formats of discussion forums (analogue to TV-formats) or imitating the UN Summit/climate conferences in planning games, thereby practicing and comprehending the societal and political discourse, examining different perspectives, dilemma-discussions

(Digital) Media for teaching: in the form of explanation videos; in the form of practical individual work by producing for example videos, podcasts, school radio, or school paper

(Digital/social) Media as the learning object: appraisal of information

External persons/institutions: e.g. from agriculture, municipality, science, local educational institutes for speeches or as interview partner at school

Excursions: for instance to research institutes, to e-mobility-producers, to places of climate change in the own region or to different kinds of power plants

Experiments: regarding photosynthesis, evaporation, and the greenhouse effect; independent measuring of climate data

5 Study 2:

Curriculare Einbindung der Klimabildung – wie ist der Stand und wo soll es hingehen?²

Zusammenfassung

Der Umgang mit dem anthropogenen Klimawandel ist heute unbestrittenermaßen eine gesamtgesellschaftliche Notwendigkeit. Bildung kann einen Schlüsselbeitrag dazu leisten, dieser Notwendigkeit zu begegnen. Inwieweit die schulische Bildung dieser Schlüsselrolle gerecht wird, lässt sich für Deutschland anhand der bundesländerspezifischen Curricula untersuchen. Die vorliegende Studie gibt anhand einer Auswahl von drei Bundesländern (Bremen, Saarland, Mecklenburg-Vorpommern) einen vertieften Einblick, inwieweit und wie die Klimabildung in deutschen Curricula der Natur- und Gesellschaftswissenschaften für die Sekundarstufe gegenwärtig umgesetzt wird. Es zeigen sich zwei Muster: zum einen, dass der Klimawandel an übergreifende Themen, wie Nachhaltigkeit, angeknüpft, zum anderen, dass dieser explizit als eigenständiger Inhalt festgeschrieben wird. In beiden Fällen gibt es sowohl curriculum-übergreifende Hinweise als auch verbindliche Fachinhalte, die das Thema aufgreifen. Schwerpunkte finden sich in den Naturwissenschaften und der Geographie, aber auch in weiteren, gesellschaftswissenschaftlichen Fächern gibt es Bezüge zum Klimawandel. Nicht erkenntlich ist in den aktuellen Dokumenten, inwieweit eine Verbindung über diese Fächer hinweg geschieht.

Schlüsselwörter: Klimabildung, Climate Literacy, Curriculum, interdisziplinäre Aufgaben, BNE

Abstract

It is one of today's unquestioned challenges to take action towards climate change as a society. Education can be a key contribution to meet this challenge. The analysis of German curricula can show to what extent the content of school education would come up to this role. The present study provides an insight into how climate education is currently being implemented in German curricula of science and social studies for secondary education in a sample of three federal states (Bremen, Saarland, Mecklenburg-Vorpommern). They show two patterns: on the one hand that climate change is addressed through cross-cutting themes such as Sustainability but on the other hand that it is also described explicitly as a specific topic of its own right. In both cases there are cross-curriculum references as well as mandatory topics. Foci are to be found in Science subjects and in Geography, but there are also references to climate change that can be found in further

² This is the-peer reviewed version of the following article: Leve, A.-K., Garrecht, C., Harms, U. (2025). Curriculare Einbindung der Klimabildung – wie ist der Stand und wo soll es hingehen? Zeitschrift für Didaktik der Naturwissenschaften. 31:3. The final print version of this article is available at: <https://doi.org/10.1007/s40573-025-00178-7>.

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social subjects. It is not visible within the current curricula documents if and how a connection between the subjects is being made.

Keywords: Climate education, Climate Literacy, Curriculum, interdisciplinary tasks, education for sustainable development

5.1 Einleitung

Das Erreichen des international vereinbarten Ziels, die Erderwärmung möglichst 1,5°C nicht überschreiten zu lassen (UNFCCC 2015), erscheint zunehmend unwahrscheinlicher (IPCC 2023). Um auf die Veränderung reagieren zu können und weitere Erwärmung zu minimieren, wird Bildung eine Schlüsselrolle zugeschrieben. Hierbei wird insbesondere die Wechselwirkung zwischen den Naturwissenschaften und aktuellen politischen und gesellschaftlichen Themen hervorgehoben, um das Interesse von Jugendlichen zu stärken und gesellschaftliche Teilhabe durch naturwissenschaftliche Bildung zu unterstützen (Kranz et al. 2022). Essentiell scheint es zu sein, dass Schülerinnen und Schüler einzelne Aspekte aus unterschiedlichen Fächern und Unterrichtsthemen verknüpfen können (Niebert 2007).

In der internationalen Literatur wird die Klimabildung unter dem Begriff der *Climate Literacy* (CL, deutsch Klimabildung) konzeptualisiert. CL umfasst neben (i) Wissen über das Klima und den Klimawandel (ii) Fähigkeiten mit Informationen umzugehen und sie zu kommunizieren, sowie (iii) Einstellungen, die zu klimafreundlichen Handlungen beitragen (Azevedo und Marques 2017). Eine inhaltliche Basis vor allem der naturwissenschaftlichen Grundlagen des Klimas und des Klimawandels für CL wurde vom US Global Change Research Program (USGCRP 2009) erarbeitet. Shepardson et al. (2012) argumentieren, dass, um den Klimawandel verstehen zu können, zunächst ein Verständnis für das Klimasystem bestehen muss, und schlagen ein Rahmenkonzept für den Unterricht über das Klimasystem vor. Für den naturwissenschaftlichen Unterricht zum Thema Klimawandel haben Schubatzky et al. (2023) diese naturwissenschaftlichen Grundlagen des Klimawandels in notwendige Themenbereiche untergliedert. Weiterführend wurden im Rahmen einer Delphi-Studie von Leve et al. (2023) relevante fachliche und fachdidaktische Themen zum Wissen von Lehrkräften und zum Unterricht über den Klimawandel herausgearbeitet. Inhaltlich finden sich in allen drei Studien ähnliche Aspekte wieder (z.B. Klimasystem, Atmosphäre, Treibhauseffekt, Kohlenstoffkreislauf, Biosphäre und Klima, Ursachen und Folgen des Klimawandels, Klimawissenschaft). Shwom et al. (2017) erweitern die naturwissenschaftliche Basis des USGCRP um sozialwissenschaftliche Aspekte, wie das öffentliche Verständnis von Klimawandel und die gesellschaftlichen Rahmenbedingungen für den Umgang mit ihm. Auch von Leve et al. (2023) werden diese Aspekte insbesondere im Hinblick auf den fachdidaktischen Bereich aufgegriffen. Auch wenn also Hinweise zu den relevanten Inhalten vorliegen, ist die Frage, ob und wie die Klimabildung in den Unterricht integriert werden kann, Gegenstand aktueller Forschung. Von Lehrkräften wird als ein Hinderungsgrund, den Klimawandel in den Unterricht zu integrieren, genannt, dass in den jeweiligen Fachcurricula der Raum für das Thema fehle (Hestness et al. 2014; Sullivan et al. 2014; Wise 2010). Nur die Einbindung des Klimawandels in die Curricula der Unterrichtsfächer kann dessen Verbindlichkeit für den Unterricht gewährleisten (Hannah und Rhubart 2020). Vor diesem Hintergrund ist das Ziel unserer Studie anknüpfend an die umfangreiche Studie von Siegmund et al. (2021), die einen quantitativen Überblick über den Stand der curricularen Einbindung der Klimabildung in ganz Deutschland gibt, exemplarisch an ausgewählten Bundesländern qualitativ vertiefend zu untersuchen, wie die Klimabildung hier (1) an fachliche Inhalte angeknüpft und (2) konkret in die Curricula eingebunden wird.

5.2 Theoretischer Hintergrund

5.2.1 Bedeutung der Curricula in Forschung und Bildung

Curriculumforschung im Bereich der naturwissenschaftlichen Fächer gelangte durch die Einführung der Bildungsstandards (2004, 2012, 2020) wieder mehr in den Fokus. Alle vier Kompetenzbereiche der Standards fanden dabei Beachtung, allerdings lag der Schwerpunkt auf dem Bereich Fachwissen (Bernholt und Parchmann 2021). Die Bildungsstandards formulieren die übergeordneten Ziele schulischen Lernens für bestimmte Jahrgangsstufen. Curricula auf Ebene der Bundesländer hingegen listen detailliert Lernziele und Inhalte in zeitlich strukturierter Anordnung (KMK 2004). In der Forschung zu Curricula und Unterricht wird unterschieden zwischen dem formalen („*official*“) Curriculum, wie es institutionell vorgegeben ist, dem intendierten („*intended*“) und schließlich dem ausgeführten („*enacted*“) Curriculum, wie es von der Lehrkraft geplant und schließlich tatsächlich im Unterricht umgesetzt wird (Remillard und Heck 2014). Die offiziellen Curricula der Bundesländer sind somit die erste Ebene auf dem Weg zur Umsetzung der Inhalte im Unterricht und Gegenstand unserer Untersuchung. Sie gliedern sich in einleitende Kapitel (z.B. zur schulischen Bildung allgemein), zum Fach und zu übergreifenden Aufgaben, bevor Kapitel zu konkreten Standards, Kompetenzen und Fachinhalten dargelegt werden.

5.2.2 Stand der Forschung zur Einbindung der Klimabildung in Curricula

Im internationalen Kontext unterscheidet Eilam (2022) bei der Einbindung des Klimawandels in schulische Fachcurricula verschiedene Ansätze. So hat die Klimabildung meistens keinen separaten Platz im Curriculum, sondern ist über einen lehrplanübergreifenden Ansatz („*cross-curriculum*“; Eilam 2022, S. 2–3) in die Fächer integriert. Hierbei kann sie sowohl übergreifend an das Thema der Nachhaltigkeit und an einzelne Fächern angeknüpft sein als auch nur in einem hauptsächlich verantwortlichen Fach oder aber über viele Fächer des gesamten Curriculums hinweg eingebunden werden (Eilam 2022). Dawson et al. (2022) haben Curricula für Australien, Israel, Finnland, Indonesien und Kanada (Ontario) hinsichtlich Klimabildung untersucht und unterschiedlich ausgeprägte Schwerpunkte in den Natur- und Geowissenschaften gefunden: Teilweise wird der Klimawandel hier nicht explizit thematisiert, sondern an übergreifende Themen, wie die Bildung für Nachhaltigkeit (BNE) gekoppelt (z.B. Israel), teilweise obliegt es den Lehrkräften, ob und wie sie das Thema umsetzen (z.B. Finnland), aber es wurden auch festgeschriebene Unterrichtseinheiten zum Klimawandel gefunden (z.B. Ontario, Indonesien) (Dawson et al. 2022). Ebenso zeigen eine Studie zum Curriculum in Australien (Colliver 2017), wie auch eine Studie für Kanada, dass sich das Thema in den Natur- und Sozialwissenschaften bzw. Geographie findet. In Kanada zeigt sich gleichzeitig aber auch ein sehr heterogenes Bild für die Verteilung zwischen beiden Fächergruppen für die unterschiedlichen Provinzen (Field et al. 2023). Für Singapur haben Chang und Pascua (2017) einzelne, wenige Fächer identifiziert, in denen zum Teil entfernte Bezüge zum Klimawandel hergestellt werden (Wirtschaft, Sozialwissenschaften), aber auch hier werden Klimawandelthemen mit unterschiedlichen Schwerpunkten (z.B. Kohlenstoffkreislauf, Atmosphäre, Auswirkungen, regenerative Energieträger) und Tiefe in Geographie und Naturwissenschaften eingebunden. Für die Schweiz stellen Adamina et al. (2018) im Abschlussbericht der Projektphase CCESO I dar, dass der Klimawandel teilweise explizit als Thema verankert ist und darüber hinaus an andere Themen angeknüpft werden kann. Deutschland stellt, ähnlich wie Kanada, durch die

föderalistisch organisierte Bildungsstruktur eine Besonderheit dar. Für Deutschland haben Siegmund et al. (2021) bereits eine lexikalische Inhaltsanalyse zur Klimabildung unter anderem in den Bildungsplänen der Bundesländer für eine große Auswahl der Fächer in der Primar- und Sekundarstufe I und II durchgeführt. Durch das methodische Vorgehen ermöglicht die Studie Erkenntnisse über Häufigkeit und Verteilung verschiedener Aspekte der Klimabildung. Auch hier zeigen sich Schwerpunkte in der Geographie (thematisch breit) und den naturwissenschaftlichen Fächern (thematisch weniger breit) (Siegmund et al. 2021). Die vorliegende Studie knüpft hier an und untersucht qualitativ und exemplarisch, wie genau die Umsetzung der angesprochenen Aspekte der Klimabildung aussieht. Die Studie geht aufgrund der Exemplarität ausgewählter Bundesländer weniger in die Breite, lässt dafür aber tiefergehende Rückschlüsse darüber zu, in welcher Art und Weise, das heißt wie verpflichtend, an welchen Stellen und mit welcher inhaltlichen Tiefe Klimawandel-Themen in deutsche Curricula eingebunden werden. Darüber hinaus soll diese Studie Erkenntnisse darüber generieren, an welche Themen die Klimabildung angeknüpft und in welchen Schulstufen sie wie ausführlich umgesetzt wird.

5.3 Forschungsfragen

In der vorliegenden Studie soll der Umfang und die Ausgestaltung der Einbindung der Klimabildung in Curricula in drei unterschiedlichen Bundesländern in Deutschland untersucht werden. Weiterhin sollen Unterschiede zwischen verschiedenen Fächern herausgestellt werden. Insbesondere der fächerintegrierte Unterricht, wie im eigenständigen Fach Naturwissenschaften, das aufgrund seiner fächerübergreifenden Struktur als besonders geeignet gilt, Schlüsselprobleme der Menschheit, wie den Klimawandel, zu adressieren (Labudde 2014), werden dabei berücksichtigt.

Folgende Forschungsfragen sollen dabei untersucht werden:

1. Angeknüpft an welche Themen, wie konkret und wie verbindlich wird die Klimabildung in aktuellen deutschen Curricula für allgemeinbildende Schulen eingebunden?
2. Welche Unterschiede gibt es bei der Anknüpfung an Themen und Tiefe der Umsetzung der Klimabildung zwischen den Fächern und Schulformen der ausgewählten Bundesländer?

5.4 Methode

Zur Beantwortung der Forschungsfragen wurden deutsche Curricula für die Sekundarstufe allgemeinbildender Schulen in den Fächern der Natur- und Gesellschaftswissenschaften mittels qualitativer Inhaltsanalyse (Mayring und Fenzl 2019) untersucht. Aufgrund der föderalistischen Struktur des deutschen Bildungssystems ergibt sich entsprechend der unterschiedlichen Schulsysteme mit verschiedenen Schularten in 16 Bundesländern eine Vielzahl potentiell zu untersuchender Curricula. Um einen umfassenden Einblick in die Einbettung der Klimabildung in diese Curricula über mehrere Bundesländer hinweg zu erhalten, wurde für die vorliegende Studie eine systematische Auswahl der Curricula für eine genaue Analyse getroffen. Im ersten Analyseschritt wurde dafür eine Präanalyse durchgeführt, um einen groben Überblick über den Umfang der Klimabildung in den Curricula aller Bundesländer zu gewinnen. Die Ergebnisse dienten als Grundlage für die Auswahl der zu untersuchenden Curricula in der anschließenden Hauptanalyse.

5.4.1 Präanalyse zur Auswahl der Curricula für die Hauptanalyse

Im ersten Schritt wurden exemplarisch die Curricula für Biologie und Geographie in Schleswig-Holstein und Nordrhein-Westfalen, über die aus Vorarbeiten bereits eine vertiefte Kenntnis bestand, sukzessive im Hinblick auf inhaltliche Bezüge zum Klimawandel durchgelesen. Relevante Textabschnitte wurden gesammelt und in ihnen Begriffe identifiziert, die an mehreren Stellen inhaltliche Bezüge zur Klimabildung anzeigten (Bezüge zu Klimawandel, Energie, Klimawandelfolgen, Klimaschutz, anthropogene Einflüsse auf der Erde, Nachhaltigkeit). Aus diesen Begriffen wurde eine enge Auswahl derjenigen Begriffe getroffen, die explizit das Phänomen Klimawandel beinhalten: *Klimawandel, Klima(ver)änderung, Treibhauseffekt, globale Erwärmung, globaler Temperaturanstieg*. Im zweiten Schritt wurden die Curricula aller Bundesländer für die Fächer Biologie, Geographie und die integrierten Fächer wie Gesellschafts- oder Naturwissenschaften nach der Häufigkeit der Klimabildungs-Begriffe durchsucht. Für das weitere Vorgehen wurden die Begriffe der engeren Auswahl (Klimawandel-bezogen) genutzt (siehe Abbildung 5-1).

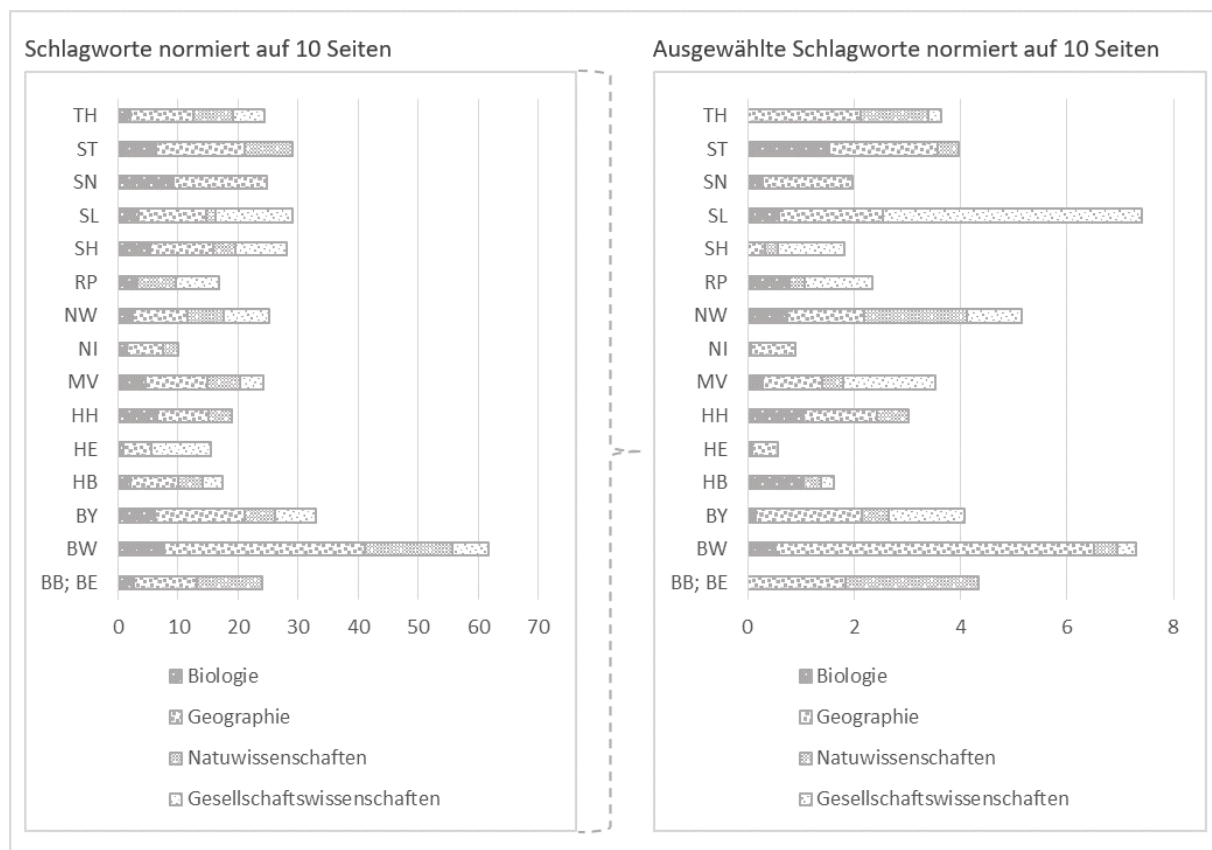


Abbildung 5-1: Anzahl der in den einzelnen Bundesländern gefundenen Schlagworte für die Fächer Biologie, Geographie, Naturwissenschaften und Gesellschaftswissenschaften über alle Lehrpläne hinweg (Jahgangsstufen, Schulformen), links: alle Klimabildungsbegriffe, rechts: enge Begriffsauswahl (Klimawandel bezogen).

Um der Tatsache Rechnung zu tragen, dass die Anzahl der Curricula in Abhängigkeit der unterschiedlichen Schulsysteme und Curriculastruktur je Bundesland ebenso variiert wie die Länge der Curriculadokumente, wurde folgender Prozess angewendet: Für jedes Bundesland wurde die mittlere Schlagworthäufigkeit für jedes Fach über die Lehrpläne für alle Jahrgangsstufen und allgemeinbildenden Schulformen hinweg ermittelt und auf zehn Seiten normiert. Diese Schlagworthäufigkeit je zehn Seiten der vier untersuchten Fächer wurde für jedes Bundesland gemittelt, um einen einzigen Vergleichswert für das Ranking zu erhalten. Die Bundesländer wurden anhand des

Mittelwertes der Anzahl gefundener Schlagwörter je zehn Seiten in einer Rangliste sortiert und in drei Häufigkeitscluster eingeteilt (siehe Tabelle 5-1). Für weitere Details zum Vorgehen siehe Anhang. Für die Hauptanalyse wurde aus jedem Cluster ein Bundesland gewählt. Bei der Auswahl war entscheidend, dass die ausgewählten Bundesländer integrierte Fächer für die Natur- und Gesellschaftswissenschaften unterrichten und dass Flächenländer, Stadtstaat und Ost- und Westdeutschland vertreten sind. Daraus resultierte folgende Auswahl: (1) Saarland (SL), (2) Mecklenburg-Vorpommern (MV), (3) Hansestadt Bremen (HB).

Tabelle 5-1: Rangliste und Cluster der Schlagworthäufigkeit je Bundesland (Präanalyse).

Oberes Cluster		Mittleres Cluster		Unteres Cluster	
Bundesland	Schlagworte/ 10 Seiten*	Bundesland	Schlagworte/ 10 Seiten*	Bundesland	Schlagworte/ 10 Seiten*
SL	1,9	BY	1,0	SH	0,5
BW	1,8	HH	1,0	HB	0,4
BB, BE	1,4	SN	1,0	NI	0,3
NW	1,3	TH	0,9	HE	0,2
ST	1,3	MV	0,9		
		RP	0,8		

**Mittelwert der Schlagworte/10 Seiten der Fächer Biologie, Geographie, integrierte Fächer (Naturwissenschaften, Gesellschaftswissenschaften) über alle Schulformen hinweg*

Es wurden jeweils Curricula für die allgemeinbildenden Schularten der Sekundarstufe untersucht: für die jeweilige mittlere Schulform (Gemeinschaftsschule (SL), die Oberschule (HB) bzw. die regionale Schule (MV) und für das Gymnasium, in MV außerdem für die schulartenübergreifende Orientierungsstufe (OS). Um einer interdisziplinären Einbeziehung der Klimabildung Rechnung zu tragen, wurden Curricula für die Naturwissenschaften und die Gesellschaftswissenschaften analysiert, jeweils einschließlich der integrierten Fächer (siehe Tabelle 5-2 für eine Übersicht über die untersuchten Fächer). Die analysierten Curricula sind zwischen 2002 und 2022 erschienen (siehe Anhang).

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Tabelle 5-2: Bezeichnungen der für die Auswertung der Analyse zusammengefassten Fächer in den Bundesländern Saarland (SL), Bremen (HB) und Mecklenburg-Vorpommern (MV) sowie Darstellung ihrer Einordnung in die verschiedenen Schulcurricula (nach Klassenstufe und Schulart).

Zusammenfassende Bezeichnung	SL		HB		MV	
Gesellschaft Politik Sozialkunde	Gesellschaftswissenschaften	5-10 (Gem.-S.)	Gesellschaft und Politik	5-10 (Ober-S.)	Gesellschaftswissenschaften	5-6 (OS)
	Sozialkunde	9-10 (Gem.-S.) 9 (Gymn.) Oberstufe	Soziologie	Oberstufe	Sozialkunde	8-10 (Reg. S.) 8-10 (Gymn.) Oberstufe
	Politik	Oberstufe	Politik	9-10 (Gymn.) Oberstufe		
Welt/Umweltkunde			Welt-Umweltkunde	5-6 (Gymn.)	Weltkunde	5-6 (OS)
					WP Zukunfts-fähige Welt	9-10 (Reg. S.)
					WP System Erde	9-10 (Gymn.)
Arbeit/Beruf Wirtschaft	Arbeitslehre	5-6 (Gem.-S.)	Wirtschaft, Arbeit, Technik	5-10 (Ober-S.) 5-10 (Gymn.)		
	Beruf und Wirtschaft	7-10 (Gem.-S.)				
	Wirtschaftslehre	Oberstufe	Wirtschaftslehre	Oberstufe		

Abkürzungen: Gem.-S.: Gemeinschaftsschule, Ober-S.: Oberschule, Reg. S.: Regionale Schule, OS: schulartübergreifende Orientierungsstufe, Gymn.: Gymnasium WP: Wahlpflichtkurs

5.4.2 Entwicklung des Analyseschlüssels und Hauptanalyse

Weil der Klimawandel als globale Herausforderung und/oder Nachhaltigkeit als übergreifendes Bildungskonzept zum einen in den einleitenden Teilen der Curricula (z.B. didaktische Vorbemerkungen, fächerübergreifende Aufgaben) genannt werden als auch unterschiedlich konkret in den Abschnitten, die sich auf Klassenstufen, Themen- und Inhaltsbereiche sowie Kompetenzerwartungen beziehen, wurde in der Analyse sowohl differenziert, welche Inhalte adressiert werden, als auch, in welcher Art und Weise diese angesprochen werden (z.B. als Konzept, als Kompetenzerwartung). Anhand der in der Präanalyse gesichteten Curricula wurde dazu induktiv ein zweidimensionaler Analyseschlüssel entwickelt (siehe Tabelle 5-3, ausführliche Analyseschlüssel siehe Anhang), indem aus den gefundenen Auszügen abgeleitet wurde, in welchen Kontexten und unter welchen Themen der Klimawandel adressiert wurde oder Bezüge zum Klimawandel möglich erschienen. Weiterhin wurde strukturiert, in welcher Form diese Inhalte jeweils dargestellt waren. Hieraus ergab sich zum einen die Dimension (a), die der inhaltlichen Kategorisierung der Curricula diene, also, welche fachlichen Inhalte (z.B. Treibhauseffekt) angesprochen werden. Zum anderen ergab sich die Dimension (b), die der Kategorisierung der Art und Weise diene, wie diese Inhalte

im Curriculum eingebunden werden (z.B. verbindliche Kompetenzerwartungen, Beispiele oder allgemeine Konzepte). Für die Hauptanalyse wurde auf Grundlage der gesamten oben genannten Klimabildungs-Begriffe die folgenden Schlagworte genutzt, die Bezüge zum Klimawandel ebenso wie zum Kontext der Nachhaltigkeit anzeigen, um alle Bereiche, die Bezüge zum Klimawandel ermöglichen, finden zu können: *Klima, Klimawandel, globale Erwärmung/Erderwärmung, Temperaturanstieg, Treibhauseffekt, nachhaltig, Nachhaltigkeit, Energie, sustainable, ökologischer Fußabdruck, ökologischer Rucksack, BNE*. Anhand der Schlagworte wurden relevante Textabschnitte identifiziert, die für die weitere Analyse in ein Tabellendokument extrahiert wurden. Hinsichtlich der Schlagworte *BNE* und *Energie* wurden solche Textabschnitte, die einen eindeutig anderen Bezug als Klima oder Klimawandel hatten, nicht mit berücksichtigt (z.B. Verbrennungsprodukte und Gesundheit oder Biokunststoffe). Als ein Textabschnitt wurden Extrakte zu einem Kapitel bzw. einer Themeneinheit betrachtet (zur Veranschaulichung siehe Anhang). Sehr lange Abschnitte wurden zur besseren Lesbarkeit auf mehrere Zeilen im Excel Tabellenblatt verteilt, in der quantitativen Auswertung jedoch zusammengezählt. Die zu analysierenden Segmente wurden mithilfe des Analyseschlüssels parallel nach Dimension (a) und (b) codiert, Mehrfachcodierungen in beiden Dimensionen waren möglich. Im Zuge eines Interratingprozesses wurden mehrere Samples, die jeweils alle Segmente ausgewählter Fächer und etwa 25% des Materials umfassten, von einem zweiten Rater codiert. Dabei wurde der Analyseschlüssel mehrfach in Abstimmung zwischen Erstautorin und zweitem Rater überarbeitet. Die abschließenden Interrater Reliabilitäten für Analyseschlüssel Dimension (a) und (b) zeigen eine nach Landis und Koch (1977) robuste Übereinstimmung (Cohen's Kappa (a)=0.69, (b)=0.67).

Tabelle 5-3: Analyseschlüssel Dimension (a) für die inhaltliche Kategorisierung und Dimension (b) für die Kategorisierung der Art und Weise der Einbindung der Inhalte. Alle Textstellen wurden jeweils parallel mit den Kategorien Dimension (a) und Dimension (b) codiert.

Analyseschlüssel	Code	Kurzbeschreibung
Dimension (a)	a-1	Nachhaltigkeit, Global Change, Anthropozän und Gesellschaft
	a-2	Explizite Nennung/Thematisierung des Klimawandels
	a-3	Gesellschaftliche Lebensweise und Handeln (Ursachen, Minderung und Anpassung)
Dimension (b)	b-1	Übergreifendes Konzept
	b-2	Verbindliche Fachinhalte und Kompetenzen
	b-3	Hinweise und Vorschläge zur unterrichtlichen Umsetzung

An einigen Stellen gab es mehrere gleichlautende Textabschnitte aufgrund einheitlicher Vorbemerkungen in den Curricula verschiedener Fächer oder der für die Sekundarstufe I parallel laufenden Curricula für das Gymnasium und die mittlere Schulform beziehungsweise verschiedener Curricula für unterschiedliche Anforderungsstufen innerhalb der Sekundarstufe I oder II. Da die quantitative Auswertung der Codierhäufigkeiten getrennt nach Schulformen, Sekundarstufe und Fächern stattfand, wurde hier meist kein Problem gesehen. Lediglich bei Dopplungen der Textabschnitte aufgrund verschiedener Anforderungsstufen wurden diese in 33 Fällen für die quantitative Analyse der Textstellen- und Codier-Häufigkeit zusammengefasst.

5.5 Ergebnisse

5.5.1 Inhalte und Umsetzung der Klimabildung in den Curricula

Der entwickelte Analyseschlüssel zeigt die Ausprägungen der zwei untersuchten Dimensionen der Einbindung der Klimabildung in deutsche Curricula. Er beinhaltet die inhaltlichen Facetten der Klimabildung (Analyseschlüssel Dimension a) und die Art und Weise, wie diese Inhalte im Curriculum umgesetzt werden (Analyseschlüssel Dimension b).

Tabelle 5-4 zeigt die Zahl der gefundenen und analysierten Textstellen in den drei Bundesländern. Ein Schwerpunkt findet sich in den naturwissenschaftlichen Fächern und in der Geographie ($\geq 75\%$ -Quartil).

Table 5-4: Anzahl der analysierten Textabschnitte je Bundesland für die verschiedenen Schularten und Fächer (bereinigt um Dopplungen für verschiedene Anforderungsstufen).

	Saarland			Bremen			Mecklenburg-Vorpommern				Summe
	Gem Sek I	Gym Sek I	Gym Sek II	Ob Sek I	Gym Sek I	Gym Sek II	OS	Reg Sek I	Gym Sek I	Gym Sek II	
Biologie	2	8	11	3	3	8	6	6	8	7	62
Chemie	6	2	12	3	5	18		5	8	7	66
Physik	3	8	5	4	4	9	5	10	11	6	65
NaWi	8	1		4	3		9				25
Geographie	2	11	17		6	6	1	5	10	11	69
Gesellschaft Politik Sozialkunde	15	1	5	4	0	2	9	1	1	3	41
Geschichte	0	0	0		0	0	0	1	1	2	4
Welt/Um- weltkunde					0		4	5	6		15
Arbeit/Beruf Wirtschaft	9		0	5	7	1					22
Summe	45	31	50	23	28	44	34	33	45	36	

Lagemaße:

25%-Quartil: 2

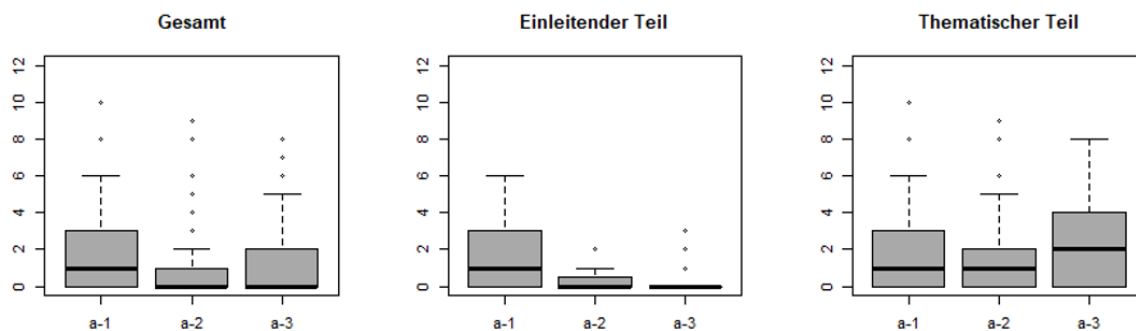
Median: 5

75%-Quartil: 8

5.5.2 Verteilung der Codierhäufigkeiten in den Curricula

Im Folgenden wird zunächst dargestellt, wie häufig die einzelnen Kategorien in den Curricula codiert wurden und in welcher Form die jeweiligen inhaltsbezogenen Kategorien jeweils eingebunden wurden. Schließlich wird auf die Verteilung in den einzelnen Bundesländern ebenso eingegangen wie auf die Fächer, und die Inhalte sowie ihre Umsetzung werden anhand von ausgewählten Textbeispielen illustriert.

Dimension a:



Dimension b:

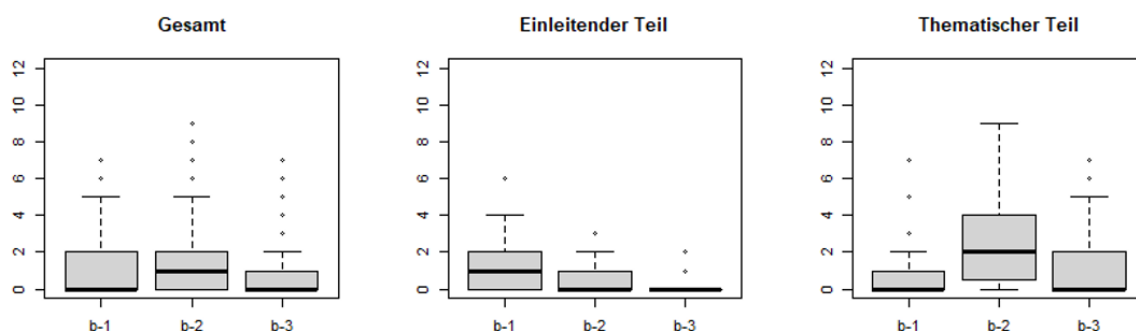


Abbildung 5-2: Häufigkeit der Kategorien der Dimension (a) und (b) (s. Tabelle 2) auf die einleitenden bzw. thematischen Teile der Curricula (Codes: a-1: Nachhaltigkeit, Global Change, Anthropozän und Gesellschaft, a-2: Explizite Nennung/Thematisierung des Klimawandels, a-3: Gesellschaftliche Lebensweise und Handeln, b-1: Übergreifendes Konzept, b-2 Verbindliche Fachinhalte und Kompetenzen, b-3: Hinweise und Vorschläge zur unterrichtlichen Umsetzung).

Abbildung 5-2 gibt einen Überblick über die Verteilung der Codierhäufigkeit aller Kategorien bei der Dimensionen insgesamt und differenziert nach einleitenden und thematischen Teilen der Curricula. Interessant ist diese Unterscheidung deshalb, weil die einleitenden (z.B. didaktische Vorbemerkungen, fächerübergreifende Aufgaben) und thematischen Teile (z.B. Themenfelder, Kompetenzerwartungen) jeweils unterschiedlich konkret und verbindlich formuliert sind.

Insgesamt sind die Bezüge zur Nachhaltigkeit (a-1) am häufigsten vertreten, gefolgt von Bezügen zur gesellschaftlichen Lebensweise (a-3), während die expliziten Bezüge zum Klimawandel (a-2) am wenigsten häufig codiert wurden. In Dimension (b) sind die verbindlichen Fachinhalte (b-1) am häufigsten vertreten, während übergreifende Konzepte (b-1) im Vergleich weniger und Hinweise zum Unterricht (b-3) weniger häufig codiert wurden.

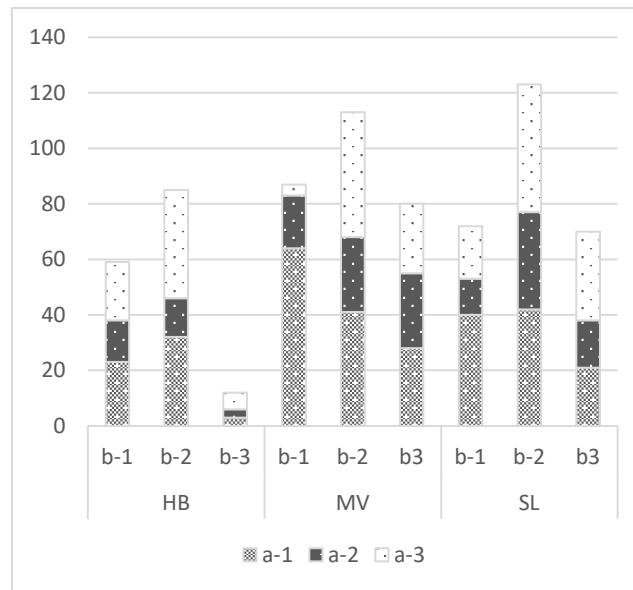


Abbildung 5-3: Häufigkeit der Codierungen der Dimensionen (a) (gestapelte Säulen) und (b) (nebeneinander) dargestellt nach Bundesländern (Codes: a-1: Nachhaltigkeit, Global Change, Anthropozän und Gesellschaft, a-2: Explizite Nennung/Thematisierung des Klimawandels, a-3: Gesellschaftliche Lebensweise und Handeln, b-1: Übergreifendes Konzept, b-2 Verbindliche Fachinhalte und Kompetenzen, b-3: Hinweise und Vorschläge zur unterrichtlichen Umsetzung).

Abbildung 5-3 zeigt, in welcher Art und Weise (Dimension b) die jeweiligen Inhalte (Dimension a) entsprechend der Codierhäufigkeit in den drei Bundesländern eingebunden sind. Durchweg wurden Bezüge zur Nachhaltigkeit (a-1) häufig codiert, insbesondere als übergreifendes Konzept (b-1), was besonders in MV deutlich wird. Beide Kategorien finden sich häufig in den einleitenden Teilen der Curricula, wie folgender Ausschnitt zeigt:

„Die Lernenden greifen im Biologieunterricht Fragestellungen auf Grundlage der Wertschätzung der Umwelt und unter dem Gesichtspunkt der Nachhaltigkeit auf. [...]

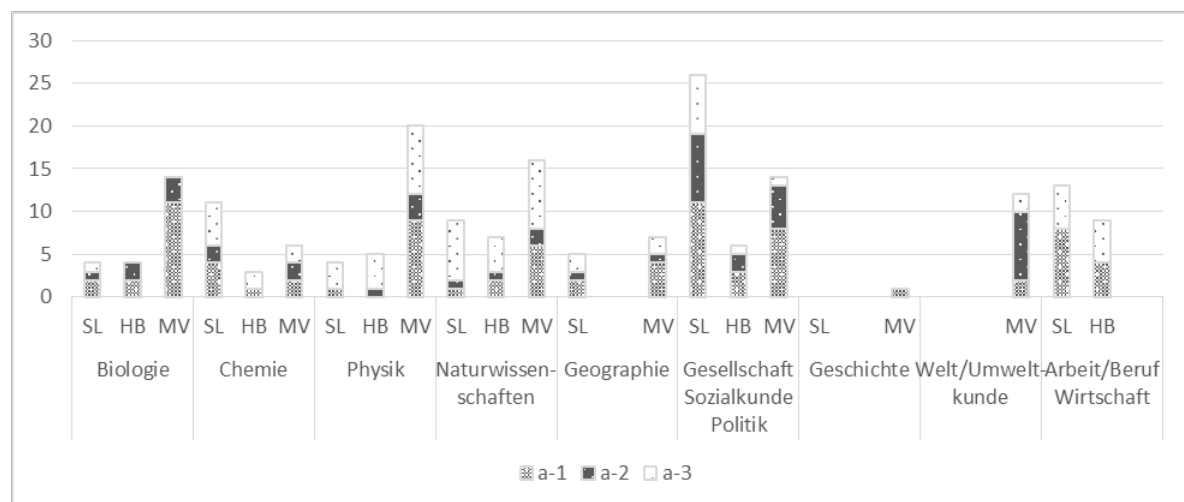
Basiskonzepte:

[...] Stoff- und Energieumwandlung: Lebewesen sind offene Systeme, die mit ihrer Umwelt in einem ständigen Stoff- und Energieaustausch stehen. Durch Assimilations- und Dissimilationsprozesse entstehen natürliche Stoffkreisläufe in Ökosystemen, in die der Mensch maßgeblich eingreift. Das Prinzip der Nachhaltigkeit ist immanenter Bestandteil dieses Basiskonzepts. [...]“

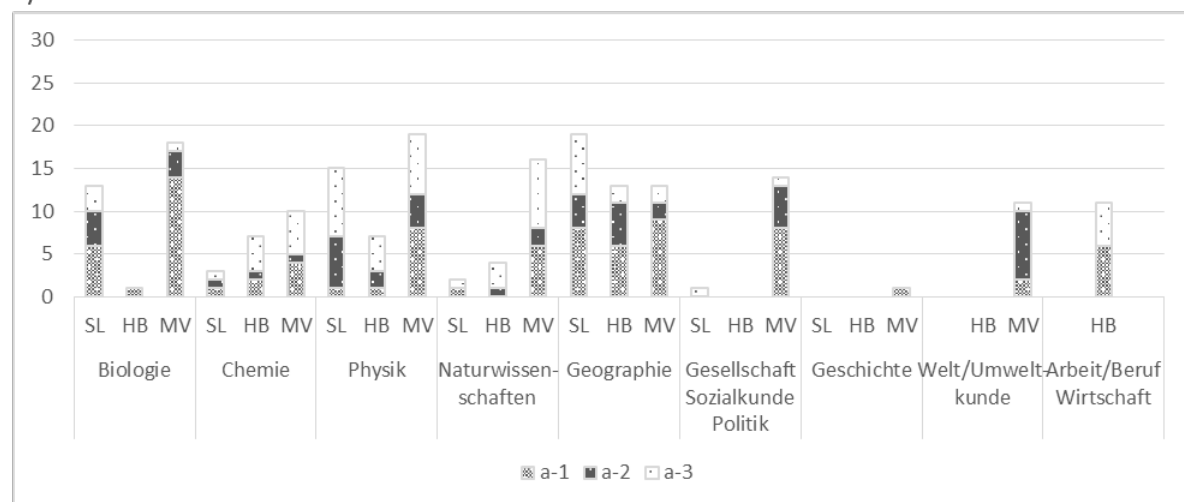
MV: Biologie Rahmenplan für die Orientierungsstufe, S. 4, 2. Beitrag des Unterrichtsfaches Biologie zum Kompetenzerwerb, 2.1 Fachprofil

Bezüge zur Nachhaltigkeit finden sich häufig in den Fächern Biologie, Geographie, Gesellschaftswissenschaften und auch den Fächern, die unter Arbeit und Wirtschaft zusammengefasst sind. Hier geht es z.B. um Ökosysteme, nachhaltige Handlungen und Ressourcenverbrauch. Abbildung 5-4 zeigt wie die inhaltsbezogenen Kategorien (Dimension a) auf die verschiedenen Fächer und Schulformen verteilt sind.

Mittlere Schulform:



Gymnasium Sek I:



Gymnasium Sek II:

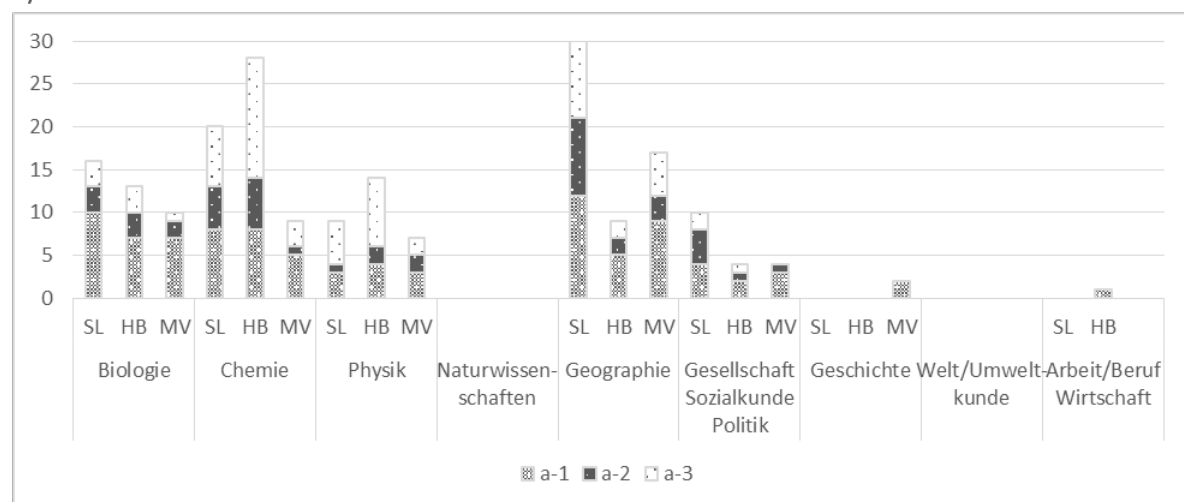


Abbildung 5-4: Codierungen in Dimension (a) nach Fächern für die untersuchten Bundesländer. Für Mecklenburg-Vorpommern wurden die Codierungen für die schulartübergreifende Orientierungsstufe zur mittleren Schulform gerechnet (Codes: a-1: Nachhaltigkeit, Global Change Anthropozän und Gesellschaft, a-2: Explizite Nennung/Thematisierung des Klimawandels, a-3: Gesellschaftliche Lebensweise und Handeln).

5.5.3 Fokus auf die thematischen Teile der Curricula und Einbindung der Klimabildung in den Fächern

In den thematischen Teilen der Curricula finden sich alle drei inhaltlichen Dimensionen häufig vertreten. Bezüge zum Klimawandel (a-2) wurden in MV und SL häufig als verbindliche Fachinhalte (b-2) codiert, wie in folgendem Beispiel:

„Klimawandel

Sachkompetenz

Schülerinnen und Schüler

- beschreiben den Treibhauseffekt und seine Folgen für den Klimawandel
- erläutern, dass der Klimawandel insbesondere arme Länder trifft
- legen exemplarisch Maßnahmen der Bundesregierung und der EU für den Klimaschutz dar
- legen Ziele für nachhaltige Entwicklung am Beispiel von SDG 13 Maßnahmen zum Klimaschutz der UN dar

weitere Kompetenzen

Schülerinnen und Schüler

- recherchieren Ursachen des Treibhauseffekts
- begründen, dass der Klimawandel eine globale Herausforderung darstellt
- recherchieren Auswirkungen des Klimawandels auf arme Länder [Methodenkompetenz]
- recherchieren Maßnahmen der Bundesregierung mit denen arme Länder unterstützt werden, ihre Klimaziele zu erreichen [Methodenkompetenz]

SL: Lehrplan Sozialkunde, gymnasiale Oberstufe, Einführungsphase, S. 16, Themenfeld Das Konzept der einen Welt

Bezüge zum Klimawandel finden sich dabei in fast allen untersuchten Fächern (mit Ausnahme von Geschichte und den unter Arbeit und Wirtschaft zusammengefassten Fächern). Inhaltlich werden hier oft der Treibhauseffekt, Stoffkreisläufe, der Strahlungshaushalt, aber auch Klimafolgen und Klimaschutz adressiert. Weniger häufig gibt es Bezüge zur Klimaforschung- und zur Klimapolitik. In MV wurden z.B. in Physik Bezüge zum Klimawandel auch als Hinweise (b-3) codiert.

„Thema Energie - Temperatur und Temperaturveränderungen

[...]

Hinweise und Anregungen

Es müssen verschiedene Temperaturveränderungen auf der Erde betrachtet werden, z. B. Tagesverlauf, Jahresverlauf und Klimawandel. [...]

Beispiele für die Verknüpfung von Inhalten und prozessbezogenen Kompetenzen:

K: Kooperatives Recherchieren zum Thema „Erderwärmung/Klimawandel“ [...]

MV: Physik Rahmenplan Orientierungsstufe, S. 18, Klasse 6, 3. Abschlussbezogene Standards, 3.2 Unterrichtsinhalte

Auch als übergreifendes Konzept (b-1) wurden Klimawandelbezüge codiert, wie z.B. in Biologie in HB:

„Leben auf der Erde - woher, wohin?

[...]

Menschen sind Teil des Ökosystems Erde, gleichzeitig aber auch ein Gegenüber, weil sie in der Lage sind, das System zu verändern. Sie züchten Lebewesen und verändern sie gentechnisch, bringen mutagene Substanzen in die Umwelt, vernichten Lebensräume. Biologische Forschung und technische Entwicklungen beeinflussen und fördern sich wechselseitig. Bewertungen erfolgen nicht allein auf biologischer Grundlage, sondern berühren ethische Fragestellungen. Damit einher geht eine Verantwortung für die Zukunft der Biosphäre, denn menschliches Handeln hat Wirkungen auf Lebensräume und Artenvielfalt, Treibhauseffekt und Klimaveränderungen, Luftbelastungen und Ozonvorkommen. “

HB: Biologie Bildungsplan für die Oberschule, S. 34, 2. Themen und Inhalte

Bezüge zur gesellschaftlichen Lebensweise (a-3) sind in allen drei Bundesländern am häufigsten als verbindliche Fachinhalte (b-2) codiert:

„Inhaltsbezogene Kompetenzen

Infrastrukturen

Schülerinnen und Schüler können

[...]

- verschiedene Arten der Energieumwandlung und Energiebereitstellung beschreiben und modellhaft anwenden
- und unter dem Gesichtspunkt der Nachhaltigkeit beurteilen,
- die Energieversorgung im Land Bremen beschreiben und aktuelle und zukünftige Energieversorgungsprobleme diskutieren,
- die Chancen regenerativer Energien an Beispielen beschreiben und beurteilen,
- Energiesparmaßnahmen beschreiben und anwenden.“

HB: Wirtschaft, Arbeit, Technik, Bildungsplan für die Oberschule, S. 12, 3. Standards, 3.2 Anforderungen am Ende der Jahrgangsstufe 8

Bezüge zur gesellschaftlichen Lebensweise finden sich besonders häufig in den Fächern Chemie, Physik, Naturwissenschaften und in Gesellschaftswissenschaften (SL). Hier liegt der Schwerpunkt oft auf Energieträgern und –ressourcen, Ursachen des Klimawandels, alternativer Energienutzung sowie gesellschaftlichem Handeln. Insbesondere in SL wurden Bezüge zur gesellschaftlichen Lebensweise ebenfalls als Hinweise (b-3) codiert:

„Themenfeld Felder

Hinweise:

Außerschulische Lernorte

- Besichtigung eines Wasserkraftwerks, eines Windparks oder einer Photovoltaik-Anlage
- Besuch des zuständigen Energieversorgungsunternehmens

[...]“

SL: Physik, Lehrplan Gymnasiale Oberstufe, S. 22, Hauptphase, Grundkurs, Leistungskurs, Themenfeld Felder

Besonders hervorzuheben ist, dass es in mehreren Fächern unterschiedlicher Bundesländer einzelne Unterthemen gibt, die sich explizit mit dem Thema Klimawandel befassen und dieses im Namen tragen: In den unter Gesellschaft/Sozialkunde/Politik der Sekundarstufe I zusammengefassten Fächern fallen darunter folgende Themeneinheiten: *Erde – Klima – Mensch* (SL, Gemeinschaftsschule, Klassenstufe 5), *Klima und Klimawandel* (SL, Gemeinschaftsschule, Klassenstufe 8), folgender Ausschnitt zeigt ein Beispiel hieraus:

„Der Klimawandel ist eines der zentralen Themen der Gegenwart und der Umgang mit dem sich weltweit ändernden Klima ist eine der vordringlichsten politischen und gesellschaftlichen Aufgaben. Zum Verständnis der komplexen Problematik können insbesondere geographische Grundkenntnisse im Bereich der Klimatologie und historische Kenntnisse über die Entwicklung der Industriegesellschaft beitragen. Somit schließt dieses Themenfeld nahtlos an das vorherige Themenfeld „Industrialisierung“ an und wird in späteren Klassenstufen im Zusammenhang mit Themen der Nachhaltigkeit wieder aufgegriffen und erweitert.

[...]Das Thema „Klimawandel“ dehnt die regionale Problemorientierung auf den globalen Maßstab aus. Natürliche und anthropogene Ursachen für die globale Erderwärmung werden differenziert, das Ausmaß des anthropogen bedingten Klimawandels wird thematisiert und sowohl Individuen als auch politische Akteure werden zum Handeln aufgefordert. [...]“

SL: Lehrplan Gesellschaftswissenschaften, Gemeinschaftsschule Klassenstufen 7 und 8, S. 25, Themenfeld Klima und Klimawandel

In der Geographie finden sich in der Sekundarstufe I die folgenden Themeneinheiten, die den Klimawandel ausführlich behandeln: *Vom Wetter zum Klima* (SL, Gymnasium, Klassenstufe 5), *Die*

Geosphäre – Nutzung, Gefährdung und Schutz – Wetter und Klima (MV, Regionale Schule/Gymnasium, Klassenstufe 7-10). Hier gibt es in der Sekundarstufe II weitere entsprechende Themeneinheiten: *Klimageographische Grundlagen einer Raumanalyse* (SL; Oberstufe Einführungsphase), *Klima und Vegetation* (MV, Oberstufe Qualifikationsphase):

„Klima und Vegetation

[...]

Hinweise und Anregungen:

Die Ursachen des Klimawandels und dessen Auswirkungen auf den Menschen sind anhand unterschiedlicher Räume zu erarbeiten und notwendige Klimaschutzmaßnahmen zu diskutieren.“

MV: Rahmenplan für die Qualifikationsphase der gymnasialen Oberstufe, Geographie, S. 10, Themenfeld Klima und Vegetation

Auch in der Chemie findet sich in HB ein eigenes Unterthema in der Sekundarstufe II (*Mit nachwachsenden Rohstoffen gegen den Klimawandel*) angeknüpft an Energie und Energiespeicherung, das den Klimawandel im Hinblick auf die Energienutzung und gesellschaftliche Lebensweise adressiert.

5.5.4 Vergleich des fächerintegrierten und des fächergetrennten Unterrichts

Ein inhaltlicher Vergleich des fächerintegrierten mit dem fächergetrennten Unterricht ist für die Cluster der Klassenstufen 5-6 und 7-10 sinnvoll (vgl. Tabelle 5-5).

Tabelle 5-5: Übersicht in welchen Bundesländern die Fächer in den jeweiligen Klassenstufen mindestens zeitweise unterrichtet werden.

	Klassenstufen 5 bis 6		Klassenstufen 7 bis 10	
	Mittlere Schulform	Gymnasium	Mittlere Schulform	Gymnasium
Naturwissenschaft	HB, MV (OS), SL	HB, MV (OS), SL	HB, SL	
Biologie	MV (OS)	MV (OS)	HB, MV, SL	HB, MV, SL
Chemie	MV		HB, MV, SL	HB, MV, SL
Physik	MV (OS)	MV (OS)	HB, MV, SL	HB, MV, SL
Weltkunde	MV (OS)	HB, MV (OS)	MV	MV
Geographie	MV (OS)	MV (OS), SL	MV, SL	HB, MV, SL
Gesellschaft, Sozialkunde, Politik	MV (OS), SL	MV (OS)	HB, MV, SL	HB, MV, SL
Geschichte	MV (OS)	MV (OS)	MV, SL	HB, MV, SL

OS: Schulartübergreifende Orientierungsstufe in Mecklenburg-Vorpommern

Eine Verteilung der Kategorien der Dimension (a) ist in Abbildung 5-5 dargestellt. In den Klassenstufen 5-6 werden die Naturwissenschaften überwiegend fächerintegriert und nicht fächergetrennt unterrichtet. Hier sind mehr Klimabildungsinhalte zu finden als in den getrennten Fächern, der Fokus liegt dabei auf Energie. In Geographie und insbesondere Gesellschaftswissenschaften kommt das Thema umfangreicher vor und wird unter mehr verschiedenen inhaltlichen Anknüpfungspunkten unterrichtet als in den unter Welt-/Umweltkunde zusammengefassten Fächern.

Letztere Fächer werden in MV (teilweise Wahlpflicht) und HB unterrichtet, aber nur in MV finden sich passende Inhalte, diese konzentrieren sich auf das Klimasystem im Allgemeinen.

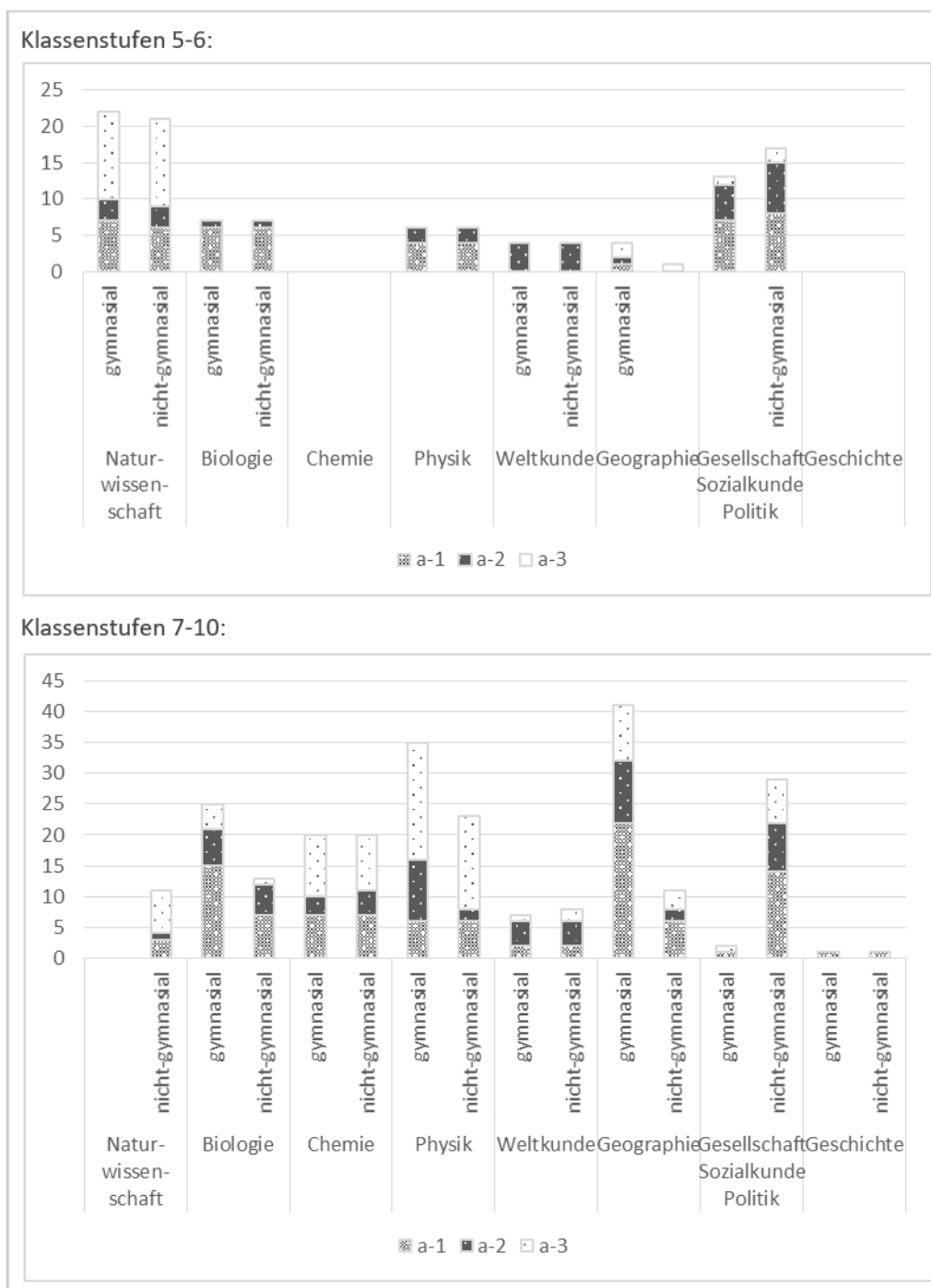


Abbildung 5-5: a) Darstellung der Kategorien Dimension (a) für den fächerintegrierten Unterricht (Naturwissenschaften und Weltkunde) im Vergleich mit dem fächergetrennten Unterricht (Codes: a-1: Nachhaltigkeit, Global Change, Anthropozän und Gesellschaft, a-2: Explizite Nennung/Thematisierung des Klimawandels, a-3: Gesellschaftliche Lebensweise und Handeln).

In den Klassenstufen 7-10 sind die Inhalte im Vergleich des fächerintegrierten und des fächergetrennten Unterrichts gleichwertiger verteilt. Der Fokus liegt hier in Naturwissenschaften, Physik und Chemie auf Energie, in Biologie hingegen auf Nachhaltigkeit und Ökosystemen sowie dem Treibhauseffekt.

Letztere Themen finden in den fächerintegrierten Naturwissenschaften weniger Beachtung. In den Wahlpflicht-Kursen (MV) und den Gesellschaftswissenschaften (SL) finden sich alle Bereiche des Themas Klimawandel, in Geographie finden sich Bezüge angeknüpft an verschiedene andere Themen (z.B. Globale Herausforderungen, Verstädterung, Wirtschaft). Hier ist die Umsetzung im Fach Gesellschaftswissenschaften am umfangreichsten.

5.5.5 Diskussion

Die Studie untersuchte anhand einer Stichprobe von drei Bundesländern, wie die Klimabildung in deutsche Curricula der natur- und gesellschaftswissenschaftlichen Fächer in der Sekundarstufe allgemeinbildender Schulen eingebunden wird. Die Ergebnisse legen nahe, dass die Einbindung der Klimabildung in diesen drei Bundesländern in Anlehnung an die Ausführungen von Eilam (2022) dem Curriculum-übergreifenden Ansatz auf zwei Ebenen folgt: zum einen wird der Klimawandel an das übergreifende Thema der Nachhaltigkeit angeknüpft und weiterhin finden sich der Klimawandel oder verwandte Aspekte in vielen einzelnen Fächern wieder. Er wird dabei in diesen drei untersuchten Bundesländern teilweise als eigenes Thema adressiert und teilweise an andere Themen angeknüpft, ähnlich wie es auch in der Studie von Adamina et al. (2018) der Fall ist. Bei Bezügen, die Nachhaltigkeit, globale Fragen und das Anthropozän umspannen, wird der Klimawandel teilweise explizit genannt oder schwingt implizit mit und könnte in Abhängigkeit von der Lehrkraft einbezogen werden (Dawson et al. 2022). Dass Bezüge zum Klimawandel und zur Lebensweise sich häufiger in den thematischen Teilen, wo die verbindlichen Fachinhalte verstärkt verortet sind, finden, spricht dafür, dass die beiden letztgenannten Kategorien eher explizit thematisiert werden. Dies ist insofern von Vorteil, als dass Lehrkräfte bei der Unterrichtsplanung auf das formale Curriculum und weitere Ressourcen zurückgreifen, um das von ihnen persönlich intendierte Curriculum in der Praxis umzusetzen (Remillard und Heck 2014). Je konkreter das formale Curriculum umsetzbare Vorgaben macht, desto leichter ist es daher möglich, diese in die Unterrichtspraxis zu bringen. Dabei werden verschiedene Aspekte rund um den Klimawandel in unterschiedlicher Ausführlichkeit an verschiedenen Stellen der Curricula angesprochen. Die naturwissenschaftlichen Grundlagen des Klimawandels, wie Wissen über das Klimasystem, Sonnenenergie und Strahlungshaushalt, die Atmosphäre, Treibhausgase und der Treibhauseffekt, Stoffkreisläufe, die Klimahistorie sowie Ursachen und Folgen des Klimawandels, finden sich häufig als Inhalte wieder, wie es sich auch schon bei Siegmund et al. (2021) gezeigt hat. Die Klimawissenschaft als expliziter Fachinhalt (Leve et al. 2023; Schubatzky et al. 2023; USGCRP 2009) hingegen, wird nur vereinzelt in den deutschen Curricula thematisiert. Bezüge zur gesellschaftlichen Lebensweise finden sich insbesondere im Zusammenhang mit Rohstoffen und Energieträgern sowie ihrer Nutzung. Explizite Handlungen werden vereinzelt direkt angesprochen, die sich auf individuelles Verhalten und Konsum beziehen, ein Fokus, der z.B. auch in Sachbüchern, die sich an ein junges Publikum richten, deutlich wird (Knauf 2023). Dieser Fokus allerdings ist in den Curricula weniger ausgeprägt, und es geht inhaltlich eher um die technologischen Phänomene der Energienutzung (Siegmund et al. 2021) oder die Problematisierung von Nutzungsweisen findet auf einer abstrakteren Ebene statt. Insgesamt werden aber die als wichtig erachteten konkreten Bezüge zur gesellschaftlichen Debatte und die hier mit hineinspielenden Aspekte zum Umgang mit dem Klimawandel und zum Klimaschutz (Leve et al. 2023; Shwom et al. 2017) weniger hergestellt, als es für die naturwissenschaftlichen Grundlagen des Klimasystems und des Klimawandels der Fall ist.

Betrachtet man die Verteilung der Codierungen der Dimension (a) auf die Fächer und Schularten, so zeigt sich in der Sekundarstufe I sowohl in der mittleren Schulform als auch am Gymnasium eine hohe Streuung der Schwerpunkte auf verschiedene Fächer. Die Unterschiede zwischen den Schulformen lassen sich damit erklären, dass sich in einigen Fällen am Gymnasium mehr Themenfelder finden als an den anderen Schulformen, in denen Nachhaltigkeit oder Klimawandelbezüge adressiert werden (Biologie, Physik in SL, Geographie in allen drei Bundesländern), in Chemie in SL ist es umgekehrt. Anderenfalls gibt es einige Fächer nur an der mittleren Schulform (zumindest in der Mittelstufe) (Naturwissenschaften und Gesellschaftswissenschaften in SL, Arbeitslehre HB). In der Sekundarstufe II hingegen ist die Inhaltsdichte insgesamt höher, die Schwerpunkte im Vergleich der Fächer untereinander sind daher weniger gestreut. Dies indiziert, dass ein signifikanter Teil der Klimabildung auf die Oberstufe geschoben wird, was problematisch ist, da nur ein Teil der Schülerinnen und Schüler in Deutschland die Oberstufe besuchen, dieser Teil der Klimabildung den anderen somit verwehrt bleibt (Feierabend et al. 2011). Diese Analyse zeigt unterschiedlich verteilte Schwerpunkte hinsichtlich der Textabschnittshäufigkeit und Codier-Verteilung in den Naturwissenschaften (HB Chemie in Sek II, SL Chemie und Biologie in Sek II, MV Physik in Sek I) und der Geographie (SL und MV in Sek I und Sek II). Ähnlich hat es sich auch in Analysen zu Curricula in verschiedenen anderen Ländern dargestellt (Chang und Pascua 2017; Colliver 2017; Dawson et al. 2022; Field et al. 2023). Auch die Schlagworthäufigkeiten der Präanalyse zeigen einen deutlichen Schwerpunkt auf der Geographie in allen Bundesländern (siehe Anhang). Inhaltlich gesehen ähneln die gefundenen Schwerpunkte der Klimabildung in den verschiedenen Fächern anderen Studien. In den Naturwissenschaften finden sich Themen der naturwissenschaftlichen Grundlagen des Klimawandels, wie der Aufbau der Atmosphäre und der Treibhauseffekt (z.B. Chemie), aber auch die Bedeutung von Energieressourcen (z.B. Physik) oder die Stoffkreisläufe und Wechselwirkungen mit dem Klima ebenso, wie Auswirkungen des Klimawandels auf die Biosphäre (z.B. in Biologie) (Chang und Pascua 2017). Mensch-Umwelt-Beziehungen insbesondere auch die Wechselseitigkeit und die Bedeutung der gesunden Umwelt für das Wohlergehen des Menschen (Jóhannesson et al. 2011) sind eher Inhalte der Sozialwissenschaften, wobei die elaborierteste Ausgestaltung der Klimabildung, die sowohl naturwissenschaftliche Grundlagen als auch Wechselwirkungen zwischen Klima und Gesellschaft umfasst, sich oft in der Geographie wiederfindet (Chang und Pascua 2017). Dafür finden sich in den untersuchten Curricula Themenfelder, die das Klima oder den Klimawandel im Namen tragen mehr in der Sekundarstufe I (z.B. Geographie SL und MV, Gesellschaftswissenschaften SL) als in der Sekundarstufe II (z.B. Chemie in HB). Auch international gibt es Themeneinheiten in Klassenstufe 7 in Naturwissenschaften (Indonesien), bzw. Klassenstufe 10 in Geographie (Ontario, Kanada) (Dawson et al. 2022).

Die Einbindung der Klimabildung in verschiedene auch sozialwissenschaftliche Fächer trägt der Idee einer interdisziplinären Herangehensweise Rechnung (Leve et al. 2023; USGCRP 2009). Die Analyse zeigt, dass in den drei untersuchten Bundesländern neben den Naturwissenschaften auch gesellschaftswissenschaftliche Fächer mit unterschiedlicher Tiefe in die Klimabildung eingebunden werden, hier ist vor allem das Fach Gesellschaftswissenschaften in der Gemeinschaftsschule in SL hervorzuheben. Auch die Präanalyse zeigt einen weiteren Schwerpunkt in den fächerintegrierten Gesellschaftswissenschaften (z.B. in Hessen, Nordrhein-Westfalen, Rheinland-Pfalz, Schleswig-Holstein). Hierbei ist wichtig zu betonen, dass auch die Lehrkräfte auf interdisziplinäres Unterrichten vorbereitet sein müssen. So tun sich Lehrkräfte, die keine entsprechende Ausbildung

haben, schwer, die naturwissenschaftlichen Komponenten des Klimawandels in den Unterricht zu integrieren, während Lehrkräfte der Naturwissenschaften die ebenso wichtigen sozialwissenschaftlichen Aspekte (Shwom et al. 2017) nicht unbedingt abdecken können (Beasy et al. 2023). Weiterhin führt die fragmentierte Verteilung der Klimabildung in verschiedenen Fächern, wie sie sich zeigt, wenn man die Curricula nach Schulformen und Bundesländern nebeneinander legt, nicht unbedingt zu CL, weil auf der inhaltlichen Ebene die Verbindung zwischen den einzelnen Aspekten fehlt (Milér und Sládek 2011; Uherek und Schüpbach 2008). Es wird nicht klar, dass die einzelnen Fragmente zusammengenommen ein kohärentes Bild ergeben, das die im Theorieteil aufgezeigten Aspekte, die zu einer umfassenden Klimabildung führen, erfüllt. Um einer umfassenden Klimabildung gerecht zu werden, müsste der gesellschaftliche Umgang mit dem Klimawandel ebenso wie die Debatten dazu und die Klimawissenschaft selbst mehr thematisiert werden und der Gesamtzusammenhang zwischen den einzelnen Fächern sichergestellt werden. Die genannten Beispiele elaborierter Themenfelder sollten als Vorbilder herangezogen werden, um die Klimabildung umfassend in die Curricula zu integrieren. Eine Vernetzung zwischen den Fächern und eine gemeinsame sinnvolle Reihenfolge wäre wünschenswert, möglicherweise durch ein Leitfach, in dem derartige Themenfelder angesiedelt werden.

5.6 Limitationen

Ein Teil der Unterschiede im Umfang der analysierten Textstellen und Codierungen, lässt sich auf die unterschiedliche Ausführlichkeit der Curricula zurückführen. So sind die Curricula in Bremen deutlich knapper formuliert, während sie im Saarland besonders ausführlich sind. Hier obliegt für die weniger ausführlichen Bereiche mehr Anteil der tatsächlichen Umsetzung und Ausgestaltung bei der individuellen Lehrkraft, wie es auch in internationalen Curricula der Fall ist (Colliver 2017). Trotz größter Sorgfalt ist die Vergleichbarkeit zwischen den untersuchten Bundesländern aufgrund der unterschiedlichen Schulstruktur und Ausführlichkeit der Curricula der verschiedenen Bundesländer eingeschränkt. Weiterhin spielt die Bandbreite der Erscheinungsjahre sicherlich eine Rolle, in neueren und modernen Curricula hat die Klimabildung eher einen Platz (Field et al. 2023), und kann, zum Beispiel über den fächerintegrierten Unterricht oder Modellfächer, wie die Gesellschaftswissenschaften in Mecklenburg-Vorpommern, aus interdisziplinärer Perspektive eingebunden werden. Da im Laufe der Zeit Curricula in den einzelnen Bundesländern erneuert werden, stellt die vorliegende Analyse eine Momentaufnahme für den gegenwärtigen Zeitraum dar.

5.7 Erklärungen

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5.9 Anhang

Zur Veranschaulichung des methodischen Vorgehens bei der Präanalyse ist im Folgenden zunächst das schrittweise Vorgehen der Präanalyse und danach die Schlagworte, die für die Stichwortsuche der Präanalyse und die darauffolgende Kontextsuche in den ausgewählten Bundesländern dargestellt. Anschließend ist der ausführliche Analyseschlüssel dargestellt.

Das Schrittweise Vorgehen ist in einer nummerierten Liste dargestellt.

Die Schlagworte sind in Tabelle 5-6 dargestellt:

- In der linken Tabellenspalte sind Schlagworte, die zum quantitativen Vergleich der Bundesländer für genutzt worden sind, dargestellt.
- In der mittleren Tabellenspalte ist die absolute gefundene Häufigkeit der Schlagworte in den Curricula aller Bundesländer der Sekundarstufe I für Geographie, Biologie, Gesellschaftskunde o.ä. (integriertes Fach) und Naturwissenschaften (integriertes Fach) dargestellt.
- In der rechten Tabellenspalte sind diejenigen Schlagworte, die für die Kontextsuche der Hauptanalyse übernommen wurden und inwieweit diese angepasst und ergänzt wurden.

Der Analyseschlüssel ist in Tabelle 5-8 und Tabelle 5-9 dargestellt

5.9.1 Präanalyse, Schlagworthäufigkeit und Entwicklung des Analyseschlüssels

Präanalyse

1. die Lehrpläne für Geographie und Biologie allgemeinbildender Schulen in S-H und NRW wurden sukzessive durchgelesen
2. Abschnitte, die den Klimawandel thematisieren oder Verbindungen zum Klimawandel (inklusive Ursachen, Folgen und Umgang) zulassen, wurden in ein Excel-Datenblatt übertragen (extrahiert)
3. Aus allen gefundenen Abschnitten wurden Schlagworte extrahiert, die den Inhalt des jeweiligen Abschnitts repräsentierten und wiedergaben („Signalwörter“)
4. die resultierenden Schlagworte wurden geringfügig reduziert auf diejenigen Schlagworte, die einen klaren Bezug zum Klimawandel und zur Nachhaltigkeit hatten
5. Diese Schlagworte wurden gelistet und thematisch gruppiert und ihre jeweilige Häufigkeit in den gefundenen Abschnitten ermittelt
6. Aus den gruppierten Schlagworten wurden repräsentative (= häufig vorkommende und weitere, die zur gesamten Abdeckung der durch die Schlagworte widergegebenen Inhalte notwendig waren) als Suchworte notiert (siehe Tabelle 5-6)
7. Die Lehrpläne für Biologie, Geographie und die natur- und gesellschaftswissenschaftlichen integrierten Fächer für die Sekundarstufe I aller Bundesländer wurden nach allen Suchworten durchsucht und ihre jeweilige Häufigkeit ermittelt (siehe Abbildung 5-6)
8. Ein Ranking wurde nur mit 5 der Suchworte (die einen eindeutigen Bezug zum Klima, Klimawandel, Treibhauseffekt hatten) erstellt (siehe Tabelle 5-7), da durch die anderen Suchworte Bereiche abgedeckt sein könnten, die nicht zwangsläufig eine Verbindung zum Klimawandel darstellen, was durch eine reine Häufigkeitsermittlung, ohne Einbeziehung der jeweiligen Kontexte, in denen die Suchworte stehen, nicht ersichtlich ist. Für das Ranking war entscheidend, in welchen Bundesländern der eindeutige Bezug zum Klimawandel häufiger oder weniger häufig zu finden ist.

Hauptanalyse: Kontextsuche

Die Schlagworte für die Kontextsuche wurden aus dem gesamten Pool der Suchworte generiert, um hier nicht nur die konkreten Bezüge zum Klimawandel sondern auch die entfernten Bezüge sowie Bezüge zu Ursachen und Handeln mit abdecken zu können, die in der vertieften Inhaltsanalyse berücksichtigt werden sollten, da man hier am Text direkt beurteilen kann, ob ein Kontext einen Bezug zum Klimawandel aufweist oder ermöglicht oder nicht. Die Schlagworte zu Klimaschutz, Auswirkungen, Handeln waren zu divers für sinnvolle Kontextsuche. Hier wurde davon ausgegangen, dass durch die übrigen Schlagworte alle relevanten Kontexte gefunden wurden, da ja bei der Auswahl der Textstellen größere Sinnzusammenhänge mit einbezogen wurden.

Begründung für die Unterschiedlichkeit der Schlagworte für Schlagwortsuche (alle Bundesländer) und Kontextsuche (3 ausgewählte Bundesländer, Hauptanalyse):

- Schlagwortsuche (Präanalyse): schmale Suche, erlaubt eindeutige Bezüge
- Kontextsuche (Hauptanalyse): breitere Suche, erlaubt sowohl enge als auch entferntere Bezüge, somit eine größere Bandbreite

Table 5-6: Schlagworte der Präanalyse in den Curricula für Sekundarstufe I aller Bundesländer für Biologie, Geographie, Naturwissenschaften (integriert) und Gesellschaftskunde o.ä. (integriert) und Auswahl der Schlagworte für die Kontextsuche (Hauptanalyse).

Schlagworte	Häufigkeit und Suchworte	Ausgewählt für Kontextsuche
Nachhaltigkeit	11	Nachhaltigkeit
nachhaltige Entwicklung	6	
Sustainable Development	1	Sustainable
nachhaltig	19	Nachhaltig
nachhaltige	10	
Nachhaltigkeitsdimensionen	1	
Nachhaltigkeitsmaxime	1	
Nachhaltigkeitsdreieck	1	
Suchwort:	nachhaltig; Nachhaltigkeit	<i>nach Pilotierung ergänzt durch: ökologischer Fußabdruck/Rucksack, BNE</i>
Klima	13	Klima
Klimasystem	1	
Klimawandel	7	Klimawandel
Klimaveränderung	5	Klima(ver)änderung
Klimaveränderungen	4	
globale Klimaveränderungen	1	
anthropogen bedingte Klimaänderungen	1	
anthropogener Einfluss auf das globale Klima	2	
Treibhauseffekt	5	Treibhauseffekt
anthropogener Treibhauseffekt	1	
anthropogen bedingter Treibhauseffekt	1	
globale Erwärmung	1	Globale Erwärmung/Erderwärmung
globaler Temperaturanstieg	1	Temperaturanstieg
Suchworte:	Klima; Klimawandel; Klima(ver)änderung; Treibhauseffekt; globale Erwärmung; globaler Temperaturanstieg	
Klimawirksamkeit	2	
klimaschädliches Verhalten im Alltag	2	
Klimaschutz	3	
Klimaschutzziele	2	
Verlangsamung der globalen Erwärmung	1	
Anpassung an Folgen des Klimawandels	1	
Anpassung an Extremwetterereignisse	1	
Hochwasservorsorge	1	
Suchworte:	Klimaschutz; klimaschädlich; klimawirksam	
Auswirkungen von Klimaveränderungen	1	
Meeresspiegelanstieg	2	
Extremwetterereignisse	2	
extreme Wetterereignisse	1	

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Schlagworte	Häufigkeit und Suchworte	Ausgewählt für Kontextsuche
Wetterextreme	1	
Hitzeperioden	1	
Waldbrände	1	
Starkregen	1	
Sturmereignisse	1	
Dürren	1	
Hochwasserereignisse	1	
Stichworte:	Wetterereignisse; Meeresspiegelanstieg	
Energieverfügbarkeit	1	
Energieträger	3	
fossile Energieträger	3	
regenerative Energien	2	
Suchworte:	Energie/n; Energieträger	Verkürzt zu Energie (deckt zusammengesetzte Worte mit ab)
Anthropozän	1	
Mensch Biosphäre	5	
menschliche Einflüsse	1	
menschliche Eingriffe	1	
Einfluss des Menschen	1	
anthropogener Einfluss	3	
anthropogene Einflüsse	1	
Eingriffe des Menschen	2	
anthropogen bedingte Bedrohung	2	
Suchworte:	menschliche/r Einflüsse/Einfluss; anthropogene/r Einflüsse/Einfluss	

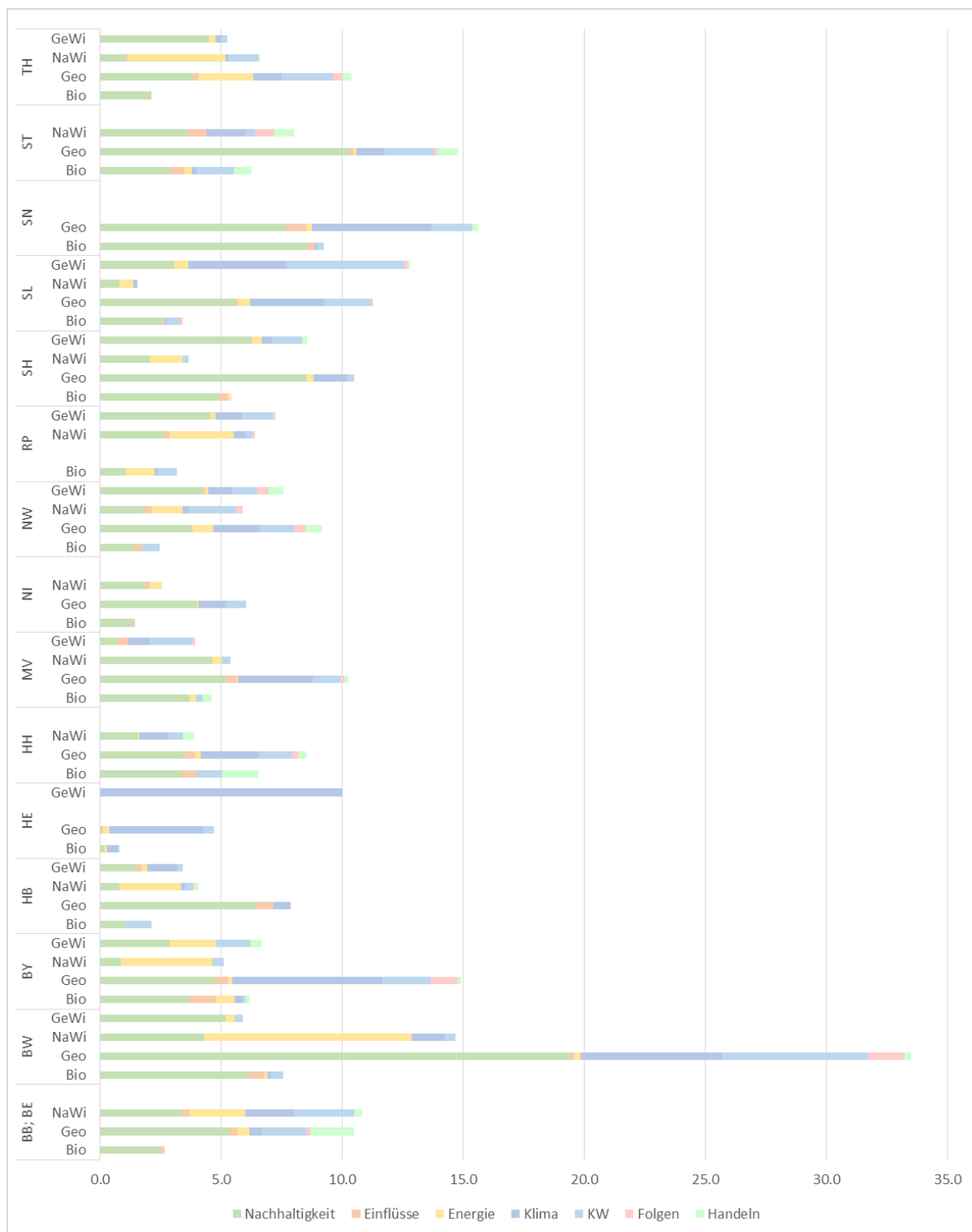


Abbildung 5-6. Häufigkeit der gesuchten Schlagworte in den Curricula aller Bundesländer für die Sekundarstufe normiert auf 10 Seiten. Suchworte: Gruppe Nachhaltigkeit: nachhaltig, Nachhaltigkeit; Gruppe Einflüsse: menschlicher/anthropogener Einfluss/e; Gruppe Energie: Energie/n, Energieträger; Gruppe Klima: Klima; Gruppe KW (Klimawandel): Klimawandel; Klima(ver)änderung; Treibhauseffekt; globale Erwärmung; globaler Temperaturanstieg; Gruppe Folgen: Wetterereignisse, Meeresspiegelanstieg; Gruppe Handeln: Klimaschutz, klimaschädlich, klimawirksam.

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Tabelle 5-7: Anzahl der Suchworte in den Curricula aller Bundesländer für die Sekundarstufe, normiert auf 10 Seiten und Ranking nach dem Mittelwert über die untersuchten Fächer hinweg. Ausgewählte Suchworte: Klimawandel, Klima(ver)änderung, Treibhauseffekt, globaler Temperaturanstieg.

Bundesland	Anzahl der ausgewählten Schlagworte (Suchworte) je 10 Seiten				
	Biologie	Geographie	NaWi	GeWi	Mittelwert
SL	0.6	1.9	0.0	4.9	1.9
BW	0.5	6.0	0.4	0.4	1.8
BB; BE	0.0	1.8	2.5		1.4
NW	0.7	1.5	1.9	1.0	1.3
ST	1.5	2.0	0.4		1.3
BY	0.2	2.0	0.5	1.4	1.0
HH	1.1	1.4	0.6		1.0
SN	0.3	1.7			1.0
TH	0.0	2.1	1.3	0.3	0.9
MV	0.3	1.1	0.4	1.7	0.9
RP	0.8		0.3	1.3	0.8
SH	0.0	0.3	0.2	1.3	0.5
HB	1.1	0.0	0.3	0.2	0.4
NI	0.1	0.8	0.0		0.3
HE	0.1	0.5		0.0	0.2

Analyseschlüssel

Der Analyseschlüssel wurde zunächst aus den am Anfang gelesenen Curricula für Biologie und Geographie in Schleswig-Holstein und Nordrhein-Westfalen auf Basis der gesammelten Textabschnitte induktiv entwickelt. Im Zuge der Pilotierung mit dem Material für die Hauptanalyse und des Interratingprozesses wurde er mehrmals überarbeitet und ausgeschärft. Der finale Analyseschlüssel ist für die inhaltsbezogenen Kategorien der Dimension (a) in Tabelle 5-8 und für die anwendungsbezogenen Kategorien der Dimension (b) in Tabelle 5-9 dargestellt.

Tabelle 5-8: Analyseschlüssel für die inhaltsbezogenen Kategorien der Dimension (a).

Code und Kurzbeschreibung	Erläuterung und Kodierregeln	Beispiele
a-1: Nachhaltigkeit, Global Change, Anthropozän und Gesellschaft	<p>Verweise auf den globalen Wandel und Veränderungsprozesse, auf Nachhaltigkeit und BNE sowie auf das Anthropozän. Allgemeine Verweise auf menschliche Einflüsse/Eingriffe und Ressourcennutzung auf der Erde und Beziehungen zwischen Mensch und Biosphäre. Bezüge zu Werten, Normen, Gestaltung und Verantwortung, Gegenwart und Zukunft. Bezüge zur gesellschaftlichen Diskussion sowie Teilhabe am gesellschaftlichen Diskurs und Wandel.</p> <p><i>Kodierhinweise:</i> Ein Bezug zur Nachhaltigkeit soll auch dann codiert werden, wenn zwei oder mehr Dimensionen der Nachhaltigkeit (z.B. ökonomische, ökologische, soziale, politische usw. Dimension) erwähnt werden, der Begriff selbst aber nicht. Der Vermerk [BNE] zu bestimmten Unterrichtsinhalten ist nicht hinreichend, damit diese Kategorie zutrifft.</p>	<p>[...] Aufgabe des Faches Geografie ist es, den Schülern Einsichten in raumprägende und raumverändernde Faktoren des Ökosystems Mensch - Erde zu ermöglichen. Die Schüler erarbeiten sich Wissen über die Erde als eine nicht vermehrbare Lebensgrundlage, mit der verantwortungsbewusst umzugehen ist. Dieses Wissen dient als Orientierungshilfe beim bewussten Handeln im landschaftsräumlichen Umfeld, bei der Mitwirkung an einer nachhaltigen Entwicklung von Räumen. Zugleich muss es die Schüler befähigen, sich raumbezogene Probleme der Gegenwart und Zukunft zu erschließen. [...]</p> <p>Themenbereich: Soziale Ungleichheit II (national und international) SuS können</p> <ul style="list-style-type: none"> - den globalen Zusammenhang von Ökonomie und Ökologie beschreiben und erklären (z.B. Globalisierung, internationale Finanzmärkte, Umwelt- und Klimafolgen). [...]
a-2: Thema Klimawandel	<p>Nennung oder direkte Thematisierung des Klimas, des Klimawandels (oder Klimaschwankungen) oder der globalen Erwärmung oder des Treibhauseffekts. Auch Bezüge zum Klimawandel, wie z.B. "Klimafolgen" oder "Klimafragen". Auch Bezüge zu klimatischen Bedingungen im Verlauf der Erdgeschichte.</p>	<p>5.6.3 Nachhaltigkeit Kompetenzbezug SuS</p> <ul style="list-style-type: none"> - informieren sich über die Bedeutung der Pflanzen für die Energieversorgung (nachwachsende Rohstoffe), - schildern den Einfluss der Pflanzen auf die Luftzusammensetzung [...] <p>Mögliche Kontexte</p> <ul style="list-style-type: none"> -Treibhauseffekt, Regenwald -Biodiesel <p>Themenfeld Evolution Kompetenzerwartungen Fachwissen SuS beschreiben die Evolution als Veränderung der vererbten Merkmale von Lebewesen über einen sehr langen Zeitraum unter verschiedenen klimatischen Bedingungen</p>
a-3: Gesellschaftliche Lebensweise und Handeln (Ursachen, Minderung und Anpassung)	<p>Konkrete Bezüge zum gegenwärtigen Lebensstil/-weise, der Nutzung von Räumen und bestimmten Ressourcen (wie z.B. Energieträger). Insbesondere der Bezug zu Energie (-gewinnung, -trägern, regenerative Formen, -verfügbarkeit, -bedarf, -verbrauch, -versorgung, -Politik), zu Mobilität oder Ernährung, aber auch zu direkten Folgen der Nutzung, wie z.B. Emissionen. Bezüge zu (gesellschaftlichem und individuellem Alltags-) Handeln im Hinblick auf Auswirkungen des und Umgang mit dem Klimawandel, Lösungen und Anpassungsstrategien, z.B. Energie, Mobilität, Ernährung, politische Maßnahmen etc.</p> <p><i>Kodierhinweis:</i> diese Kategorie trifft zu, wenn auf Energiequellen oder Ressourcen verwiesen wird und/oder das individuelle oder gesellschaftliche Verhalten angesprochen wird, wenn eine Anknüpfung zum Thema Klimawandel (Ursachen oder Umgang damit) denkbar wäre (aber nicht explizit erwähnt sein muss).</p>	<p>Themenfeld Energieströme (Sprachen-zweig) Der Schwerpunkt des Themenfeldes ist jedoch die gesellschaftliche Dimension der Energie. Die Schülerinnen und Schüler sollen in die Lage versetzt werden, an der Diskussion um die heutige und zukünftige Energieversorgung verantwortlich teilzunehmen. Dazu ist von den relevanten Energiewandlern vom Typ Kraftwerk ein hinreichendes Faktenwissen unabdingbar</p> <p>Themenbereich Haushalt und Konsum SuS können</p> <ul style="list-style-type: none"> -Beispiele für ein nachhaltiges Konsumverhalten entwickeln und individuelle und gesellschaftliche Konsequenzen beurteilen, - den Einfluss von Konsumentscheidungen auf Produktionsprozesse und -bedingungen erklären und Auswirkungen auf lokale, nationale und globale Lebens- und Arbeitsbedingungen identifizieren

Tabelle 5-9: Analyseschlüssel für die anwendungsbezogenen Kategorien der Dimension (b).

Code und Kurzbeschreibung	Erläuterung und Kodierregeln	Beispiele
b-1: Übergreifendes Konzept	Didaktische Vorbemerkung oder Beschreibung eines allgemeinen Konzepts, das sich auf im jeweiligen Abschnitt des Curriculums folgende konkrete Inhalte und Kompetenzen bezieht. Hier können schon Wissensbereiche oder Kompetenzen, die Schülerinnen und Schüler erlangen sollen, in allgemeiner Weise beschrieben werden.	<p>[...] Die Schülerinnen und Schüler sollen befähigt werden, sich kritisch mit den wirtschaftlichen, gesellschaftlichen und ökologischen Herausforderungen in Gegenwart und Zukunft auseinander zu setzen und Stellung zu beziehen. [...] [a-63]</p> <p>[...] Unter Einbeziehung der Erfahrungen der Schüler sowie der Auswertung von thematischen Karten, Klimadiagrammen, Sachtexten und Neuen Medien erkennen sie wesentliche geodynamische und klimatische Prozesse sowie anthropogene Einflussfaktoren in Deutschland und Europa und können diese in europäische Zusammenhänge einordnen. [...]</p>
b-2: Verbindliche Fachinhalte und Kompetenzen	Konkret aufgelistete und beschriebene Fachinhalte (z.B. "fachbezogene Kompetenzen") und/oder Kompetenzen/Kompetenzerwartungen (z.B. "weitere Kompetenzen"), die sich auf die Fachinhalte beziehen. Verbindliche Fachbegriffe (wie z.B. "Basisbegriffe") oder "Hinweise" sind als Fachinhalte zu verstehen und sollen hier codiert werden. In allgemeinen Passagen (übergreifenden Konzepten) genanntes Wissen oder Kompetenzen sollten hier nicht codiert werden.	<p>Inhalte: Antarktis in Gefahr Hinweise: - Ansprüche von Staaten - Auswirkungen von Klimaveränderungen auf die Antarktis (Treibhauseffekt, Ozonloch) [...] Entdeckung durch den Tourismus</p> <p>Themenfeld Energieströme (Sprachenzweig) Energiehaushalt und Energieentwertung Fachwissen: SuS geben den jährlichen Bedarf an elektrischer Energie für einen durchschnittlichen Haushalt an Erkenntnisgewinnung, Kommunikation, Bewertung: SuS diskutieren Maßnahmen zur Energieeinsparung auf lokaler und globaler Ebene.</p>
b-3: Hinweise und Vorschläge zur unterrichtlichen Umsetzung	Vorschläge oder Beispiele für Fachinhalte, die explizit nicht verbindlich/verpflichtend für den Unterricht sind. Entsprechende Inhalte werden angezeigt durch Formulierungen, wie "zum Beispiel", "kann/können behandelt/thematisiert werden", "fakultativ", "mögliche Einstiege/Kontexte/...". Vorschläge für bestimmte Methoden, Unterrichtsmaterialien, Quellen, Exkursionen usw. für die unterrichtliche Umsetzung oder Hinweise auf fächerübergreifende Bezüge. Hierzu zählen auch Hinweise auf fächerverbindende Bezüge.	<p>Themenfeld Felder Hinweise: Außerschulische Lernorte - Besichtigung eines Wasserkraftwerks, eines Windparks oder einer Photovoltaik-Anlage - Besuch des zuständigen Energieversorgungsunternehmens</p> <p>Themenbereich Unternehmen und Produktion fakultativ: - Ökologische Nachhaltigkeit der Produktion [...]</p>

5.9.2 Veranschaulichung des Vorgehens der Textstellenauswahl und –bearbeitung

Zur Veranschaulichung des methodischen Vorgehens ist im Folgenden ein Auszug aus dem Tabellendatenblatt zur Sammlung der Textabschnitte dargestellt. Der Auszug stellt dar, wie die extrahierten Textabschnitte aus dem Curriculum (hier der Bildungsplan für die Oberschule in Bremen für das Fach Wirtschaft/Arbeit/Technik) im Tabellendokument geordnet wurden, um sie dann codieren zu können:

Schulart	Sti	Klassen	Fach	Seite	Ausw	Abschnitt	Thema und Textsegment (Zitat)	
Oberschule	Sek I	5-10	Wirtsch	5	E	1. Aufgaben und Ziele	... Jugendlichen setzen sich mit den verschiedenen Formen von Arbeit, Arbeitsprozessen und Arbeitssystemen, der Arbeitsorganisation und Haushalt, Familie und Betrieb auseinander. Die Frage der Geschlechtstypen Bestimmtheit von Männer- und Frauenarbeit, geschlechtsspezifischer Arbeitsteilung und Sozialisation sowie der nachhaltigen Entwicklung sind Gegenstand der Auseinandersetzung, ...	Textabschnitt 1
						Kapitelüberschrift 1	Infrastrukturen Schwerpunkt sind historische Entwicklungen und grundlegende Funktionszusammenhänge in den Bereichen Verkehrs- und Transportmittel, Informations- und Kommunikationsmittel und Energie. Außerdem geht es um die Beurteilung nach ökonomischen, sozialen und ökologischen Kriterien ...	Anderer Textkontext wurde ausgelassen
Oberschule	Sek I	5-10	Wirtsch	6-7	T	2. Themen und Inhalte	Themenbereich Haushalt und Konsum ... wie im Haushalt	Textabschnitt 2
						Kapitelüberschrift 2	Kapitel 2, Thema 1	
Oberschule	Sek I	5-10	Wirtsch	7	T	2. Themen und Inhalte	Themenbereich Unternehmen und Produktion - nachhaltiges Wirtschaften fakultativ: - Ökologische Nachhaltigkeit der Produktion ...	Textabschnitt 3
							Kapitel 2, Thema 2	
Oberschule	Sek I	7-8	Wirtsch	11	T	3. Standards 3.2 Anforderungen am Ende der Jahrgangsstufe	Inhaltsbezogene Kompetenzen Haushalt und Konsum SuS können ...	Textabschnitt 4
						Kapitelüberschrift 3	Kapitel 3, Thema 1	
							beschreiben und fachpraktisch anwenden, sowie die eigene Konsumentenrolle und individuelle Handlungsmuster, auch bezogen auf e-commerce, beurteilen, - Beispiele für ein nachhaltiges Konsumverhalten und individuelle und gesellschaftliche Konsequenzen entwickeln.	
Oberschule	Sek I	7-8	Wirtsch	12	T	3. Standards 3.2 Anforderungen am Ende der Jahrgangsstufe 8	Inhaltsbezogene Kompetenzen Infrastrukturen SuS können ... - verschiedene ... - beschreiben und modellhaft anwenden - und unter dem Gesichtspunkt der Nachhaltigkeit beurteilen, - die Energieversorgung im Land Bremen beschreiben und aktuelle und zukünftige Energieversorgungsprobleme diskutieren, - die Chancen regenerativer Energien an Beispielen beschreiben und beurteilen,	Textabschnitt 5
							Kapitel 3, Thema 2	

Textsegmente im Tabellenblatt zitiert aus dem Bildungsplan der Freien und Hansestadt Bremen: *Wirtschaft/Arbeit/Technik, Bildungsplan für die Oberschule, 2012*

5.9.3 Liste der analysierten Curricula

Die Curricula wurden am 01.09.2022 und 16.02.2023 von den Homepages der Bildungsbehörden heruntergeladen.

Freie Hansestadt Bremen: Landesinstitut für Schule
<https://www.lis.bremen.de/schulqualitaet/bildungsplaene-15219>

Mecklenburg-Vorpommern: Ministerium für Bildung und Kindertagesförderung, Bildungsserver
<https://www.bildung-mv.de/schueler/schule-und-unterricht/faecher-und-rahmenplaene/rahmenplaene-an-allgemeinbildenden-schulen/>

Saarland: Ministerium für Bildung und Kultur, Bildungsserver
https://www.saarland.de/mbk/DE/portale/bildungsserver/themen/unterricht-und-bildungsthemen/lehrplaenehandreichungen/lehrplaeneallgemeinbildende/lehrplaeneallgemeinbildende_node.html

Bremen

Oberschule

Die Senatorin für Bildung und Wissenschaft Freie Hansestadt Bremen: Naturwissenschaften – Biologie, Chemie, Physik – Bildungsplan für die Oberschule (2010)

Die Senatorin für Bildung und Wissenschaft Freie Hansestadt Bremen: Gesellschaft und Politik – Geographie, Geschichte, Politik – Bildungsplan für die Oberschule (2010)

Die Senatorin für Bildung, Wissenschaft und Gesundheit Freie Hansestadt Bremen: Wirtschaft/Arbeit/Technik – Bildungsplan für die Oberschule (2012)

Gymnasium Sekundarstufe I

Der Senator für Bildung und Wissenschaft Freie Hansestadt Bremen: Naturwissenschaften – Biologie, Chemie, Physik – Bildungsplan für das Gymnasium, Jahrgangsstufe 5-10 (2006) (*unter Berücksichtigung der Anlage zur Mitteilung 239/2022 Einschränkung der Gültigkeit des Bildungsplans Naturwissenschaften, Biologie-Chemie-Physik für das Gymnasium, Jahrgangsstufe 5-10, auf die Jahrgangsstufen 5-9*)

Der Senator für Bildung und Wissenschaft Freie Hansestadt Bremen: Welt-Umweltkunde, Geschichte, Geografie, Politik – Bildungsplan für das Gymnasium, Jahrgangsstufe 5-10 (2006)

Der Senator für Bildung und Wissenschaft Freie Hansestadt Bremen: Wirtschaft-Arbeit-Technik – Bildungsplan für das Gymnasium, Jahrgangsstufe 5-10 (2006)

Gymnasium Sekundarstufe II

Die Senatorin für Kinder und Bildung Freie Hansestadt Bremen: Biologie – Bildungsplan für die Gymnasiale Oberstufe – Einführungsphase und Qualifikationsphase (2022)

Die Senatorin für Kinder und Bildung Freie Hansestadt Bremen: Chemie – Bildungsplan für die Gymnasiale Oberstufe – Einführungsphase und Qualifikationsphase (2022)

Die Senatorin für Kinder und Bildung Freie Hansestadt Bremen: Physik – Bildungsplan für die Gymnasiale Oberstufe – Einführungsphase und Qualifikationsphase (2022)

Landesinstitut für Schule Bremen: Physik – Handreichung zum Bildungsplan für das Gymnasium – Qualifikationsphase (2008)

Die Senatorin für Bildung und Wissenschaft Freie Hansestadt Bremen: Geografie – Bildungsplan für die Gymnasiale Oberstufe – Qualifikationsphase (2008)

Die Senatorin für Bildung und Wissenschaft Freie Hansestadt Bremen: Geschichte – Bildungsplan für die Gymnasiale Oberstufe – Qualifikationsphase (2008)

Die Senatorin für Bildung und Wissenschaft Freie Hansestadt Bremen: Politik – Bildungsplan für die Gymnasiale Oberstufe – Qualifikationsphase (2008)

Die Senatorin für Bildung und Wissenschaft Freie Hansestadt Bremen: Soziologie – Bildungsplan für die Gymnasiale Oberstufe – Qualifikationsphase (2009)

Die Senatorin für Bildung und Wissenschaft Freie Hansestadt Bremen: Wirtschaftslehre – Bildungsplan für die Gymnasiale Oberstufe – Qualifikationsphase (2008)

Mecklenburg-Vorpommern

Orientierungsstufe

Mecklenburg-Vorpommern Ministerium für Bildung, Wissenschaft und Kultur: Rahmenplan für die Orientierungsstufe, Biologie – Erprobungsfassung (2022)

Mecklenburg-Vorpommern Ministerium für Bildung, Wissenschaft und Kultur: Rahmenplan, Naturwissenschaften, für die Jahrgangsstufen 5 und 6 an der Integrierten Gesamtschule sowie an der Regionalen Schule – Erprobungsfassung (2010)

Mecklenburg-Vorpommern Ministerium für Bildung und Kindertagesförderung: Rahmenplan Orientierungsstufe, Klasse 6, Physik – Erprobungsfassung (2022)

Mecklenburg-Vorpommern Ministerium für Bildung, Wissenschaft und Kultur: Rahmenplan für die Orientierungsstufe, Geografie (ohne Titelseite und Jahresangabe)

Mecklenburg-Vorpommern Ministerium für Bildung, Wissenschaft und Kultur: Rahmenplan für die Orientierungsstufe, Geschichte (ohne Titelseite und Jahresangabe)

Mecklenburg-Vorpommern Ministerium für Bildung und Kindertagesförderung: Rahmenplan, Orientierungsstufe, Klasse 5/6, Gesellschaftswissenschaften – Erprobungsfassung (ohne Jahresangabe)

Mecklenburg-Vorpommern Ministerium für Bildung, Wissenschaft und Kultur: Rahmenplan, Integrierte Gesamtschule, Jahrgangsstufen 5/6, Weltkunde – Erprobungsfassung (2004)

Regionale Schule Sekundarstufe I

Mecklenburg-Vorpommern Ministerium für Bildung, Wissenschaft und Kultur: Rahmenplan für die Sekundarstufe I – Regionale Schule, Gesamtschule, Biologie (2021)

Mecklenburg-Vorpommern Ministerium für Bildung, Wissenschaft und Kultur: Rahmenplan für die Sekundarstufe I – Regionale Schule, Gesamtschule, Chemie (2021)

Mecklenburg-Vorpommern Ministerium für Bildung, Wissenschaft und Kultur: Rahmenplan für die Sekundarstufe I – Regionale Schule, Gesamtschule, Physik (2021)

Mecklenburg-Vorpommern Ministerium für Bildung, Wissenschaft und Kultur: Rahmenplan – Regionale Schule, Verbundene Haupt- und Realschule, Hauptschule, Realschule, Integrierte Gesamtschule, Jahrgangsstufen 7-10, Geographie – Erprobungsfassung (2002)

Mecklenburg-Vorpommern Ministerium für Bildung, Wissenschaft und Kultur: Rahmenplan – Regionale Schule, Verbundene Haupt- und Realschule, Hauptschule, Realschule, Integrierte Gesamtschule, Jahrgangsstufen 7-10, Geschichte – Erprobungsfassung (2002)

Mecklenburg-Vorpommern Ministerium für Bildung, Wissenschaft und Kultur: Rahmenplan – Regionale Schule, Verbundene Haupt- und Realschule, Hauptschule, Realschule, Integrierte Gesamtschule, Jahrgangsstufen 7-10, Sozialkunde – Erprobungsfassung (2002)

Landesinstitut für Schule und Ausbildung MV: Handreichung zum Rahmenplan Fächerverbindender/fächerübergreifender Wahlpflichtkurs „Gestaltung einer zukunftsfähigen Welt“ (Fächer: Geographie, Biologie und Sozialkunde) – Regionalschule, Integrierte Gesamtschule, Realschule, Jahrgangsstufen 9/10 (2006)

Gymnasium Sekundarstufe I

Mecklenburg-Vorpommern Ministerium für Bildung und Kindertagesförderung: Rahmenplan für den Sekundarbereich I – Gymnasium/Gesamtschule, Biologie – Erprobungsfassung (2022)

Mecklenburg-Vorpommern Ministerium für Bildung, Wissenschaft und Kultur: Rahmenplan für die Sekundarstufe I – Gymnasium, Gesamtschule, Chemie (2021)

Mecklenburg-Vorpommern Ministerium für Bildung und Kindertagesförderung: Rahmenplan für den Sekundarbereich I – Gymnasium/Gesamtschule, Physik – Erprobungsfassung (2022)

Mecklenburg-Vorpommern Ministerium für Bildung, Wissenschaft und Kultur: Rahmenplan – Gymnasium, Integrierte Gesamtschule, Jahrgangsstufen 7-10, Geographie – Erprobungsfassung (2002)

Mecklenburg-Vorpommern Ministerium für Bildung, Wissenschaft und Kultur: Rahmenplan – Gymnasium, Integrierte Gesamtschule, Jahrgangsstufen 7-10, Geschichte – Erprobungsfassung (2002)

Mecklenburg-Vorpommern Ministerium für Bildung, Wissenschaft und Kultur: Rahmenplan – Gymnasium, Integrierte Gesamtschule, Jahrgangsstufen 7-10, Sozialkunde – Erprobungsfassung (2002)

STUDY 2

Mecklenburg-Vorpommern Ministerium für Bildung, Wissenschaft und Kultur: Rahmenplan Fächerverbindender/fächerübergreifender Wahlpflichtkurs System Erde (Biologie, Chemie, Geographie, Physik, Sozialkunde) – Gymnasium, Gesamtschule, Jahrgangsstufen 9/10 (ohne Jahresangabe)

Gymnasium Sekundarstufe II

Mecklenburg-Vorpommern Ministerium für Bildung und Kindertagesförderung: Rahmenplan für die Qualifikationsphase der gymnasialen Oberstufe, Biologie – Erprobungsfassung (2022)

Mecklenburg-Vorpommern Ministerium für Bildung und Kindertagesförderung: Rahmenplan für die Qualifikationsphase der gymnasialen Oberstufe, Chemie – Erprobungsfassung (2022)

Mecklenburg-Vorpommern Ministerium für Bildung und Kindertagesförderung: Rahmenplan für die Qualifikationsphase der gymnasialen Oberstufe, Physik – Erprobungsfassung (2022)

Mecklenburg-Vorpommern Ministerium für Bildung, Wissenschaft und Kultur: Rahmenplan für die Qualifikationsphase der gymnasialen Oberstufe, Geografie (2019)

Mecklenburg-Vorpommern Ministerium für Bildung, Wissenschaft und Kultur: Rahmenplan für die Qualifikationsphase der gymnasialen Oberstufe, Geschichte und Politische Bildung (2019)

Mecklenburg-Vorpommern Ministerium für Bildung, Wissenschaft und Kultur: Rahmenplan für die Qualifikationsphase der gymnasialen Oberstufe, Sozialkunde (2019)

Saarland

Gemeinschaftsschulen Sekundarstufe I

Saarland Ministerium für Bildung und Kultur: Lehrplan Biologie, Gemeinschaftsschule – Erprobungsphase (2016)

Saarland Ministerium für Bildung und Kultur: Lehrplan Chemie, Gemeinschaftsschule – Erprobungsphase (2016)

Saarland Ministerium für Bildung und Kultur: Lehrplan Naturwissenschaften – Vorwort und Jahrgangsübergreifender Teil, Gemeinschaftsschule – Erprobungsphase (2014)

Saarland Ministerium für Bildung und Kultur: Lehrplan Naturwissenschaften – Klassenstufen 5 und 6, Gemeinschaftsschule – Erprobungsphase (2014)

Saarland Ministerium für Bildung und Kultur: Lehrplan Naturwissenschaften – Klassenstufen 7 und 8, Gemeinschaftsschule – Erprobungsphase (2014)

Saarland Ministerium für Bildung und Kultur: Lehrplan Physik, Gemeinschaftsschule – Erprobungsphase (2016)

Saarland Ministerium für Bildung und Kultur: Lehrplan Arbeitslehre – Klassenstufen 5 und 6, Gemeinschaftsschule – Entwurf (2012)

Saarland Ministerium für Bildung und Kultur: Lehrplan Beruf und Wirtschaft, Gemeinschaftsschule – Erprobungsphase (2014)

Saarland Ministerium für Bildung und Kultur: Lehrplan Erdkunde – Klassenstufen 9 und 10, Gemeinschaftsschule – Erprobungsphase (2015)

Saarland Ministerium für Bildung und Kultur: Lehrplan Gesellschaftswissenschaften – Vorwort und Jahrgangsübergreifender Teil, Gemeinschaftsschule – Erprobungsphase (2014)

Saarland Ministerium für Bildung und Kultur: Lehrplan Gesellschaftswissenschaften – Klassenstufen 5 und 6, Gemeinschaftsschule – Erprobungsphase (2014)

Saarland Ministerium für Bildung und Kultur: Lehrplan Gesellschaftswissenschaften – Klassenstufen 7 und 8, Gemeinschaftsschule (2021)

Saarland Ministerium für Bildung und Kultur: Lehrplan Gesellschaftswissenschaften – Klassenstufen 9 und 10, Gemeinschaftsschule – Erprobungsphase (2014)

Saarland Ministerium für Bildung und Kultur: Lehrplan Geschichte – Klassenstufen 9 und 10, Gemeinschaftsschule – Erprobungsphase (2015)

Saarland Ministerium für Bildung und Kultur: Lehrplan Sozialkunde – Klassenstufen 9 und 10, Gemeinschaftsschule – Erprobungsphase (2015)

Gymnasium Sekundarstufe I

Saarland Ministerium für Bildung und Kultur: Lehrplan Biologie – Vorwort und Jahrgangsübergreifender Teil, Gymnasium (2014)

- Saarland Ministerium für Bildung und Kultur: Lehrplan Biologie – Klassenstufe 7, Gymnasium (2014)
- Saarland Ministerium für Bildung und Kultur: Lehrplan Biologie, naturwissenschaftlicher Zweig – Klassenstufe 8, Gymnasium (2014)
- Saarland Ministerium für Bildung und Kultur: Lehrplan Biologie – Klassenstufe 9, Gymnasium – Erprobungsphase (2014)
- Saarland Ministerium für Bildung und Kultur: Lehrplan Chemie – Klassenstufen 8 und 9, Gymnasium – Erprobungsphase (2012)
- Saarland Ministerium für Bildung und Kultur: Lehrplan Chemie, naturwissenschaftlicher Zweig – Klassenstufen 8 und 9, Gymnasium – Erprobungsphase (2012)
- Saarland Ministerium für Bildung und Kultur: Lehrplan Naturwissenschaften – Klassenstufen 5 und 6, Gymnasium – Erprobungsphase (2012)
- Saarland Ministerium für Bildung und Kultur: Lehrplan Physik – Klassenstufen 7 und 8, Gymnasium – Erprobungsphase (2013)
- Saarland Ministerium für Bildung und Kultur: Lehrplan Physik, Sprachenzweig – Klassenstufe 9, Gymnasium – Erprobungsphase (2014)
- Saarland Ministerium für Bildung und Kultur: Lehrplan Physik, naturwissenschaftlicher Zweig – Klassenstufe 9, Gymnasium – Erprobungsphase (2014)
- Saarland Ministerium für Bildung und Kultur: Lehrplan Erdkunde – Vorwort und Jahrgangsübergreifender Teil, Gymnasium (2014)
- Saarland Ministerium für Bildung und Kultur: Lehrplan Erdkunde – Klassenstufe 5, Gymnasium (2014)
- Saarland Ministerium für Bildung und Kultur: Lehrplan Erdkunde – Klassenstufe 7, Gymnasium (2014)
- Saarland Ministerium für Bildung und Kultur: Lehrplan Erdkunde – Klassenstufe 8, Gymnasium (2014)
- Saarland Ministerium für Bildung und Kultur: Lehrplan Geschichte – Vorwort und Jahrgangsübergreifender Teil, Gymnasium (2014)
- Saarland Ministerium für Bildung und Kultur: Lehrplan Geschichte – Klassenstufe 6, Gymnasium (2014)
- Saarland Ministerium für Bildung und Kultur: Lehrplan Geschichte – Klassenstufe 7, Gymnasium (2014)
- Saarland Ministerium für Bildung und Kultur: Lehrplan Geschichte – Klassenstufe 8, Gymnasium – Erprobungsphase (2014)
- Saarland Ministerium für Bildung und Kultur: Lehrplan Geschichte – Klassenstufe 9, Gymnasium – Erprobungsphase (2014)
- Saarland Ministerium für Bildung und Kultur: Lehrplan Sozialkunde – Klassenstufe 9, Gymnasium (2020)

Gymnasium Sekundarstufe II

- Saarland Ministerium für Bildung und Kultur: Lehrplan Biologie – Einführungsphase, Gymnasiale Oberstufe – Erprobungsphase (2019)
- Saarland Ministerium für Bildung und Kultur: Lehrplan Biologie – Hauptphase Grundkurs, Gymnasiale Oberstufe – Erprobungsphase (2019)
- Saarland Ministerium für Bildung und Kultur: Lehrplan Biologie – Hauptphase Leistungskurs, Gymnasiale Oberstufe – Erprobungsphase (2019)
- Saarland Ministerium für Bildung und Kultur: Lehrplan Chemie, sprachlicher Zweig – Einführungsphase, Gymnasiale Oberstufe – Erprobungsphase (2019)
- Saarland Ministerium für Bildung und Kultur: Lehrplan Chemie, naturwissenschaftlicher Zweig – Einführungsphase, Gymnasiale Oberstufe – Erprobungsphase (2019)
- Saarland Ministerium für Bildung und Kultur: Lehrplan Chemie – Hauptphase Grundkurs, Gymnasiale Oberstufe – Erprobungsphase (2019)
- Saarland Ministerium für Bildung und Kultur: Lehrplan Chemie – Hauptphase Leistungskurs, Gymnasiale Oberstufe – Erprobungsphase (2019)
- Saarland Ministerium für Bildung und Kultur: Lehrplan Physik – Einführungsphase, Gymnasiale Oberstufe – Erprobungsphase (2015)
- Saarland Ministerium für Bildung und Kultur: Lehrplan Physik – Hauptphase Grundkurs, Gymnasiale Oberstufe – Erprobungsphase (2019)
- Saarland Ministerium für Bildung und Kultur: Lehrplan Physik – Hauptphase Leistungskurs, Gymnasiale Oberstufe – Erprobungsphase (2019)

STUDY 2

Saarland Ministerium für Bildung und Kultur: Lehrplan Erdkunde – Einführungsphase, Gymnasiale Oberstufe – Erprobungsphase (2015)

Saarland Ministerium für Bildung und Kultur: Lehrplan Erdkunde – Hauptphase Grundkurs, Gymnasiale Oberstufe – Erprobungsphase (2019)

Saarland Ministerium für Bildung und Kultur: Lehrplan Erdkunde – Hauptphase Leistungskurs, Gymnasiale Oberstufe – Erprobungsphase (2019)

Saarland Ministerium für Bildung und Kultur: Lehrplan Geschichte – Einführungsphase, Gymnasiale Oberstufe – Erprobungsphase (2016)

Saarland Ministerium für Bildung und Kultur: Lehrplan Geschichte – Hauptphase Grundkurs, Gymnasiale Oberstufe – Erprobungsphase (2019)

Saarland Ministerium für Bildung und Kultur: Lehrplan Geschichte – Hauptphase Leistungskurs, Gymnasiale Oberstufe – Erprobungsphase (2019)

Saarland Ministerium für Bildung und Kultur: Lehrplan Politik – Hauptphase Grundkurs, Gymnasiale Oberstufe – Erprobungsphase (2019)

Saarland Ministerium für Bildung und Kultur: Lehrplan Politik – Hauptphase Leistungskurs, Gymnasiale Saarland Ministerium für Bildung und Kultur: Lehrplan Sozialkunde – Einführungsphase, Gymnasiale Oberstufe (2021)

Oberstufe – Erprobungsphase (2019)

Saarland Ministerium für Bildung, Kultur und Wissenschaft: Lehrplan Wirtschaftslehre – Vorwort, Gymnasiale Oberstufe – Erprobungsphase (2006)

Saarland Ministerium für Bildung, Kultur und Wissenschaft: Lehrplan Wirtschaftslehre – Einführungsphase, Gymnasiale Oberstufe (2006)

Saarland Ministerium für Bildung, Familie, Frauen und Kultur: Lehrplan Wirtschaftslehre – Hauptphase G-Kurs, Gymnasiale Oberstufe (2008)

Saarland Ministerium für Bildung, Familie, Frauen und Kultur: Lehrplan Wirtschaftslehre – Hauptphase E-Kurs, Gymnasiale Oberstufe (2008)

6 Study 3

A fragmented endeavour

– Climate education contents in natural science, geography, and social sciences textbooks³

Abstract:

Climate change is one of today's most urgent global challenges. School education is an important key to preparing future generations to meet its impacts. Climate education can help students to develop the knowledge, skills, and attitudes, i.e. climate literacy, necessary to elaborate approaches for mitigating climate change and for adapting to the climate to come. Due to the interdisciplinarity of the phenomenon 'climate change' and its impacts, it can be assumed that climate education takes place in natural science as well as in the social sciences' subjects. To gain a deeper insight into current climate education in schools, we conducted a comprehensive textbook analysis with textbooks for secondary education from science subjects, geography, and social studies from the UK and Germany. In both countries, we found a wide range of climate education topics within geography textbooks a particular focus on energy content within textbooks for the natural science subjects of chemistry and physics, but less coverage of climate education in biology and social studies. Overall, basic knowledge about the climate system and the greenhouse effect, anthropogenic causes of climate change and mitigation strategies are most strongly represented. For the development of a comprehensive climate education, however, societal transformation and adaptation strategies should be more addressed.

Keywords: climate literacy, textbook analysis, science education, climate change, teaching

³ This is a peer-reviewed version of the following manuscript: Leve, A.-K., Garrecht, C., Harms, U.: A fragmented endeavour — Climate education contents in natural science, geography, and social sciences textbooks. The manuscript will be further submitted in an adapted and further revised version.

6.1 Introduction

Globally, climate change is one of today's most pressing problems. Science education and climate literacy (CL) are hypothesized to be relevant drivers for the implementation of mitigation and adaptation measures for climate change throughout society (IPCC, 2023, pp. 9, 30; Ledley et al., 2017). Global strategies to moderate climate change and to adapt to its impacts are extremely relevant. Especially adaptation is limited by low CL and low political commitment in society (IPCC, 2023, p. 9). Climate change is one such global challenge that requires to include the social dimensions of science as well as interdisciplinary approaches with respect to the history, philosophy and sociology of science in science education (Erduran, 2020). Similar as suggested by Reiss (2020) for the issue of COVID-19, it would be appropriate for climate education to include sociological practices as well as the interplay of economics, politics, psychology and science. This offers an opportunity for school science to leverage processes in society by supporting students towards becoming active citizens (Levrini et al., 2021). Lee and Park (2024) suggest a concept for Anthropocene Literacy which involves meeting challenges such as climate change and emphasizing a multidisciplinary approach as one of three necessary key elements. Sharma (2012) presents climate change as a societal problem and argues that social questions are much more intertwined with the issue than technological solutions. He therefore proposes that the role of science education in the context of climate change is to make the basic processes and principles of climate and climate change accessible to students so that they can participate in social debate as members of society. Similarly, Zeidler & Newton (2017) present climate change within a socioscientific issue framework.

In order to investigate how climate change as a socioscientific issue is currently included in school teaching, Morris (2014) conducted a textbook analysis of a physics school textbook based on several key ideas related to global inequalities, scientific progress, and technological progress as part of the problem as well as part of the solution. She found a predominant representation of scientific and technological solutions, whereas the social aspect is largely neglected. So, it remains unclear, if the latter falls to any other subjects and, if so, what role the specific subjects play with regard to the scientific and social aspects of climate change. Reviewing empirical research on climate education, Bhattacharya et al. (2021) found that climate education is rather included in biology, environmental science, Earth science and less in chemistry and physics and that the content focus is on respective topics of those subjects, e.g. the greenhouse effect or the carbon cycle. Furthermore, the review reveals a very low scope of time that teachers spend on climate education. Another review by Hestness et al. (2014) reports that while Earth science⁴ teachers would most likely include climate education, other science teachers would also be willing to include the topic, but they feel little prepared. Regarding the role of different subjects in climate education, the topic of climate change seems to be inadequately covered by subject curricula (Hestness et al., 2014). Yet, subjects beyond geography should provide opportunities to include climate content e.g. by transdisciplinary concepts of radiation, temperature and others (Dupigny-Giroux, 2010).

⁴ Some scholars refer to Earth science, some refer to geography and some refer to both. This is due to the fact that subjects' names are different throughout different countries. We refer to geography in our study area (Germany and UK) but we use the wording of other scholars when referring to their research.

While teachers criticise that they lack resources for teaching climate change in classrooms (Sullivan et al., 2014), Uherek & Schüpbach (2008) report on curricula and teaching practice in Europe, stating that climate change being rather additional to traditional curricula than actually an integrated part of them and that textbooks are following this default. Yet, textbooks are a well-founded resource that undergo publishing and approval processes and provide a reliable basis for the development of classroom teaching, which is why we consider them as reflecting what is actually taught. Research conclusively indicates a low coverage of climate education throughout subject curricula and unclear competencies within the different subjects. Therefore, the current coverage and representation of climate change within teaching material such as approved textbooks is of interest. A curriculum study from Germany revealed that climate change content is rather to be found in geography, science subjects as well as some social study subjects (Leve et al., 2024). In order to shed light on the situation of teaching material, we conducted a comprehensive textbook analysis to get insight into current climate education at school. To this end, we considered textbooks in two countries – the UK and Germany – from geography and social studies as well as from natural science subjects to cover these relevant subjects at the present stage.

6.2 Theoretical Background

6.2.1 Climate Literacy as a framework for climate education

The preconditions for climate education are discussed in diverse ways as climate change is considered a complex issue that can be difficult to understand for both teachers and learners (Dupigny-Giroux, 2010; Hestness et al., 2014). The conceptualisation of CL locates climate education close to science education, namely within scientific literacy (SL) (Azevedo & Marques, 2017).

Nevertheless, many scholars cite the fact that both a physical science basis as well as social aspects must be integrated. To this end several visions of SL have been put forward: Vision I is about scientific content knowledge, Vision II is about the comprehension of science for means of everyday life and society, as developed and outlined by Roberts (Roberts, 2010). Vision III deals with the application of science education to justice-orientation, societal participation and citizenship enhancing social transformation (Sjöblom et al., 2023; Sjöström & Eilks, 2018). Sjöblom et al. (2023) call for climate education to be oriented in a way that aims for a vision III of SL.

For this study, the following aspects considering Vision III of SL become relevant: the political discourse in science education for societal participation and the associated societal debate.

The related concept of CL has been outlined by different scholars in the past. Therefore, in a review by Azevedo & Marques (2017), three basic aspects of CL are mapped out: (1) knowledge about the climate system and climate change, (2) skills e.g., to assess scientific information and (3) attitudes that may lead to climate friendly behaviour (Azevedo & Marques, 2017). The US Global Change Research Program (USGCRP) developed a compilation of CL essential principles that focus mainly on scientific elements around climate change. Yet, they also mention the necessity for a further compilation taking into account the social aspects as well (USGCRP, 2009) and they recently published a revised version of the CL principles including social aspects (USGCRP, 2024). Shwom et al. (2017) had introduced two new CL principles embedded in social science, which are to consider (1) the public understanding of climate change as a social and psychological phenomenon and (2) social context as either driver or deceleration of mitigation and adaptation. Furthermore, with a

focus on teachers' professional knowledge and teaching strategies, Leve et al. (2023) present several themes related to CL in the educational context that cover scientific, social, and interdisciplinary content knowledge aspects as well as a focus on pedagogical content knowledge for CL. Transcending the physical science basis and including social aspects, Kranz et al. (2022) take into account the political side of climate change mitigation and adaptation and propose from their review that political aspects should be incorporated in CL education including public sphere action. We build our study on the concept of CL considering both the science focus as well as the relation to societal and political aspects, which is why we chose to focus on textbooks from the field of science subjects as well as geography and social studies.

For this study the following aspects considering the conceptualisation of CL become relevant: the knowledge aspects about the physical science basis (the climate system, climate science, causes and impacts of climate change) as presented in the essential principles (USGCRP, 2009), strategies to react to climate change (mitigation, adaptation) and the societal debate about climate change. Furthermore, skills as proposed by Azevedo & Marques (2017) as well as attitudes are implicitly relevant within the aforementioned.

6.2.2 The role of textbooks in research and teaching

If and in which way climate change is being included in curricula differs across different countries and subjects. It might be attached to the topic of sustainability or included in one or few subjects or dispersed across many different subjects (cross-curriculum) or it might be included in non- or interdisciplinary curriculum sections (e.g. projects-based) (Eilam, 2022). According to Remillard and Heck (2014) the formal curricula that have been authorized by an institution ("official curriculum") and the classroom teaching that teachers enact the curriculum as ("operational curriculum") might differ. Textbooks, however, as instructional materials, play a key role in the implementation of the formal curricula guidelines into teaching practice as they are closely interrelated with the formal curriculum (Remillard & Heck, 2014). The formal curriculum is being agreed on by professionals, users, and governments and represents their current consensus (Heyneman, 2006). Textbooks, however, provide the formal curriculum to be transferred for the use in classroom teaching (Stein et al., 2007). Textbooks are being approved by governmental institutions and therefore are considered as reliable instruments for the use at schools. Yet they might also be shaped by political influence and represent current social world views (Bruillard, 2022; Shapiro, 2012) as they are being produced by the collaboration of authors, editors, reviewers, and publishers combining their values and interests (DiGiuseppe, 2014). Hence, textbooks are the most important material for classroom teaching at schools and how teachers make use of them impacts students' learning (Stern & Roseman, 2004). It is therefore not surprising that teachers report how they rely on student textbooks as a main source for their teaching (King, 2001).

6.2.3 The state of research on climate education in textbooks

On an international level, research has been increasingly interested in how climate change is addressed within textbooks, mainly in the subjects of natural science and geography. One study examined the development of the inclusion of climate change in American textbooks over a period from the 1970s to the 2010s. The results show that the topic has taken up increasingly more space over the years and the focus has shifted from simply describing the greenhouse effect to describing the impacts of climate change (Ansari & Landin, 2022). Other studies refer to current textbook

issues and are characterised by common focal points: Describing the greenhouse effect, causes and consequences of climate change and, although less frequently, indications of possible solutions. Bagoly-Simó (2013), for example, found that the focus within textbooks of three different countries (Germany, Romania, Mexico) is on the anthropogenic causes of climate change rather than on natural fluctuations. At the same time he found that concepts, causes and consequences are being discussed inconsistently within the investigated countries (Bagoly-Simó, 2013). Meanwhile, causes of climate change as well as its consequences and possible solutions including international strategies are being involved within textbooks in the Czech Republic, Poland, the UK, Norway, and South Africa additionally to the basic knowledge around the greenhouse effect and global warming in general (Baarova & Hibszer, 2022; Morris, 2014; Trædal et al., 2022). Ethiopian textbooks include the scientific basics around climate change and its causes and consequences, but leave out the aspects of policy and societal discussion or transformation (Dalelo, 2011). The main focus in Colombia as well as in Spain is more on causes and impacts than on solution, and scholars as well as teachers consider the topic of climate change as inadequately addressed in textbooks (Bonilla & Quesada, 2024; Morote & Hernández-Hernández, 2023). In their investigation of how climate change is visualized in textbooks from Germany, Schauss et al. (2024) found that diagrams and pictures show the impacts of climate change and nature rather than mitigation measures. Apart from these content focal points mentioned above, some studies found that at least parts of the investigated textbooks in the United States presented climate change as a topic with scientific uncertainty especially regarding its causes (i.e. human or natural) (Meehan et al., 2018; Román & Busch, 2016). This perceived uncertainty seems to be inherited by US teachers who avoid to address and discuss the anthropogenic causes of climate change (Nation & Feldman, 2022). Regarding the representation of content within the investigated textbooks some studies revealed that students' misconceptions are not being solved by the presentation of climate change-related content. In contrast, investigated books in the United States included presentations that can even foster misconceptions whilst specific scientific concepts were not covered within the books (Choi et al., 2010). Misconceptions related to the atmosphere that can be found throughout science textbooks in the UK are congruent with findings across climate education research (King, 2010). It has been found that misconceptions of the greenhouse effect can be provoked through presentations in textbooks in general (Shepardson et al., 2011). The inclusion of the topic of climate change in a subject curriculum might depend on the specific subject and on the respective age group. Hence, in primary school in Germany the topic of climate change is hardly implemented as a topic of its own right, but rather indirectly attached to sustainability topics including reasons for climate change and action towards sustainable development (Moelter-Reich et al., 2023).

6.3 Research Questions

Due to the low coverage of climate change within different subject curricula and the unclear current situation of climate education within classroom teaching according to the role different subjects play and the inclusion of scientific and social aspects we aim to investigate how climate change is being included in teaching materials. Given the fact that CL comprises aspects from natural science and social studies (Shwom et al., 2017; USGCRP, 2009) we decided to consider a whole range of subjects as relevant to our present study. This decision is underpinned by the fact that teachers and scholars place the topic rather within geography and Earth science but would agree

to the necessity to transcend this subject frame according to research (Dupigny-Giroux, 2010; Hestness et al., 2014). Considering textbooks that undergo approval processes as representative teaching material most used at classroom teaching, the present study investigates textbooks for secondary education to get insight into climate education at school at the current state. We thereby intend to answer the following research questions:

- To which extent is climate education being addressed in natural science and social studies textbooks in secondary education in the UK and in Germany?
- What are the main focus topics of climate education in natural science and social studies textbooks in secondary education in the UK and in Germany?
- In which ways do textbooks for natural science or for social studies address climate education differently?

By investigating (1) the extent, (2) the focus topics, and (3) the different ways of inclusion between science and social subjects, we aim to find out (1) how relevant climate education is conceptualised within the different subjects, (2) which topics from the physical science basis and/or the societal consideration of our CL conceptualisation gain more significance (with respect to vision III of SL and our CL conceptualisation), and (3) if the science subjects address climate education in a way that acknowledges vision III of SL and/or if the social subjects play a complementary role to achieve this vision.

6.4 Methodology

6.4.1 Selection of textbooks from the UK and from Germany

Our aim was to analyse textbooks from two countries from the range of natural science on the one hand and social studies on the other hand. We decided on two European countries: Germany as the country where the authors work to provide an insight for the international community and on the UK, an English-speaking country accessible for an international community and in the same time from a similar geographical and political background. We decided to choose books for the subjects of biology, chemistry, physics, combined science (covering natural science), citizenship studies (UK), world studies (Germany) (covering social science) and geography (representing both sides (Lambert et al., 2015)). Structures, labels and textbooks for the social studies are less uniform and widespread which is why the sample is smaller on this side.

In order to have a comparable sample from both our focus countries we chose the selection of textbooks as follows: For the UK we decided to use textbooks towards the General Certificate of Secondary Education (GCSE) (Year 11 age 15 or 16). We selected textbooks that were published by OCR (Oxford, Cambridge and RSA Examinations), one of the five leading awarding bodies (for A-level and GCSE examinations) in the UK in year 2016. Here we chose books from two lines (A and B) to have a broader range of books in our sample. For Germany we decided to use textbooks towards the medium examination (*Mittlerer Schulabschluss*, Year 10, age 16) published by Westermann, one of the three main publishing houses in Germany in the years 2017-2023. Germany has a diverse federal school system, but basically, there are (1) common schools leading towards medium examination (but sometimes also offering higher school certificates) and (2) high schools leading towards academic careers (but also awarding medium examinations). So, we chose books from these two strands in order to cover both paths of the German school system.

We applied a qualitative content analysis (Kuckartz, 2019; Mayring & Fenzl, 2019) to our textbook analysis. For the selection of the coding material, the potentially relevant chapters were defined by screening the table of contents. Additionally, the material was completed by searching for terms within the index that indicate climate change related content: *climate, climate system, climate change (+related terms that start with 'climate' e.g. climate research), global warming, carbon cycle, greenhouse effect, greenhouse gases, energy (or related terms such as energy depot, only relevant contexts of energy), crude oil, natural gas, ecological assessment, ecological footprint, sustainable, sustainability*.

Every potentially relevant chapter was scanned, transferred to pdf format and imported to MAXQDA 2022 (VERBI Software, 2021) – a software for qualitative data analysis. During the analysis, only relevant subchapters were coded and one subchapter was regarded as one coding unit. Additionally, relevant illustrations were coded, regarding one illustration as one coding unit.

6.4.2 The category system

The category system (Table 6-1) was developed deductively based on former studies by the authors (a qualitative analysis of school curricula in Germany (Leve et al., 2025) as well as a study by Moelter-Reich et al. (2023) (qualitative analysis of textbooks for primary schools). Both category systems were compared and categories were adopted from both systems. The resulting category system was piloted and revised after piloting and during the interrater process which revealed equivocal definitions in the first place. Interrater was conducted with approximately 20% of the material of the book sections (UK: books in the natural science textbooks sample only): $\kappa_{\text{Brennan\&Prediger}} = 0.7$).

Table 6-1: The two levels of categories in the final category system. The detailed category system with descriptions of all categories is to be found in the supplementary materials

Category Level 1	Category Level 2
Climate system	<i>Space and time</i>
	<i>Components and Processes</i>
Climate change	
Causes	<i>Natural</i>
	<i>Anthropogenic</i>
Impacts	<i>Natural environment</i>
	<i>Ecosystems/Biosphere</i>
	<i>Human society</i>
Ways to deal with climate change	<i>Values, norms, discussion</i>
	<i>Adaptation</i>
	<i>Mitigation</i>
Sustainable development, ESD, sustainability concept	

In the category system the categories *climate system*, *causes* and *impacts* mainly reflect the physical science basis of climate and climate change. The sub-categories *anthropogenic causes* and *impacts on human society* represent strong relations between natural and human systems and they interfere with ways of living, which can be a matter of discussion in society. Yet, these categories represent central knowledge aspects from CL as mentioned by Azevedo & Marques (2017) and outlined by the USGCRP (2009). Thus, the category *ways to deal with climate change* and its sub-categories reflect the social side of climate change. The *mitigation* and *adaptation* categories are slightly represented by the USGCRP and all three subcategories are represented by Shwom et al. (2017). The sub-category *values, norms, discussion* represents processes of social interaction and transformation mostly represented by Shwom et al. (2017) and as well by the attitudes proposed by Azevedo & Marques (2017). This sub-category has the strongest relation to SL vision III. The category *climate change* is an overarching category that is supposed to indicate if the respective text passage has an explicit reference to the topic of climate change. The category *sustainable development, [...] as another overarching category*, indicates either if the text passage transcends climate change by relating it to the sustainability concept or further sustainability topics or vice versa or if the general concept of sustainability is referred to and climate change might be subsumed implicitly.

6.5 Results

Considering our first research question, the numbers of pages with coded text passages in all analysed textbooks are displayed in relation to the respective total number of pages per book in Table 6-2. Half of all analysed textbooks have only 2.6% of their number of pages coded. About one quarter has between 3 and 5.4% of their pages coded and only one quarter has more than 5.4% coded with two books having about 9% coded and one book (*UK: geography B*) having 13.9% of its pages coded. The largest extent of coded pages ($\geq 5.9\%$) is to be found within four analysed geography books (*UK: 1, GER: 3*), one social studies book (*GER*), three chemistry books (*UK: 2, GER: 1*) and two physics books (*UK: 1, GER: 1*). Two geography books (*GER*), one combined science book (*GER*), two physics book (*UK: 1, GER: 1*), one chemistry book (*GER*) and one biology book (*GER*) have a medium extent of coded pages (3.0 to 5.4%). A low extent of coded pages can be found within five biology books (*GER: 1, UK: 4*), three combined science books (*GER*) three social studies books (*UK: 1, GER: 2*), three physics books (*UK: 2, GER: 1*), and two chemistry books (*UK*). Two biology books (*GER*) and one combined science book (*GER*) have no coded pages at all. Summarizing, geography books are rather to be found among the higher extent of codings in both countries, physics and chemistry books are more widespread among a low, medium, and high extent of coded pages, biology, combined science and social studies books are rather among the medium to low extent of coded pages. Regarding physics and chemistry textbooks in the UK, the *21st century* series is rather to be found within the higher extent of coded pages while the *gateway* series is rather located within the lower extent of coded pages. The investigated series of books from Germany are both widespread among lower and higher extents of coded pages. An overview of the respective chapters within all books that contain codings is provided in the supplementary material.

Table 6-2: List of analysed textbooks, number of pages and number of pages with coded material. Indications for subjects and type of schools are given for German labels (*h. school* = high school (oriented towards an academic career), *c. school* = common school (oriented towards medium certification)).

Textbook	Total number of pages	Number of pages with coded material	Percentage of pages with coded material
<u>Geography</u>			
GER: Seydlitz Erdkunde Gymnasium 1 (<i>geography h. school</i>)	226	17	7.5
GER: Seydlitz Erdkunde Gymnasium 2 (<i>geography h. school</i>)	349	19	5.4
GER: Seydlitz Erdkunde Real+ 1 (<i>geography c. school</i>)	331	10	3
GER: Seydlitz Erdkunde Real+ 2 (<i>geography c. school</i>)	215	20	9.3
GER: Seydlitz Erdkunde Real+ 3 (<i>geography c. school</i>)	206	14	6.8
UK: Geography B	317	44	13.9
$\Sigma_{\text{geography}}$ and average percentage	1644	124	7.65
<u>Social studies</u>			
GER: Weltkunde 5-6 (<i>world studies c. school</i>)	317	7	2.2
GER: Weltkunde 7-8 (<i>world studies c. school</i>)	302	5	1.7
GER: Weltkunde 9-10 (<i>world studies c. school</i>)	286	26	9.1
UK: Citizenship studies	207	2	1
$\Sigma_{\text{social studies}}$ and average percentage	1112	40	3,5
<u>Natural science</u>			
GER: Biologie heute 1 (<i>biology, h. school</i>)	263	0	0
GER: Biologie heute 2 (<i>biology, h. school</i>)	453	12	2.6
GER: Biologie blickpunkt 1 (<i>biology, h. school</i>)	311	0	0
GER: Biologie blickpunkt 7-10 (<i>biology, c. school</i>)	455	14	3.1
GER: Chemie heute (<i>chemistry h. school</i>)	461	18	3.9
GER: Chemie blickpunkt (<i>chemistry c. school</i>)	455	32	7
GER: Physik heute 1 (<i>physics h. school</i>)	142	3	2.1
GER: Physik Heute Gesamtband (<i>physics c. school</i>)	341	20	5.9
GER: Physik blickpunkt SI (<i>physics c. school</i>)	423	14	3.3
UK: 21st Century Biology	323	8	2.5
UK: Gateway Biology	311	3	1
UK: 21st Century Chemistry	351	22	6.3
UK: Gateway Chemistry	331	6	1.8
UK: 21st Century Physics	335	17	5.1

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UK: Gateway Physics	314	5	1.6
$\Sigma_{science}$ and average percentage	5269	174	3.3
<u>Combined science</u>			
GER: Naturwissenschaften heute 5 (<i>science h. school</i>)	191	0	0
GER: Naturwissenschaften heute 6 (<i>science h. school</i>)	167	4	2.4
GER: Naturwissenschaften Blickpunkt 1 (<i>science c. school</i>)	447	10	2.2
GER: Naturwissenschaften Blickpunkt 2 (<i>science c. school</i>)	367	19	5.2
GER: Naturwissenschaften Blickpunkt 3 (<i>science c. school</i>)	383	7	1.8
UK: 21st Century Biology combined Science	371	4	1.1
UK: Gateway Biology combined Science	255	2	0.8
UK: 21st Century Chemistry combined Science	301	18	6
UK: Gateway Chemistry combined Science	356	6	1.7
UK: 21st Century Physics combined Science	285	17	6
UK: Gateway Physics combined Science	242	4	1.7
$\Sigma_{combined\ science}$ and average percentage	3365	91	2.7

6.5.1 Inclusion of the categories

With regard to our second research question, high frequencies of codings are to be found in all main categories (Level 1) for the textbooks from Germany and the UK. In order to compare the coding frequencies between both countries, it is important to consider the different publication dates of the investigated textbooks which was 2016 for UK textbooks in comparison to 2017-2023 for German textbooks. Altogether, the textbooks from the UK comprised less pages than the books from Germany, which results in less absolute overall codings across all categories and books in the UK (sum: 574) than in Germany (sum: 839). For a meaningful comparison, the coding frequencies of all categories were related to those absolute numbers as representing 100% for each country. The relative coding frequencies are compared in Figure 6-1 and the relative coding frequencies across the categories by different subjects are displayed in Figure 6-2. In summary, the distribution of high as well as low coding frequencies is similar among both countries except that the regional and temporal display of the climate as well as the topic of sustainability have both been more frequently coded within textbooks from Germany and the explicit references to climate change as well as impacts of climate change to the natural environment have been coded more frequently within textbooks from the UK. The most striking features of the category distributions are outlined in the following: the two categories of *anthropogenic causes* and *mitigation* are coded most frequently in both countries. The *climate system* category *space and time* is coded more often in Germany than in the UK, whilst the explicit *climate change* category is coded more often in the UK than in Germany. *Natural causes of climate change* do hardly occur in the textbooks. *Impacts of climate change* on the *natural environment* are coded to a limited extent, more often in the UK than in Germany, whilst *impacts to ecosystems* and *human society* are hardly referred to. The category of *values, norms and discussion* occurs to a limited extent in both countries, while

adaptation does hardly occur. The category of *sustainability* has been coded medium frequently in Germany, but rarely at all in the UK.

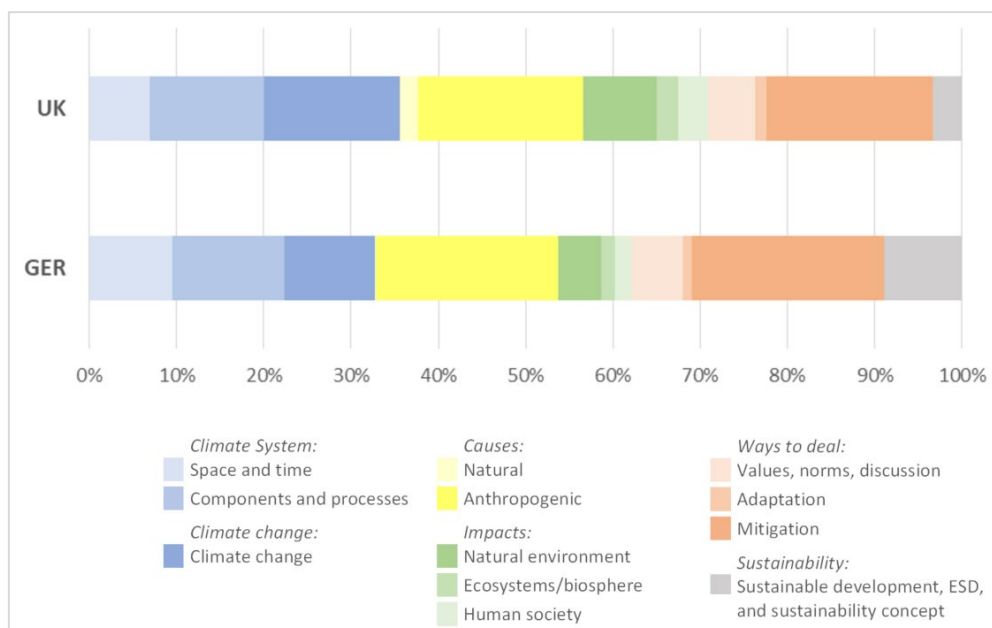


Figure 6-1: Distribution of categories among all subjects and textbooks for the UK and Germany.

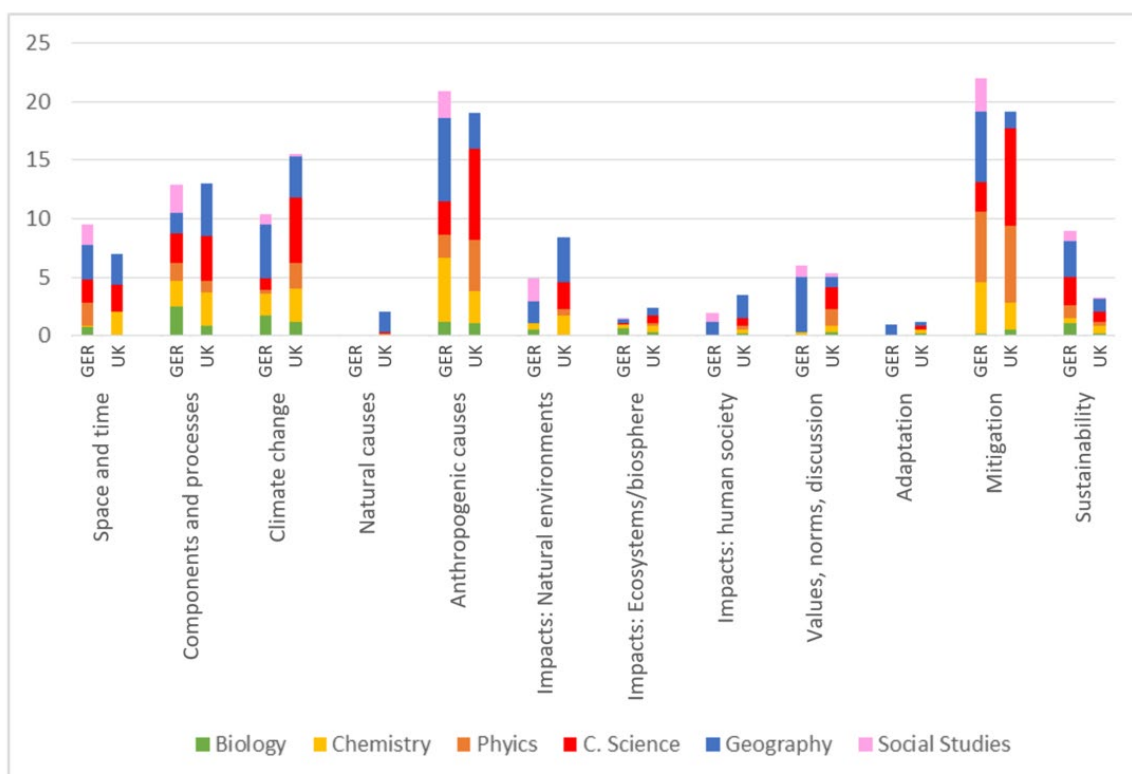


Figure 6-2: Percentage of category assignment displayed by the different subjects for the textbooks from Germany and the UK. The respective overall sum of codings per country was used as 100%-reference (UK: 574, GER: 839).

6.5.2 Inclusion of climate education by subjects

With respect to our third research question, regarding coding frequencies throughout the different subjects, similar patterns but different details show through the two countries. Figure 6-3 and Figure 6-4 display in further detail how often the categories have been coded within the different textbooks. In the textbooks from Germany the highest coding frequencies are to be found for geography and chemistry and in both subjects, codings are quite widespread across the categories. Low to medium coding frequencies can be found for physics, combined science, biology and social studies. Here the focus is rather on the *climate system* categories, *anthropogenic causes*, *mitigation* and *sustainability*. The book for grade 9-10 in social studies is a clear outlier with a very high coding frequency and widespread codings across almost all categories. Hence, differences in coding frequencies occur rather between the age focus of textbooks: textbooks for older age groups tend to have higher coding frequencies than the books for younger age groups. No clear differences were found between the books of the same subjects for different school types.

In the UK sample, the textbook with the highest coding frequency is the geography book with codings widespread through all categories. The textbooks for both, chemistry and physics have high coding frequencies regarding the 21st century series and low coding frequencies regarding the gateway series. Thus, a clear difference between the A- and B-strand is given. In biology, all textbooks show low coding frequencies. In textbooks with lower coding frequencies, the codings are more widespread across the different categories for most of the subjects in UK compared to Germany, except for biology. Regarding the differences between the science books and the books for combined science it shows that coding numbers are similar for chemistry and physics and their combined science editions, while for biology the number of codings in the combined science edition is only 50% of the full edition. The textbook for citizenship studies has the lowest coding frequency that cover only three of all categories, hence only one chapter of this book was relevant for coding.

In summary, the highest coding frequencies are to be found within geography textbooks in both countries with a broad coverage of all categories and the UK presenting an outlier with the highest coding frequency of all analysed textbooks. The science subjects show no clear distribution pattern among both countries, only biology falls within low coding frequencies in the UK, while in Germany we find a difference for age groups with no codings for the younger age and medium coding frequencies for a higher age group. Social studies show medium coding frequencies and one high frequency outlier in Germany and very low coding frequencies in the UK, so we see clear differences here.

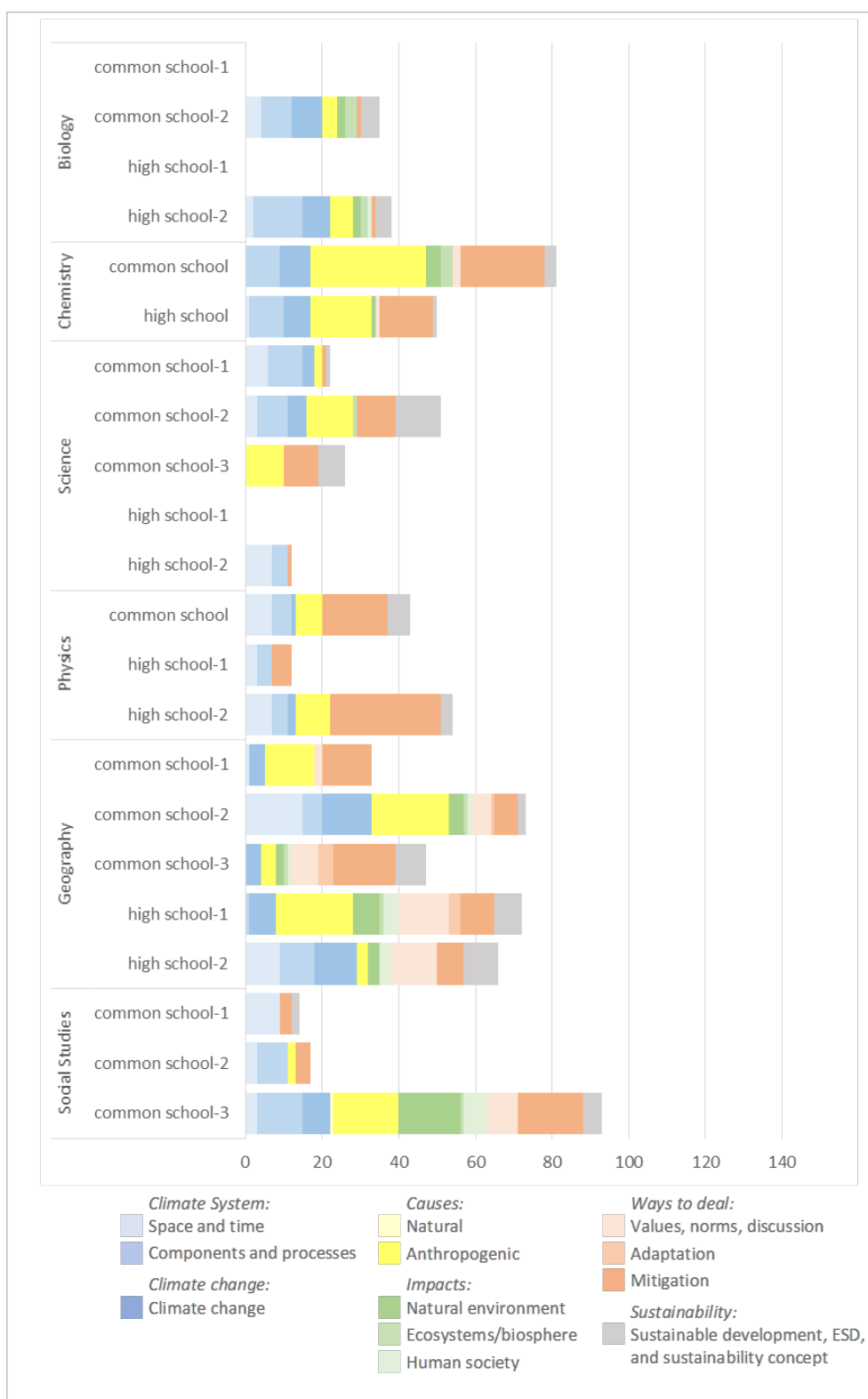


Figure 6-3: Coding frequencies throughout the categories by subject for the textbooks from Germany. Each bar represents one single textbook. The numbers (e.g. common school/high school-1, 2,...) indicate that these are book one, two,... from a series for different age levels (e.g. biology: high school-1 = biology "heute"-series for high school, textbook 1 for grade 5-6). Common schools represent schools leading towards medium certification, high schools represent schools leading to academic careers.

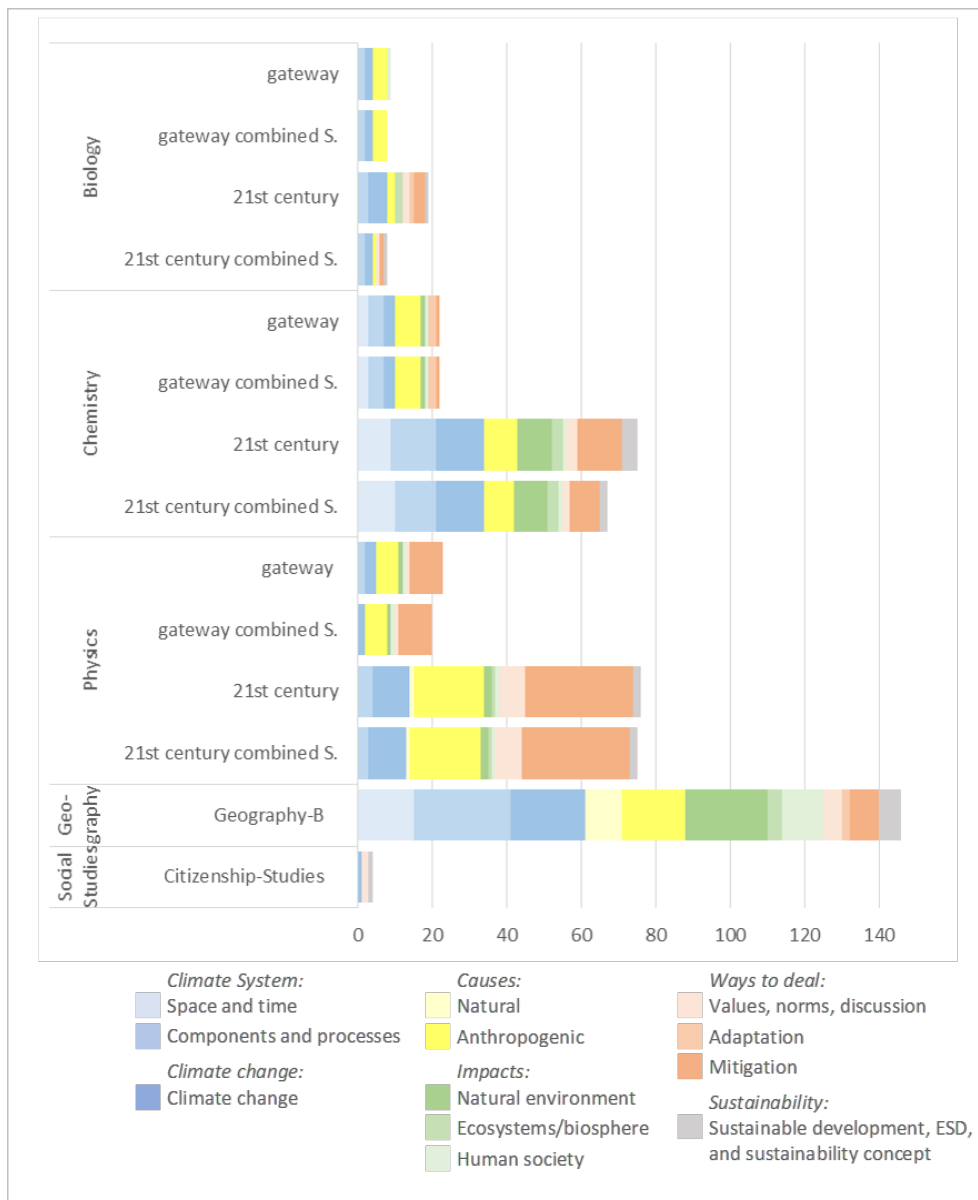


Figure 6-4: Coding frequencies throughout the categories by subjects for the UK textbooks. Each bar represents one single textbook. The labels indicate the respective textbook series (e.g. gateway) or short-title (e.g. Citizenship studies). The label "combined S." indicates the respective textbook for combined science (e.g. Biology for combined science).

6.5.3 The contents of climate education throughout science and social study textbooks

Regarding our second and third research question, the topic of climate change in textbooks is being addressed in diverse ways and subsumed under different themes. Table 6-4, Table 6-5 and Table 6-6 in the supplementary materials list the book chapters, which include references to the topic of climate change. The main content areas of the individual subjects are described below.

Geography

The **textbook** from the **UK** describes global pressure and circulation patterns as well as weather hazards such as tropical storms and droughts and depicts the natural and enhanced greenhouse effect. Human causes of climate change are mentioned as well as the use of natural resources and fossil fuels and deforestation. The book addresses impacts of climate change such as extreme weather events, melting ice, food security and others. It further includes discussions about climate

change and ways to deal with it, for example as part of the Paris agreement and public protests. Energy demands and different kind of energy resources, especially renewable energies are also mentioned. Additionally, the book includes sustainability by presenting the Sustainable Development Goals (SDG) and a sustainability Venn diagram.

In the **textbooks** from **Germany** climate change and sustainability are mentioned in the introductory chapter (high school). The main focal points are similar to the UK: The books for both strands discuss the production of fossil fuels, public controversies, renewable energies and energy resources in Germany. They describe seasons, solar radiation, climate zones, the atmosphere, the natural greenhouse effect and its anthropogenic enhancement in detail including carbon emissions, contributions of different countries and impacts of climate change such as migration and climate patterns. They also address public discussions and protests. Public controversies towards renewable energy production and dilemmas around biofuels and food production are included as well as the Green New Deal of the EU. The textbook for common school also includes energy production in Europe and Africa and the SDGs. The book for high school addresses resources and climate change impacts in extreme habitats (desert, rainforest, arctic).

Social studies

The **textbook** on social studies has a different focus in **UK** (*"citizenship studies"*) than in Germany (*"world studies"*), where more geographical content is included since the subject is a combination of different classical social subjects such as geography, history, and economics. Thus, the textbook from the UK has only few references towards climate change in one of its chapters (The UK and its relations with the wider world). Here, international efforts including efforts by the UN towards global challenges such as climate change are mentioned, e.g. the Paris agreement.

The **textbooks** from **Germany** on social studies for the younger age in contrast, include the Earth's rotation and the climate zones of Germany and Europe, as well as the pressure and wind systems in the tropics. They address renewable energy in agricultural areas in Europe with controversies towards food production as well as energy consumption in China and greenhouse gas emission and renewable energy consumption by different countries. Also, the book for the older age group includes one chapter on climate change and energy consumption. This chapter mentions natural climate fluctuations and climate history and depicts climate factors, the atmosphere, the natural and anthropogenic enhanced greenhouse effect, carbon concentration and rising temperatures. Furthermore, it addresses impacts of climate change such as extreme weather events and melting ice shields, rising sea levels and the respective consequences for regions such as the Arctic, Greenland or small islands. Fossil fuels and their production, energy consumption as well as controversies around wind energy, but also climate conferences such as the Paris conference and public demonstrations around climate change are included.

Biology

In the **textbooks** from the **UK** the carbon cycle is addressed in both series. In the gateway series global warming and fossil fuels are mentioned in the same context. In the 21st century series, global warming is mentioned in the context of changes in the environment and biodiversity as well as food security. Here, the chapter that focuses most on climate change is missing in the edition for combined science.

The **textbooks** from **Germany** for biology have no references to climate change in the books for younger grades. The books for upper grades differing from the UK refer to the importance of forests for the climate, their role as carbon sink, the endangerment of tropical rain forests and forest damage, the importance of other ecosystems and climate in cities, the greenhouse effect, general impacts of climate change, and the sustainability concept. The book for common schools includes climate change impacts in Germany, climate models, and buying regional and seasonal food as a way of mitigation. The book for high schools includes general climate and the condition of forests and lakes during ice age.

Chemistry

The chemistry **textbooks** from the **UK** address the Earth's atmosphere in the past and present, the greenhouse effect, the change of carbon dioxide levels and global temperature, climate science and climate modelling, as well as the scientific consensus regarding climate change. They mention the role of human activity, emissions from cars or power stations, and the use of energy resources as e.g. crude oil. The 21st century series includes impacts of climate change such as sea level rise, extreme weather, impact on crops, and examples of decision making.

The **textbooks** from **Germany** similarly refer to the composition of the atmosphere, the carbon cycle, the greenhouse effect, the rise of carbon dioxide and global warming. They mention the origin of fossil fuels, their production and use, the role of greenhouse gases and renewable energy resources and power plants. There is a focus on power to gas and hydrogen production, but also solar and wind energy and biogas are mentioned. The book for high schools also includes climate models and scenarios.

Physics

The **UK textbooks'** coverage of the topic of climate change differs by series. The full edition of the gateway series addresses the Earth's atmosphere and temperature as well as radiation and the atmosphere, and the greenhouse effect. The 21st century series has a stronger focus on rising global temperature and rising carbon dioxide levels. It includes impacts of climate change, climate modelling and climate change sceptics. Both series address records from nature, such as ice cores, and depict the use of energy resources in the UK, the amount of renewable and non-renewable resources as well as different kinds of fossil fuels or renewable technologies, including offshore wind parks or tidal power stations and their advantages and disadvantages. Here, again, the 21st century series has a broader range of topics and the full edition additionally includes more details on solar energy and hydroelectric power stations.

The **textbook** from **Germany**, contrasting to the UK, refers to the atmosphere, solar radiation, seasons, wind, and solar energy in the younger grades. The textbooks for the upper grades address Earth's rotation, solar radiation, the atmosphere, the greenhouse effect, seasons, climate zones, and weather. Similarly to the UK they include fossil fuels and fossil power plants, the energy supply in households and energy production in Germany, and different kinds of renewable energies as well as the sustainability concept. The book for high schools also refers to sustainable housing and mobility, and climate conferences.

Combined science

The **textbooks** for combined science in the **UK** have been subsumed under the respective subjects because they have a large overlap with the full editions of the textbooks. In **Germany**, however, **textbooks** for combined science that refer to the different subjects within the same book are published for all age groups according to common schools and for the younger grades according to high schools. Both books for the younger grades address the Earth's rotation, the atmosphere, solar radiation, seasons, and climate zones, the book for common schools additionally includes a focus on greenhouse gases, rising temperature, and rising carbon dioxide emissions. Both books address examples of renewable energies. The textbooks for the upper grades have a stronger focus on the greenhouse effect and they include the effect of trees and greening on climate and forest damage as well as threats for the tropical rainforest. They depict the origin and use of fossil fuels, the sources of energy production in Germany, renewable energies and their supply, and the sustainability concept.

Illustrations

While the references outlined above are described in various text segments, graphics and photos illustrate some of them in recurring ways throughout the analysed textbooks in both countries. As such, graphical schemes illustrate the atmosphere, pressure systems and wind patterns, the Earth in the solar system and the natural and enhanced greenhouse effect. Maps illustrate climate zones, biomes, currents, and the occurrence of extreme weather events or temperature anomalies. Schemes and images illustrate the carbon cycle and the services of forests and trees. Graphs illustrate the development of global temperature and carbon dioxide emissions. Charts illustrate the use or supply of energy resources. Images illustrate the origin, extraction, mining, and production of fossil fuels and fossil fuels themselves; furthermore, they illustrate renewable energy facilities. Concerning impacts of climate change images and photos illustrate e.g. glacier retreat, flooding events or forest fires. Photos (e.g. ice cores) and graphs (climate scenarios) illustrate climate research, photos illustrate public protest for climate action and graphics illustrate the SDGs and the sustainability concept (e.g. Venn diagram).

6.6 Discussion

This study analysed secondary school textbooks from Germany and the UK for natural science and social studies subjects. The aim was to investigate which climate education contents are to be found and to which extent within textbooks as representative teaching material with regard to different subjects and within two different countries. The results showed differences in the scope and extent of content across the different subjects, but also between different book series.

Climate education presented throughout the analysed textbooks covers scientific basics around the climate system and climate change, fossil and renewable energy resources, impacts of climate change, solutions, and public discussion. Hence, the focus on the scientific basis includes the greenhouse effect and its anthropogenic enhancement, the causes of climate change, including greenhouse gas emissions and resulting global temperature rise, as other studies have shown in natural science or geography textbooks in Czech Republic, Poland, Ethiopia and UK (Baarova & Hibszer, 2022; Dalelo, 2011; Morris, 2014). The content on energy resources addresses fossil fuels on the one hand as a cause, but particularly their production, supply and use. On the other hand,

they present renewable energies as mitigation strategies and in particular their technologies, provision, and use. Public discussions, protests and common solutions receive little attention, and this also applies to climate science. Possible action or solutions to climate change were found in textbooks in Poland, Czech Republic, and the UK (Baarova & Hibszer, 2022; Morris, 2014), whereas little content on solutions was found in Colombia and the US (Bonilla & Quesada, 2024; Meehan et al., 2018).

6.6.1 Comparing textbooks from the UK and Germany and their different subject foci

Comparing the analyses of textbooks from the UK and Germany, we find similar patterns of broad content coverage in the natural science subjects of chemistry and physics; only in biology, the coverage is low in the books from the UK and medium in the books from Germany. The different publication dates of the analysed textbooks (2016 (UK), 2017-2023 (GER)) might have had an effect on content coverage, but since there was no structural lower content coverage throughout all textbooks in the UK, it remains uncertain to which extent this effect exists. Research suggests that climate education is a task for many subjects, especially Earth science, geography, and the natural science subjects, and that teachers from these subjects are willing to address the topic in their lessons (Hestness et al., 2014; Johnson et al., 2008). The coverage of climate education by different subjects complies with the need for an interdisciplinary approach to the topic and the opportunities that numerous subjects provide to address climate education from many different perspectives (Leve et al., 2023). A closer look at social science and natural science subjects in the present study reveals that geography is clearly a focus subject of climate education coverage and other social studies subjects show a variation between low to high coverage depending on country and age group. Notwithstanding, the UK textbook for geography is a clear highlight in extent and range of content coverage. The most striking difference between the two countries, though, can be seen in social studies, where the focus of the subjects seems to be very different. However, even within Germany there may occur striking differences between the subjects throughout the country because social studies are being represented by regionally differently outlined subjects.

6.6.2 Climate change in the analysed textbooks according to the investigated coding categories

Bringing together the overall coding frequencies throughout the category system, it becomes obvious that the main focus within the analysed textbooks lies within the *climate system* and *climate change* categories (*space and time* – but rather on space than time; *components and processes*; *climate change*), as well as the *anthropogenic causes* and the *ways of mitigation*. The *space and time* category was coded more often in Germany and the *climate change* category was coded more often in the UK. Hence, a slight tendency is apparent that regional and global climate patterns have a higher relevance in German textbooks, while the topic of climate change is being made explicit more often in the UK. These contents have been highlighted through compilations of and research on what aspects contribute to CL (Leve et al., 2023; USGCRP, 2009), as outlined in the theoretical background of CL. Yet, certain aspects are underrepresented or even missing. Whilst studies in the US found that in some textbooks climate change has been framed as scientifically uncertain (Meehan et al., 2018; Román & Busch, 2016), the textbooks within the current study did not reflect this at all. Climate change science is being subsumed under the *climate change* category, yet, only two books (*gateway chemistry (for c. S.)*) explicitly refer to the scientific consensus on the anthropogenic causes of climate change. Furthermore, the scientific process is

more included in the textbooks from UK. Hence, it is beneficial to treat climate education not solely as content knowledge and scientific facts, but also to include the scientific work behind it and to include activities that develop scientific skills (Holthuis et al., 2014), which is why this low coverage of the scientific process can be considered as a clear deficit within the investigated textbooks. Regarding misconceptions, former studies have reported misconceptions about the atmosphere (King, 2010) and the lack of accurate descriptions of scientific concepts and representations within textbooks that even foster misconceptions (Choi et al., 2010). While the representation of misconceptions in images in textbooks were not the focus of this study, it became clear that they prevail, especially in the presentation of the greenhouse effect, e.g. that greenhouse gases are deposited as a layer in the atmosphere and trap the radiation. This misconception has been found to be reproduced commonly within textbooks (Choi et al., 2010; Shepardson et al., 2011). Besides depicting the greenhouse effect and further schemes of the climate system, images analysed by the current study showed a focus on energy resources and supply. This includes renewable energies, which are described as mitigation strategies.

A former study on textbooks from Germany reported that the impacts of climate change were presented rather than mitigation strategies (Schauss et al., 2024). In the present study, images of the impacts of climate change were identified, but not as many, as the impacts of climate change play a rather subordinate role within the analysed textbooks in general. Yet, they are more frequently coded in the textbooks from the UK than from Germany, even more importantly, impacts on the natural environment are included to a limited degree, while impacts on ecosystems and on human society do not play any significant role. However, impacts of climate change on the Earth system as well as on human societies are considered as an essential component of CL content knowledge, equivocal to causes and coping strategies, according to the CL framework of the USGCRP (2009, 2024) and further research of CL education (Leve et al., 2023). In that sense, this aspect of CL is generally underrepresented within the investigated textbooks, especially in the science textbooks. Regarding the causes of climate change the focus in almost all textbooks is on the anthropogenic causes of current climate change. Only five textbooks (*21st century chemistry (for c. S.)*; *gateway chemistry (for c. S.)*; *Weltkunde 9-10*) include natural climate fluctuations and rather in the UK than in Germany, such low coverage has been shown by previous research on textbooks from Germany, Romania, and Mexico (Bagoly-Simó, 2013). Adaptation strategies, however, are only addressed within few of the analysed textbooks. Hence, the presentation of ways to deal with climate change is rather technical, there is little content about individual or collective action; however, the category of values, norms, discussion is represented in some but not many cases in both countries. Thus, such aspects of public understanding and societal agreement as suggested by Shwom et al. (2017) fall behind the technical and knowledge based aspects outlined above. At the same time, whilst skills of assessing information and communication might possibly be achieved, the third CL aspect of attitudes that are intertwined with mitigation and adaptation strategies (Azevedo & Marques, 2017) falls short, because the relevant categories regarding values and discussion in society and adaptation strategies are only covered to a limited extent. The same holds true for the current elaboration of CL principles (USGCRP, 2024) as well as in the compilation of the themes of relevant CL content for teachers' professional knowledge and teaching practice by Leve et al. (2023) where mitigation, adaptation and transformation play a pivotal role. Except

for mitigation strategies these aspects are underrepresented in the investigated textbooks. Eventually, the general inclusion of sustainability, as indicated by the respective category, may either allow teachers to include climate education under this notion or vice versa – to transcend the topic of climate change with relation to further sustainability topics or global challenges. Hence, the coverage of this category differs between the two investigated countries. This might be due to the fact that Germany includes ESD and sustainability as an overarching task of all subjects within virtually all curricula (KMK, 2024) whereas the national curriculum in UK does not mention the concept at all (Department of Education, 2014).

6.6.3 Fragmentation of climate education and implications for science education

The question arises if climate education is represented in a sufficient way. It could be of benefit if climate education would be addressed as a whole topic throughout an education biography but the current fragmentation throughout the subjects does not seem to meet this demand. As presented by the analysed textbooks, climate change is being approached by a cross-curriculum approach (Eilam, 2022) that spreads the topic to separate subjects, sometimes subsumed under the notion of sustainability, in most cases though, as a topic of its own right. Yet, neither is the responsibility – which aspects are to be allocated to which subjects – of the single subjects clarified, nor is the completeness of all aspects ensured by this approach (Eilam et al., 2020). It is argued that the scientific as well as socio-economic aspects around climate change are clearly elaborated and communicated in research, but that the complex issue of climate change as a main challenge for society is not adequately approachable in a separate disciplinary way (Eilam, 2022). As the complexity of the issue is difficult to grasp anyway, education in separate disciplines that all relate to the topic – even within natural science– does not help to get to understand this complexity (Schreiner et al., 2005). Hence, a holistic learning about the Earth's systems does not seem to be possible through subject-oriented structures that even exclude societal aspects within natural sciences especially in the context of environmental issues. At current state, the interconnectedness of humanity and natural systems is not inherent in the separate disciplines (Lehtonen et al., 2019). However, this interconnectedness makes it necessary to transform science education in an adequate way and to integrate social studies. As Roberts (2010) argues with his Vision II of SL that considers school science as providing the relevance of science to life as a citizen rather than considering schools science as producing new scientists (Vision I). It has been discussed by scholars that scientific and technological problem solving is not enough to meet the challenges of climate change, and that science education should rather foster students' self-conception as active citizens (Sharma, 2012). Hence, what has been proposed of a CL in the framework of a Vision III notion of SL (Sjöblom et al., 2023) would be preferable, but seems currently not to be met by the content coverage of textbooks. This is due to the fact that the main focus of content coverage within the investigated textbooks is on the physical science basis of the climate system and climate change as well as on anthropogenic causes and mitigation strategies. Aspects about societal values and discussion as well as possible adaptation strategies and their relevance are not adequately covered. When referring to the category of values, norms and discussion, political climate conferences and the Paris agreement are most often mentioned, furthermore public protest for climate protection is mentioned by textbooks from both countries. In Germany the discussion of controversies around biofuels and food production as well as around wind energy plants are to be found, whereas in the UK aspects of decision making as well as climate sceptic argumentation is referred

to. Yet, only few text passages were found, so no structural differences in values and worldviews between both countries were indicated. In both countries discussions of societal transformation or the balance between the political and the individual responsibility do not appear. It has been discussed that the integration of disciplines as well as the inclusion of values would provide valuable opportunities to empower students for actively participating in a changing world (Hodson, 2003). In this context, these missing aspects of CL contributing to attitudes, the handling of adaptation strategies, societal transformation, and discussion (Azevedo & Marques, 2017; Leve et al., 2023; USGCRP, 2024) are a relevant gap within the textbook content coverage. To this end, latest textbooks show tendencies of including values and societal measures of scientific aspects by the representation of climate change. Yet, they currently lack the opportunities of integration and interconnectedness for they follow the traditional curricular default.

6.7 Conclusion

The coverage of climate education throughout the analysed textbooks reveals the impression of topic fragmentation. This becomes obvious by the different climate education foci, the over- and underrepresentation of the different aspects and different patterns of category distribution throughout the analysed textbooks and respective subjects. Many duplications (e.g. the greenhouse effect, the technology of fossil fuels) between the different subjects do exist, which is not a generally bad idea, but important aspects are missing throughout certain subjects (e.g. adaptation strategies and societal transformation processes) and a reasonable relation between the different subjects seems to be missing. One example for this is the case of combined science: the content out of the different combined science subjects should rather be interrelated and not as a composite out of different sections extracted from the existing separate subjects and material. Relations and coordination between separate subjects could contribute to a holistic climate education but remain a challenge in science education that yet needs to be overcome by joint efforts from scholars, curriculum developers, textbook authors, teachers, and teacher educators. Furthermore, the societal aspects that are integrated into the latest CL frameworks need to find their way into the content coverage of textbooks. On the one hand the unstructured and short appearance of social studies subjects would play a significant role as well as the necessary integration of social aspects into science subjects as it has been proposed by SL Vision II and III, not only recently.

6.8 Limitations

Given the fact that in UK as well as in Germany many different awarding bodies and publishing houses exist that provide textbooks, we could only analyse a sample out of them. Hence, the differences found between the single series analysed in the present study show a hint that there might be further differences between the analysed books and the many further editions of textbooks that are available. Furthermore, the sample on the social studies side was smaller than on the science side due to the limited offering and availability of regular geography and social studies textbooks. Further investigations on more social studies textbooks might be fruitful and it is to hope that the publishing of such books will develop further and more such books might cover the currently missing aspects of climate education. However, the findings of our study could offer a relevant starting point to this perspective.

6.9 Declarations

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Competing interests

On behalf of all authors, the corresponding author states that there is no conflict of interest.

Authors' contribution

The study was designed by Anna-Kathryn Leve. Ute Harms and Carola Garrecht contributed to the study conception and design. Material preparation, data collection and analysis were performed by Anna-Kathryn Leve. The first draft of the manuscript was written by Anna-Kathryn Leve. Carola Garrecht and Ute Harms thoroughly revised previous versions of the manuscript. All authors read and approved the final manuscript.

Ethics statement

Our study did not require ethics approval because data was exclusively collected from published books and no humans or animals were involved in data collection.

Data availability

Data was generated from recently published and accessible books. A full list of the used books is provided in the supplementary material.

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6.11 Supplementary Materials

6.11.1 List of analysed textbooks

UK

Science – OCR gateway series

OCR gateway. GCSE biology. Student book (2016). Oxford University Press.

OCR gateway GCSE chemistry. Student book (2016). Oxford University Press.

OCR gateway. GCSE physics. Student book (2016). Oxford University Press.

OCR gateway GCSE biology for combined science. Student book (2016). Oxford University Press.

OCR gateway physics for GCSE combined science. Student book (2016). Oxford University Press.

OCR gateway chemistry for GCSE combined science (2016). Oxford University Press.

Science – 21st Century science series

Twenty first century science. GCSE biology. Student book (2016). Oxford University Press.

Twenty first century science. GCSE chemistry. Student book (2016). Oxford University Press.

Twenty first century science. OCR GCSE physics. Student book (2016). Oxford University Press.

Twenty first century science. Biology for GCSE. Combined science (higher). Student book (2015). Oxford University Press.

Twenty first century science. Chemistry for GCSE combined science (2016). Oxford University Press.

Twenty first century science. Physics for GCSE combined sciences. Student book (2016). Oxford University Press.

Social studies

Citizenship studies. OCR GCSE [9-1] (2016). Hodder Education.

Geography B – Geography for enquiring minds (2016). Hodder Education.

Germany

Science – Blickpunkt series

Blickpunkt Biologie (2020). Allgemeine Ausgabe, Schulbuch 1. Westermann.

Blickpunkt Biologie (2021). Allgemeine Ausgabe, Gesamtband. Westermann.

Blickpunkt Chemie (2023). Ausgabe für die östlichen Bundesländer. Westermann.

Blickpunkt Physik (2023). Ausgabe für Mecklenburg-Vorpommern, Sachsen-Anhalt, Sachsen, Thüringen. Westermann.

Blickpunkt Naturwissenschaften (2020). Allgemeine Ausgabe, Schulbuch 1. Westermann.

Blickpunkt Naturwissenschaften (2021). Allgemeine Ausgabe, Schulbuch 2. Westermann.

Blickpunkt Naturwissenschaften (2022). Allgemeine Ausgabe, Schulbuch 3. Westermann.

Science – Heute series

Biologie heute. (2019). Aktuelle allgemeine Ausgabe, Schulbuch 1. Westermann.

Biologie heute 2. (2021). Aktuelle allgemeine Ausgabe, Gesamtband. Westermann.

Chemie heute SI (2023). Allgemeine Ausgabe, Gesamtband. Westermann.

Physik heute (2019). Aktuelle Ausgabe für das G9 in Nordrhein-Westfalen, Schulbuch 1. Westermann.

Physik heute (2022). Aktuelle Ausgabe für das G9 in Nordrhein-Westfalen, Gesamtband 7-10. Westermann.

Naturwissenschaften heute (2021). Aktuelle Ausgabe, Schulbuch 5. Westermann.

Naturwissenschaften heute (2021) Aktuelle Ausgabe, Schulbuch 6. Westermann.

Social studies

STUDY 3

Seydlitz Erdkunde 1 (2021) Gymnasium Rheinland-Pfalz. Westermann.

Seydlitz Erdkunde 2 (2022) Gymnasium Rheinland-Pfalz. Westermann.

Seydlitz Erdkunde 1 (2021) Ausgabe für Realschulen plus in Rheinland-Pfalz. Westermann.

Seydlitz Erdkunde 2 (2022) Ausgabe für Realschulen plus in Rheinland-Pfalz. Westermann.

Seydlitz Erdkunde 3 (2022) Ausgabe für Realschulen plus in Rheinland-Pfalz. Westermann.

Weltkunde (2016) Klasse 5/6 Schleswig-Holstein. Westermann.

Weltkunde (2017) Klasse 7/8 Schleswig-Holstein. Westermann.

Weltkunde (2018) Klasse 9/10 Schleswig-Holstein. Westermann.

6.11.2 Detailed category system used for the textbook analysis

Table 6-3: Full category system.

Category Level 1	Category Level 2	Description	Example	Comment
Climate system	Space and time	weather and climate (not mere weather phenomena); Earth history and atmospheric composition, historical climate-fluctuations; regional and global climate	ice ages (and vegetation); seasons, Earth's rotation, the angle/altitude of the sun; climes; definition climate/ differentiation weather and climate	not: weather phenomena such as rainfall, wind, air, water cycle; local climate graphs, solar systems/ any planetary orbits
	Components and Processes	the overall system and subsystems of the climate: e.g. atmosphere, hydrosphere, global wind systems; environmental factors such as temperature on a climatic or global level; cause-effect arrangement, tipping points; radiation budget and the role of solar radiation, Earth's energy balance; natural greenhouse effect; carbon cycle (including carbon sinks); influencing factors of the climate (solar radiation, global airstreams, sea currents, pressure systems), (not mere weather phenomena)	carbon cycle; carbon sinks; reciprocal effects ecosystem climate (forest, moor); greenhouse effect; climatic parameters; radiation, atmosphere, wind systems	not: nitrogen cycle; water cycle; weather phenomena such as rainfall, wind (local), air; general energy strategies or energy types (meaning radiation budget and energy balance within the framework of solar radiation and the greenhouse effect are coded, but not radiant energy in the sense of physical types of energy); local pressure- or wind systems (these would rather be categorised as weather); a specific lighting zone or clime (e.g. the tropics); zenith in the course of one year at a specific place
Climate change		mention of climate change (or global warming, ...) or anthropogenically reinforced greenhouse effect; scientific evidence of climate change and research regarding climate change; depiction of climate change on the basis of data or research	keyword climate change; context of climate change; depiction climate change (e.g. temperature profile and CO ₂ content, ice cores)	

Table 6-3 continued

Category Level 1	Category Level 2	Description	Example	Comment
Causes	Natural	natural causes (climate variability); external driving factors (e.g. Earth's orbital parameters), internal driving factors (e.g. ocean-atmosphere: ENSO, NAO)	Melancowich cycles	these are causes of long-term fluctuations, which thus do not describe the anthropogenic climate change; they can have additional effects, but they take an effect more slowly
	Anthropogenic	anthropogenic reinforcement of the natural climate change due to an increasing concentration of greenhouse gases through emissions (carbon dioxide, methane, nitrous oxide,...) or e.g. deforestation; addressing the topic of different greenhouse gases and their formation; description, naming and/or formation of fossil energy sources; infrastructure and mobility that base on fossil energy sources (transport, heat supply); increase of energy requirement (urbanisation, population growth); anthropogenic degradation of natural surfaces (decrease of efficiency of CO ₂ -sinks)	carbon dioxide emissions (due to fuels, deforestation) (if emissions, greenhouse gases are explicitly mentioned); greenhouse gases and anthropogenic greenhouse effect; carbon dioxide emission of different activities (CO ₂ -calculator); energy supply in conjunction with emissions (if emissions/ greenhouse gases are explicitly mentioned); deforestation (present time); power stations (fossil); different power stations; fuels (fossil); composition of power sources in households/ energy supply (proportion of fossil fuels)	not: quantitative degree of funding; export countries, import countries etc. of crude oil, crude oil products, that are not energy sources (e.g. synthetics); transport volume, transport routes etc. of resources and energy sources
Impacts	Natural environment	change of Earth's natural environments: e.g. atmosphere, hydrosphere, ice coverage: e.g. increase of the global average temperature, rise of sea levels, decline of ice and snow, increasing frequency and intensity of extreme weather events (e.g. heat waves, floods, drought)	glacier retreat; unfreezing permafrost	
	Ecosystems/Biosphere	effects on the biosphere: damages to ecosystems, extinctions of species and loss of biodiversity (through climate change as the cause); change of spreading patterns of flora and fauna (e.g. bird migration), acidification of the seas and impacts on marine ecosystems (e.g. coral reefs)	forests, moors; tree species; seals, polar bears	notice in regard of the extinction of species and the loss of biodiversity: here exist further possible causes other than climate change- these do not count for this category
	Human society	effects on human society: food production (e.g. food security), health consequences (e.g. heat, pathogens), economy, migration, new scientific possibilities	shipping routes in the Arctic; uncovering mineral resources (the Arctic); permafrost, sinking of houses	

Table 6-3 continued

Category Level 1	Category Level 2	Description	Example	Comment
Ways to deal with climate change	<i>Values, norms, discussion</i>	references to values, norms, organisation and responsibility, present day and future; societal discussion and evaluation/argumentation- also in regard of the societal discourse; societal/political agreements/frameworks e.g. regarding the climate protection and the adherence of the 1.5 °C goal	discussion about different power stations; discussion biofuel vs. food cultivation; international conventions and agreements (climate summit, Arctic Treaty, EU Green Deal); demonstrations	
	<i>Adaptation</i>	human development (improved access to education, health); reduction of vulnerability (risk management, fight against poverty); planning of space - and land use (of a region, a community, a country); individual measures of the individual (person or family): taking action in regard of dealing with climate change, solutions and adaption-strategies: (protective measures, adaption, form of usage, migration through individual persons, families, companies)	composition of forests; flood control; protection of glaciers by covering them; agriculture: adaption of the fruit cultivation, adapted irrigation systems; flight	
Sustainable development, ESD, sustainability concept	<i>Mitigation</i>	technical opportunities to reduce emissions (renewable energies); use of renewable energy sources; international agreements (e.g. 1.5 °C goal); measures to decrease net emissions (reduction of consumption, decarbonisation, sequestration); measures to support carbon sinks (reforestation i.a.); integrated approach: combine different measures optimally (cost efficiency); geo-engineering measures; individual measures: taking action in regard of the effects of climate change: energy, rubbish, mobility, habitation, consumption	renewable energy sources (solar, wind); composition of power sources in households (proportion of renewable power sources); sustainable energy supply; protection of forests; societal/political measures in order to protect climate; agreed reduction of emissions; composition of sources of power for households; individual behaviour; individual emissions and savings; household, shopping, transport	
		sustainability concept (quadrangle-/ triangle of sustainability: social issues, economy, ecology, politics); education regarding sustainable development (german: BNE); ecological backpack, footprint, handprint; Sustainable Development Goals (SDGs)	origin of the sustainability concept in forestry/ use of forests; 3 (4) pillars of sustainability; individual aspects of sustainability; ecological footprint, backpack; agreed goals regarding sustainability	rather general references to sustainability, no concrete references to climate change or energy supply; not: lifestyle, individual actions, actions/measures in the context of climate change

6.11.3 Overview of the chapters that have been analysed and that include coded material of all analysed textbooks

Table 6-4: Chapters within the geography and social studies textbooks that include codings. *indicated chapters that clearly refer to climate change or an explicit focus on fossil vs. renewable energies; **indicates chapters that have a focus on the topic of climate change.

Subject	Geography GER	Geography UK	Social Studies GER	Social Studies UK
Books and chapters				
<i>Seydlitz Gymn. 1</i>	Introduction	<i>Geography-B</i>	<i>Weltkunde 5-6</i>	<i>Citizenship Studies</i>
	Living in extreme places	How can weather be hazardous?	Humans look for orientation	The UK and its relations with the wider world
	Holiday places – tourism and recreation	**What evidence is there that suggest climate change is a natural process?	Germany – diversity and change	
	Resources, production...	Why should tropical rainforests matter to us?	Europe – a continent grows together	
<i>Seydlitz Gymn. 2</i>	Introduction	Why are natural ecosystems important?	<i>Weltkunde 7-8</i>	
	Geofactors as basis for life	Is there more to polar environments than ice?	Progress – wealth for everyone?	
	Limits of landuse	Will we run out of natural resources?	Africa – crisis hotspot or underestimated continent?	
	Feeding the world – between abundance and deficiency	Can we feed nine billion people by 2050?	<i>Weltkunde 9-10</i>	
	Europe – Union and diversity		**Climate change and energy age	
<i>Seydlitz Real. 1</i>	From Rheinland-Pfalz into the World			
	Resources and energy			
<i>Seydlitz Real. 2</i>	**Geofactors and geozones			
<i>Seydlitz Real. 3</i>	Europe – Union and diversity			
	Regional planning			
	Countries and their development			

Table 6-5: Chapters within the chemistry and physics textbooks that include codings. *indicates chapters that clearly refer to climate change or an explicit focus on fossil vs. renewable energies; **indicates chapters that have a focus on the topic of climate change.

Subject	Chemistry GER	Chemistry UK	Physics GER	Physics UK
Books and chapters	Blickpunkt S1	21 st century	blickpunkt	21 st century
Chemical reactions	How has the Earth's atmosphere changed over time, and why?	Temperature, warmth, weather	**What is climate change and what is the evidence for it?	
Fire	Why are there temperature changes in chemical reactions?	Energy is everywhere	How much energy do we use?	
**The Air	**What is the evidence for climate change and why is it occurring?	Induction	*How can electricity be generated?	
Water	Why is crude oil important as a source of new materials?	<i>heute 1</i>	How can solar energy make a difference?	
Electrochemistry	How are chemicals made on an industrial scale?	Energy on the move	<i>heute Gesamt</i>	
**Hydrocarbons	How could an increase in carbon dioxide levels affect ocean life?	The sun and the moon	gateway	
<i>heute</i>	gateway	Types of energy	*Powering Earth	
Combustions	Organic chemistry	Greenhouse effect and climate change	Beyond Earth	
**Future energy	**Interpreting and interacting with Earth systems	Renewable energy sources and their use		
Electricity from redoxreaction		Energy storage		
Hydrocarbons		Sustainability		

Table 6-6: Chapters within the biology and combined science textbooks that include codings. *indicates chapters that clearly refer to climate change or an explicit focus on fossil vs. renewable energies; **indicates chapters that have a focus on the topic of climate change.

Subject	Biology GER	Biology UK	Combined Science GER	Combined Science UK
Books and chapters	Biology GER	Biology UK	Combined Science GER	Combined Science UK
	<i>blickpunkt 1</i>	<i>21st century</i>	<i>blickpunkt 1</i>	<i>21st century Biology f. combined S.</i>
	-	How are organisms in an ecosystem interdependent?	Living with the change of seasons	How are organisms in an ecosystem interdependent?
	<i>blickpunkt 7-10</i>	*How is biodiversity threatened and how can we protect it?	Water and its properties	How is biodiversity threatened and how can we protect it?
	The ecosystem forest	<i>gateway</i>	**Matter as a basis for life	<i>21st century Chemistry f. combined S.</i>
	The ecosystems waters and cities	*Ecosystems	Project: Weather and climate	How has the Earth's atmosphere changed over time, and why?
	Human's metabolism	Feeding the human race	<i>blickpunkt 2</i>	**What is the evidence for climate change and why is it occurring?
	<i>heute 1</i>		Energyflows in our environment	Why is crude oil important as a source of new materials?
	-		Project: The ecosystems waters and cities	How could an increase in carbon dioxide levels affect ocean life?
	<i>heute 2</i>		*Humans alter the environment	<i>21st century Physics f. combined S.</i>
	Living beings transform matter into energy		*Sustainable use of energy	**What is climate change and what is the evidence for it?
	Endangerment and protection of forests		Energy transformation and nutrient cycles	How much energy do we use?
			<i>blickpunkt 3</i>	*How can electricity be generated?
			*Energy converters	How can solar energy make a difference?
			<i>heute 5</i>	<i>gateway Biology f. combined S.</i>
			-	*Ecosystems
			<i>heute 6</i>	<i>gateway Chemistry f. combined S.</i>
			Water and the sun	Improving processes and products
				**Interpreting and interacting with Earth systems
				<i>gateway Physics f. combined S.</i>
				*Powering Earth

7 Summaries of the conducted studies

Study 1: Implementing climate literacy in schools – what to teach our teachers?

This study was built on the theoretical framework of climate literacy on the one hand and on teachers' professional knowledge on the other hand. The purpose of the study was to figure out, what professional knowledge aspects teachers need to be enabled to foster students' climate literacy. For this study, teachers' professional knowledge was conceptualized as including content knowledge (CK), pedagogical content knowledge (PCK) and pedagogical knowledge (PK). For the study, only the two content-related facets, CK and PCK, were considered because with climate literacy a specific teaching content was in focus. Therefore, the study aimed to compile a catalogue of knowledge aspects including both science and society and referring to teachers' CK and PCK. To this end, a Delphi-study, a multilevel interrogation of experts in the field of study, was conducted. The Delphi-method is a group communication process that aims to find consensus or opinion stability among an expert panel (Linstone & Turoff, 1975; Osborne et al., 2003; Powell, 2003). The process included three subsequent interrogation rounds. Round one prompted few open-ended questions towards an expert panel of climate researchers, education researchers, teacher educators and teachers (n=44 participants in total). Their answers were analysed by qualitative content analysis and twenty themes describing CK and PCK aspects were derived in the first place. Round two presented the twenty themes to the expert panel (n=64 participants) and asked them to rate the themes by relevance (Likert-scale: 1 = 'not relevant' to 7 = 'very relevant') and to suggest possible changes. The answers were analysed qualitatively and quantitatively and the themes were revised according to the experts' feedback. Round 3 presented the remaining thirteen themes to the expert panel (n=45 participants), including the panel's ratings from the previous round. The experts were asked to rerate the themes and to comment on them. After this final round, the themes were revised using further suggestions from the panel and adjustments of wording. Central tendencies of ratings were calculated as to figure out which relevance was attributed to the respective themes by the experts. As a result, the study yielded 13 delineated and highly rated themes, seven of which describe relevant CK and six of which describe the relevant PCK. All themes consist of a heading followed by a description text. The CK-related themes refer to the climate system, climate science, climate information, causes of, impacts of and ways to deal with climate change and the interrelation of climate change with further global challenges. The PCK-related themes refer to students' pre- and misconceptions, teaching strategies, the personal relevance of the topic, students' role as change agents and argumentation skills, possibilities and limits of individual and collective action and put a particular emphasis on the interdisciplinary structure of climate education. The findings stress the interdisciplinary nature of climate education. They can be used as a starting point for teacher education and to point out the relevant teaching content in the context of climate literacy according to a broad and multidisciplinary expert panel.

Study 2: *Curriculare Einbindung der Klimabildung – wie ist der Stand und wo soll es hingehen?* (= Curricular inclusion of climate education – what is the status quo and where should we go?)

This study was based on the significance that curricula have in education and on the ways in which climate education can be implemented in school curricula. The purpose of the study was to figure out to what extent the content of school education might contribute to handling the challenge of

climate change as a society, based on what is already included in the standards and specification of education content. Therefore, the study aimed to provide an insight into how climate education is currently being implemented into the curricula of natural science and social studies subjects in secondary education in Germany. 'How' in this term means to which extent and in which way, within what topics and in which subjects. To this end, the subject curricula of three federal states of Germany (Bremen, Mecklenburg-Vorpommern, Saarland) were selected based on a quantitative pre-analysis that counted the frequency of climate-related key-words within curricula of all federal states. The selected curricula represented federal states with a (1) low, (2) medium and (3) high key-word frequency. The subject curricula of science subjects (biology, chemistry, physics, combined science), of geography and of social studies subjects (social studies, economy, history) were analysed by qualitative content analysis. A two-dimensional analysis key was developed inductively. One dimension (a) represented the specific content that was included in the curriculum. The second dimension (b) represented the way in which the content was applied within the curriculum. Relevant text segments were extracted from the curricula by a key-word search process and all extracted segments were coded by qualitative content analysis (Mayring & Fenzl, 2019) with both dimensions of the analysis key. The analysis key was revised according to the material. As a result, the study yielded the analysis key with three categories in the content-related dimension (a) (sustainability-related content, climate change-related content, human living related content) and three categories in the application-related dimension (b) (overarching concepts, mandatory content or optional examples). Climate education is included in a cross-curriculum way (Eilam, 2022). The sustainability-category was most often represented, but human ways of living were also strongly represented in different subjects. The climate change related teaching content is included as overarching concepts but also as mandatory topics. Thus, climate change is often addressed through cross-cutting themes such as sustainability but also, less often, described explicitly as a topic of its own right. Focus topics are to be found in the science subjects as well as in geography, but references can still be found in further social studies subjects. The findings stress that climate education is being addressed throughout within the curricula of different subjects. Yet, a coherent climate education along the school biography of an individual cannot be ensured. This is because relevant aspects as for example climate science and societal transformation are missing and the single subjects' content remains fragmented. Examples of much elaborated topics were found in the analysis, though, and could be used as starting points for a comprehensive and interrelated interdisciplinary kind of climate education.

Study 3: A fragmented endeavour – Climate education contents in natural science, geography, and social sciences textbooks

This study was based on the theoretical framework of climate literacy on the one hand and on the importance of textbooks as curricular materials for teaching and lesson planning on the other hand. The purpose of the study was to provide an insight into current climate education in schools as it is being represented by textbooks, a prevalent resource of lesson planning. Therefore, the study aimed to figure out how climate education is currently being addressed in natural science and social science subjects in Germany and the UK. 'How' in this term means to which extent and within what topics and if there are differences between the two subject areas. Textbooks for lower secondary education from one publishing house in each country were selected for biology, chemistry, physics, combined science, geography and social studies. The textbooks were analysed using

qualitative content analysis (Kuckartz, 2019; Mayring & Fenzl, 2019). A category system for coding was developed deductively based on a former study (curricula analysis, see above) and a study by Moelter-Reich (2023), who investigated primary school textbooks. The category system was piloted and revised according to the material. Relevant book chapters were selected by the table of contents and complemented by an index research with predefined climate-related key-terms. During coding, the text of one subchapter was regarded as one coding unit. Additionally relevant illustrations within the chapters were coded, regarding each illustration as one coding unit. During the coding process it was specified for each coding if it referred to either a text segment or an illustration. As a result, the study yielded the category system with six level-1 categories and 10 level-2 categories reflecting the climate system, climate change, causes of, impacts of and ways to deal with climate change, as well as sustainable development. In both countries, the textbooks for geography, chemistry and physics provided the highest coverage of climate education in general compared to biology and social studies. The physical science basis as, for example, the climate system and greenhouse effect were widely covered, but the largest extent of coding was found for the anthropogenic causes of climate change and mitigation strategies. The findings stress that climate education has found its way into the teaching material of different subjects with an emphasis on geography and the science subjects. The relevance and relation of anthropogenic causes on the one hand, and mitigation strategies on the other hand, become very obvious. However, while those aspects are almost over-represented and appear throughout several subjects, other aspects are underrepresented or even missing. A reasonable and structured relation between the different subjects including scientific and social aspects would be needed to enhance climate literacy.

8 Discussion and perspectives

This dissertation aimed to investigate the preconditions for successful climate education by the means of relevant teaching content, teachers' professional knowledge, institutional requirements and actual teaching content according to curricular materials. The three conducted studies contributed to this aim by providing insight into (1) relevant teaching content and teachers' knowledge from an experts' perspective, into (2) relevant teaching content from an institutional perspective provided by subject curricula and into (3) actual teaching content as represented by classroom material in the form of textbooks. The discussion will be structured in the following way: To start with, the main results of the three conducted studies will be briefly highlighted in answer to the two preparatory research questions (chapter 8.1), before they are contrasted to each other with respect to their representation of climate education (chapter 8.2). The studies' content categories and coverage will be related to each other and to existing literature in chapter 8.3 taking into account the physical science basis as well as the social aspects of climate education and highlighting areas of limited coverage in climate education. Eventually, the outcome of this dissertation will be contrasted to the theoretical framework as outlined in the beginning in chapter 8.4 with respect to the conclusive overarching research question and taking into account teachers' professional knowledge, ESD and the interdisciplinary character of a climate education curriculum.

8.1 The outline of climate education

To start with, the main results of the three conducted studies will be referred to the two preparatory research questions of the dissertation. The resulting themes and categories of the three studies reflect the relevance and coverage of content aspects in climate education according to experts' perspective or curricular materials respectively. With respect to the first overarching research question (*What do teachers need to know and what should be included in teaching in the context of climate literacy?*), the first study, a Delphi-study, yielded 13 themes describing relevant aspects of teachers' CK and PCK. The six CK-themes cover the climate system, causes and impacts of as well as ways to deal with climate change, climate science and relations to other global challenges. The seven PCK-themes include the interdisciplinary structure of climate education, students' conceptions, individual action, argumentation, students' environments and teaching strategies. Altogether the CK-related themes are quite congruent with the outline of the CLEP from the USGCRP (2009). The PCK-related themes transcend this framework by the means of teaching strategies, misconceptions and particularly, relations towards those social aspects proposed by Shwom (2017) and later on by the USGCRP (2024). They embrace the unique notion of teachers' professional knowledge that has not been acknowledged by the other frameworks, but that is suitable to foster climate literacy according to Azevedo & Marques (2017).

Regarding the second overarching research question (*How is climate education being included by institutional requirements (curricula) and teaching material (textbooks) considering different subjects especially regarding natural sciences and social studies?*), the results of the second and third studies will be outlined briefly in the following and complemented in the following sub-chapters. The second study, a curricula analysis, yielded three content-related and three implementation-related categories, reflecting by which content foci and in which ways climate education is being included in German curricula. The categories cover sustainability, the explicit reference to climate

change and human ways of living, that are either reflected as overarching concepts, as mandatory content or as optional examples. The third study, a textbook analysis, yielded six main- and ten subordinate-categories reflecting the contents of climate education represented within different subjects according to textbooks. The categories cover the climate system, climate change, its causes and impacts, ways to deal with climate change and sustainability. Broadly speaking, the focus is on the physical science side as well as on causes and mitigation of climate change as represented by some of the CLEP from the USGCRP (2009). Transcending the framework of climate education, relationships towards ESD are being found, which opens up to a twofold opportunity: On the one hand, climate education might be subsumed under ESD-references and on the other hand, relations from climate change towards further ESD-topics might be facilitated.

8.2 Contrasting the three conducted studies

In order to get an idea of how the joined results of the three conducted studies enrich the current and required preconditions of climate education, it is necessary to take a closer look at their different structure and at the same time, their commonalities. A comparison of the category systems from studies 2 and 3 provides an insight into the congruence of institutional requirements and their implementation into teaching practice. In contrast, the resulting themes from study 1 provide an insight into the compatibility of experts' perspectives on climate education. This comparison will provide an answer to the third overarching research question (*How does the current state of climate education by curricular inclusion and teaching implementation compare to the required climate education towards climate literacy as proposed by experts?*). The themes and categories of the three conducted studies are differently structured and resolved into three broad categories in study 2 and six plus 10 narrow (sub-)categories in study 3. In study 1, the differentiation between CK- and PCK-themes is another particularity that has to be considered. Yet, the categories and themes can be arranged in a way that emphasises a common structure of the overarching results from the three studies as illustrated in Figure 6. Broadly, five common focus sections reflect the coverage of teaching contents and CK respectively as follows: (1) the focus on the climate system and climate change, (2) the focus on impacts of climate change, (3) the focus on the causes of climate change, (4) the focus on reactions to climate change and (5) the focus on sustainability. Considering the themes of study 1, the PCK-themes take a particular role. Some of them can be intertwined with specific aspects of a reaction to climate change as displayed in Figure 8-1. Others must be considered as overarching themes throughout the whole topic, hence, they are cutting across all five sections. This makes perfect sense, since PCK can mediate the effect that CK has on students learning outcomes (Mahler et al., 2017). As such, the interdisciplinary structure, students' conceptions and teaching strategies play a significant role for teaching and thus, for bringing all categories in all sections to practice.

	Curricula	Textbooks	Experts
Climate system and climate change	The topic of climate change	Climate system Space and time Components and Processes Climate change	Climate history and climate fluctuation Components and functioning of the climate system Climate science and dealing with information
Impacts of climate change		Impacts Natural environment Ecosystems/Biosphere Human society	Impacts of anthropogenic climate change
Causes of climate change	Way of living and action (causes, mitigation, adaptation)	Causes Natural Anthropogenic	Climate history and climate fluctuation Causes of anthropogenic climate change
Reacting to climate change		Ways to deal with climate change Values, norms, discussion Adaptation Mitigation	Formation of an opinion and argumentation integrated into climate education Dealing with climate change Dealing with willingness and capacity to act Self-reference: living environments and options to act
Sustainability	Sustainability, global change, anthropocene and society	Sustainable development, ESD, sustainability concept	Relation to other societal and global problems

Figure 8-1: The resulting categories (studies: 2 – curricula; 3 – textbooks) and themes (study 1 – experts) of the three conducted studies can be arranged next to each other in order of an overall comparison. Five common focus sections on the left hand side of the figure reflect the coverage of teaching content and CK within the three studies. In the column of study 2 (curricula) the categories of dimension (b) are cutting across the content-related categories of dimension (a) and therefore they are highlighted in yellow. In the column of study 1 (experts) the PCK-themes are highlighted in yellow, three of them are cutting across all other themes and categories.

8.3 The coverage of climate education

The compatibility between institutional requirements and their implementation into teaching practice with experts' perspectives is highly relevant from a science education perspective in this dissertation. Therefore, the coverage of categories within the curricula and textbooks in comparison to the relevance of themes from the experts' perspective shall be considered in the following. The respective numbers are displayed in Table 8-1. As of the experts' perspective, all of the resulting themes from study 1 were rated as relevant to very relevant (≥ 5.8 on a Likert-scale from 1='not relevant' to 7='very relevant'). Thus, the themes can be considered as an expedient catalogue of holistic climate education from the experts' perspective, while the coverage of the categories within the curricula and textbooks reflect the status quo. In the following subchapters the content coverage of the studies' results will be further referenced to each other following the first four common focus sections according to Figure 6. The focus section of sustainability will be referred to in chapter 8.4.

Table 8-1: Coverage of climate education aspects according to coding frequencies of the categories from studies 2 and 3 (**highest coding frequencies, *medium coding frequencies) and the ratings of themes from study 1 (ratings on a Likert-scale from 1='not relevant' to 7='very relevant')

	Curricula			Textbooks			Experts		
	Categories	Coding-Frequencies	Categories	Subcategories	Coding-Frequencies GER/UK	Themes	Ratings (Mean)		
Climate system and climate change	Topic of climate change	123	Climate system	Space and time	80 40	Climate history and climate fluctuation	6.2	Interdisciplinary structure of climate education and curricular integration: 6.3 Pre- and misconceptions: 5.8 Teaching strategies and illustration: 6.3	
			Climate change	Components and processes	108 85	Components and functioning of the climate system	6.5		
Impacts of climate change			Impacts	Natural environment	87 89	climate science and dealing with information	6.3		
				Ecosystem/biosphere	41 48				
				Human society	13 14	Impacts of anthropogenic climate change	6.5		
Causes of climate change	Way of living	188	Causes	Natural	1 12	climate history and climate fluctuation	6.2		
				Anthropogenic	175 109	Causes of anthropogenic climate change	6.7		
Reacting to climate change			Ways to deal with climate change	Values, norms, discussion	50 31	Formation of an opinion and argumentation	5.8		
				Adaptation	8 7	Dealing with climate change	6.6		
Sustainability				Mitigation	185 110	Dealing with willingness and capacity to act	6.2		
						Self-reference: living environments and options to act	6.2		
	Sustainability, global change, Anthropocene and society	239	Sustainable development, ESD, sustainability concepts		75 19	Relation to other societal and global problems	6.0		
			As overarching: 127 As mandatory content: 115 As optional content: 52						

8.3.1 The physical science basis of climate education

The physical science basis seems to be a significant pillar of climate education. First of all, the physical science basis is in focus in the CLEP (USGCRP, 2009), which name similar aspects as they were collated and rated highly by the participating experts in study 1: the climate system, causes of, impacts of and ways to deal with climate change. At the same time, the physical science aspects seem to be the main focus within the analysed curricular materials of study 2 and study 3. The first focus section (*climate system and climate change*) includes categories and themes that refer to the climate system and climate change in general, with specific physical and climate science content (Figure 8-2).

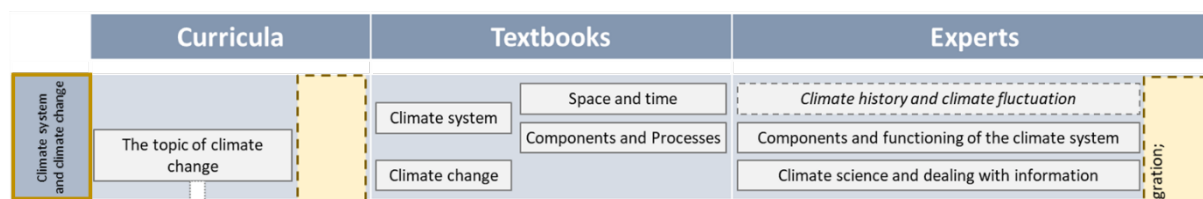


Figure 8-2: Overall comparison of the three conducted studies – the first focus section 'Climate system and climate change'.

Considering curricula, the respective category reflects any content that mentions or refers to climate change, while for textbooks, the categories differentiate between the climate system and climate change. The themes from experts' perspectives resemble the textbooks categories, but furthermore, mention climate science and information (e.g. from the media). In the curricula analysis, this category has been least coded in comparison to the other categories. If climate change is referred to in the curricula, the greenhouse effect, Earth's radiation budget and biogeochemical cycles are most often referred to, while climate science and policy are hardly mentioned. Topics such as the climate system, solar radiation, the atmosphere, greenhouse gases and the greenhouse effect or the carbon cycle are in focus most often, but the impacts of climate change also play a significant role. These contents representing the physical science basis of climate change were found at a similar rate in other curricula studies (Siegmund et al., 2021), with a particular stress on the science subjects of chemistry, physics and biology in this context (Chang & Pascua, 2017). However, in the textbook analysis, medium to high numbers of codings are to be found. The largest focus is on 'components and processes' of the climate system whilst references to climate science play a subordinate role. The scientific consensus of anthropogenic climate change (Cook et al., 2013) is a significant aspect especially in the context of education research within the United States. Studies report that teachers are challenged by a perceived controversy of the climate change topic and therefore tend to leave the anthropogenic causes of climate change open to discussion in the classroom (Sullivan et al., 2014; Wise, 2010). Furthermore, textbook studies found the representation of a scientific uncertainty of anthropogenic climate change in US textbooks (Meehan et al., 2018; Román & Busch, 2016). Such representations were not evident, though, within the investigated material from Germany and the UK of study 3. The ability to understand the scientific process and the nature of climate science is crucial to grasp the scientific evolution of the phenomenon, to evaluate information from the media and to position oneself to climate change denial (Monroe et al., 2019; cf. Niepold et al., 2007). This holds true for teachers' professional knowledge and for their ability to transfer this sensitive notions into classroom teaching, which some teachers seem to have difficulties with (Hestness et al., 2014; Johnson et al., 2008;

Liu et al., 2015). Hence, study 1 presents a CK-related theme reflecting climate science and climate change information as well as a PCK-related theme concerning the development of argumentation skills. Both are closely interrelated. However, the investigated textbooks of study 3 did rarely address the scientific process of climate science. Considering the investigated curricula of study 2, the scientific process of climate science was absent as an explicit notion of climate education. Yet, the structure of German science curricula (e.g. biology) explicitly include the scientific process as a standard-competency predefined by the national education standards (KMK, 2004a, 2020).

The second focus section (*Impacts of climate change*) includes categories and themes that refer to impacts of climate change (Figure 8-3).

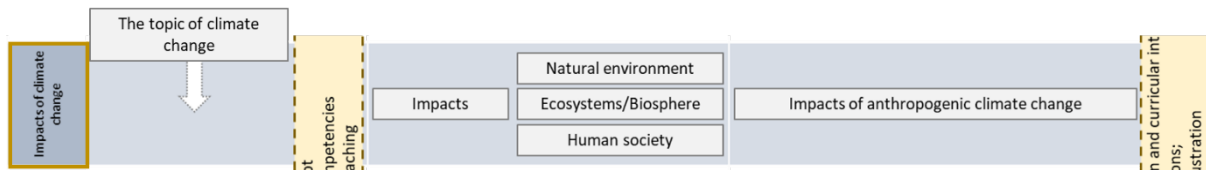


Figure 8-3: Overall comparison of the three conducted studies – second focus section 'Impacts of climate change'.

Considering the investigated curricula, the impacts are being reflected by the same category with references to climate change. For textbooks, the categories differentiate impacts on the natural environment, the biosphere and human society. The themes from experts' perspectives aggregate impacts of climate change in one theme. In the curricula analysis, impacts of climate change fall into the least frequently coded category (*the topic of climate change*). Yet, impacts of climate change are among those topics that are most often referred to within the category. In the textbook analysis, it becomes obvious that impacts on the natural environment are coded at a medium frequency and are far more frequently referred to than impacts on the biosphere or human society. This neglects the severity and significance of the effects of climate and climate change on human lives (IPCC, 2023; Shwom et al., 2017; USGCRP, 2009, 2024). The same topics reflecting the physical science basis of climate change (e.g. the greenhouse effect) or causes of climate change (e.g. greenhouse gas emissions) were found similarly in other textbook studies in different countries (Baarova & Hibszer, 2022; Dalelo, 2011; Morris, 2014).

8.3.2 The social aspects of climate education

Following up and interrelated to the physical science basis as outlined above, are the societal debate and the social aspect of climate education. The development of climate literacy frameworks outlined in the theoretical background illustrates that the social aspects have been thought about from the beginning (USGCRP, 2009). They are also implicit within the climate literacy related skills and attitudes (Azevedo & Marques, 2017). Yet, they have been acknowledged and explicitly formulated only later (Shwom et al., 2017; USGCRP, 2024). Considering the studies within the framework of this dissertation, relations to the societal significance and social aspects of climate change become relevant within several categories and themes. Hence, the category about ways of living in study 2 and the categories about causes and ways to deal with climate change in study 3 relate to the social aspects of climate education. The same holds true for the content-related themes about causes of climate change and dealing with climate change, as well as several PCK-related themes in study 1.

The third focus section (*Causes of climate change*) includes categories and themes that refer to causes of climate change (Figure 8-4).

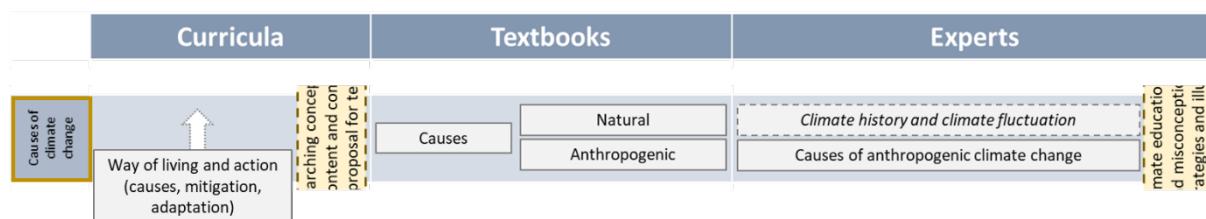


Figure 8-4: Overall comparison of the three conducted studies – third focus section 'Causes of climate change'.

Considering the investigated curricula, the category falling into this section reflects ways of living contributing to the causes of climate change. For the textbooks, the categories differentiate between natural and anthropogenic causes. The themes from experts' perspectives actually aggregate the anthropogenic causes of climate change in one theme. Furthermore, the same theme that was already mentioned in focus section one, reflecting natural climate fluctuation, can be arranged here again next to the natural causes category within textbooks. In the curricula analysis, the category is coded at a medium frequency compared to the other categories. Although it covers causes as well as reactions to climate change, causes are often mentioned within the category. Natural causes of climate change, however, fall out of this category. They would have been coded within the explicit *climate change* category, but do occur less frequently. In the textbook analysis natural causes are rarely referred to, but anthropogenic causes of climate change appear most frequently.

The fourth focus section (*Reacting to climate change*) includes categories and themes that refer to reactions to climate change (Figure 8-5).

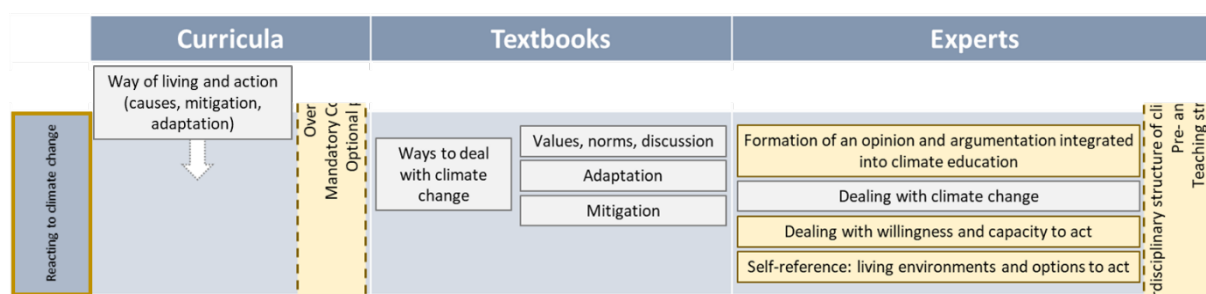


Figure 8-5: Overall comparison of the three conducted studies – fourth focus section 'Reacting to climate change'.

Considering the investigated curricula, the same category reflecting ways of living falls into this section again with reflecting action contributing to mitigation of and adaptation to climate change. For the textbooks, the categories differentiate ways to deal with climate change into mitigation and adaptation and furthermore into societal values, norms and discussion. The themes from experts' perspectives aggregate dealing with climate change into one CK-theme, but additionally, three PCK-themes intertwine with categories from curricula and textbooks: Self-reference and living environments are closely connected to ways of living contributing to causes (in curricula) and action towards mitigation and adaptation reflected in curricula and textbooks. The same holds true for the willingness and capacity to act, which is particularly relevant for the way teachers include individual action, limitations of individual action and societal action into classroom teaching. Furthermore, opinion formation and argumentation are closely related to societal discussion

as reflected in textbooks. This theme also plays a particular role in the way teachers implement climate education in classroom teaching. In the curricula analysis, the category way of living is coded with a medium frequency. Within this category, alternative energy resources as well as ways of action are mentioned. Within the analysed curricula, such relations were found with respect to technical functioning of energy resources but also related to their risks and chances. Within the analysed textbook material, the scope was rather on the technical functioning side and current share of energy consumption. However, in the textbook analysis mitigation strategies are most often coded, but also values, norms and discussion are mentioned at a medium frequency, whilst adaptation does hardly appear. The representation of fossil fuels and climate change is kept rather abstract and technical. At the same time, measures of action are rarely addressed and if so, they are limited to individual action and consumption, which has also been found in science books for young children (Knauf, 2023). Adaptation strategies as well as collective action, political measures and societal debate play a subordinate role in both, curricula and textbooks, which is corroborated by findings from other studies (Bonilla & Quesada, 2024; Meehan et al., 2018; Siegmund et al., 2021), yet, others found a stronger focus on climate change solutions (Baarova & Hibszer, 2022; Morris, 2014).

8.3.3 The overall coverage and limitations of current climate education according to curricula and experts' perspectives

In order to conclude the comparison of the three conducted studies with respect to the conclusive overarching research question, the experts' perspective shall be compared to the current implementation of climate education in the following. Altogether, the Delphi-study outlines the physical science basis of climate change through the themes related to the climate system and climate history, as well as the social aspects through the themes related to the causes of, impacts of and ways to deal with climate change and the related PCK-themes. Here, it becomes obvious that significant parts of these themes are already being considered by curricula and by textbooks which is in line with Bhattacharya et al. (2021b). Yet, as outlined above, the analysed material falls short on climate history (curricula & textbooks) and impacts of climate change (textbooks). To know about the process of natural fluctuation would help to understand the actual causes of present climate change and to follow or debunk (non-)scientific argumentation in discussion or media (USGCRP, 2009). Considering the theme of ways to deal with climate change, it has to be stated that adaptation strategies should play an equal role as mitigation strategies do according to the expert panel, which was also proposed by Kranz et al. (2022). Yet, this is not the case in the analysed material. Especially considering the rather technical inclusion of fossil fuels within textbooks it becomes obvious that here the balance is more on causes of climate change (use of fossil fuels) and mitigation strategies (use of alternative energy resources). However, the results from study 1 clearly show that the interrogated experts highlight the significance of the social aspects of climate education. In this context, one PCK-related theme focuses explicitly on the inclusion of students' living environment. Relating climate change to one's own life doesn't seem to be something that students just do (Shepardson, Niyogi, et al., 2011), so this relation needs to be enhanced in classroom teaching. This would also help to reduce psychological distance towards climate change, which supports higher personal concern (Busch & Ayala Chávez, 2022). Another PCK-related theme points to the individual scope of action, which is in line with Kranz et al. (2022). Yet, according to the results from study 2 and 3 curricular materials to not achieve these recommendations

so far. Eventually, the formation of an own opinion with the societal debate on climate change is being included in one PCK-related theme, which would contribute to the development of a reflective role as an active and participatory citizen as called for (Jorgenson et al., 2019; Kranz et al., 2022).

Altogether, the scientific basis of climate change appears currently well covered by curricular materials. Yet, curricula and textbook fall short on adaptation strategies and societal aspects, especially different levels of individual and societal action as well as societal discussion are little covered, while experts highlight these content areas as equally relevant. The fact that these aspects are reflected within both, CK- and especially PCK-related themes from the experts' perspectives, stresses the need for teachers to be professionally prepared for climate education and these aspects should find their way into curricular materials in order to achieve a holistic climate education.

8.4 Crosscutting climate education

Some aspects of climate education appear to be cutting across the whole topic in different ways: (1) teachers' professional knowledge comprises themes that are relevant throughout all content foci, (2) the notion of sustainability is overarching the whole topic and (3) the interdisciplinary structure is interwoven throughout all focus topics. All three aspects will be considered in the following with regard to the theoretical framework of the dissertation.

8.4.1 Teachers' PCK to foster climate literacy

Three PCK-related themes from study 1 are cutting across all content-related themes and categories of the three studies. They are cross-linked to the specifications of the scientific and social aspects of climate education and they embrace the whole of CK-related themes and those PCK-related themes that are specifically intertwined with the social aspects. Pre- and misconceptions in the context of climate education are of particular relevance regarding teachers' professional knowledge on the one hand and teaching material on the other hand. First of all, research revealed that teachers hold misconceptions themselves (Anyanwu et al., 2015; Hestness et al., 2014; Papadimitriou, 2004; Ratinen, 2013), which is why teachers professional development needs to foster teachers' CK with respect to the physical science basis (Sullivan et al., 2014) outlined above. Additionally, teachers need to know common pre- and misconceptions in the context of climate change, as they were collated in the results of study 1 in accordance with existing literature in the field (McCaffrey & Buhr, 2008; McCuin et al., 2014; Shepardson, Niyogi, et al., 2011). The knowledge of misconceptions and adequate consequences for teaching strategies are of particular importance when it comes to textbooks that include representations that either depict or foster misconceptions, especially regarding the greenhouse effect (Choi et al., 2010; King, 2010; Shepardson, Choi, et al., 2011). Study 3 analysed the content that was represented in text passages and figures within the textbook material and thus, did not detect or analyse misconceptions separately. Yet, it was still recognised that such misleading representations, especially of the greenhouse effect, did exist. Apart from the fact that such representations within textbooks should be improved, the respective knowledge of misconceptions would help teachers to handle such figures within the existing material. The second overarching and significant PCK-related theme revealed by study 1 is about teaching strategies for addressing climate change in the classroom. Such

strategies, as they were collated by the experts, reflected the inclusion of practical activities, personal environments and multiple perspectives which resemble other research (Dupigny-Giroux, 2010; Hestness et al., 2014; Johnson et al., 2008; Kirk et al., 2014; Sullivan et al., 2014). Regarding the analysed curricula and textbooks of studies 2 and 3 the inclusion of teaching strategies is, if at all, rather implicit than explicit and was not deliberately investigated by the respective category systems, since this would have changed the focus. However, within the analysed curricula, linkages towards teaching strategies could be made via the second dimension of categories regarding examples for the implementation into teaching. Here, the necessity to use different and adequate teaching strategies to foster the respective competencies (KMK, 2010) is implicitly involved on the one hand and some of the examples included explicit suggestions for, e.g., practical field trips. The case of textbooks then again is another consideration. The study 3 did not analyse the involved tasks that were linked to the text and figures content, which would be another promising approach of textbook analysis. However, teachers' PCK is of severe importance in the implementation of climate education transcending single content aspects and therefore contributing to a holistic approach of climate education.

8.4.2 Overarching climate education: sustainability

The fifth focus section (*Sustainability*) includes categories and themes that refer to sustainability (Figure 8-6).

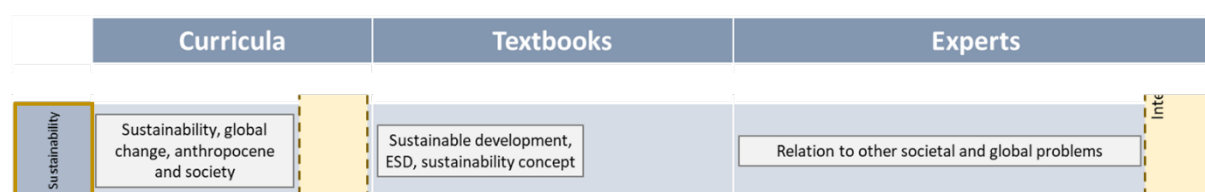


Figure 8-6: Overall comparison of the three conducted studies – fifth focus section 'Sustainability'.

Considering the curricula, the category reflects the often overarching concepts of sustainability or the Anthropocene, which are mentioned in several subjects on different scales. In the investigated textbooks the respective category mainly refers to the sustainability concept. The theme from experts' perspectives reflects the relation of climate change to further global challenges, but without literally mentioning sustainability. Regarding the curricula analysis, this is the most frequently coded category. Yet, in many cases, this category is reflected as an overarching topic or general remarks within the curricula, as ESD is implemented as a crosscutting task (Buddeberg, 2016; KMK, 2024). Therefore, it is cutting across the entire curriculum and at the same time, it is an overarching concept within specific subjects, which makes climate change double-subsumed (Eilam, 2022). In the textbook analysis, however, this category appears less frequently, especially in the UK and with a different notion. Here, content aspects of sustainability topics or different dimensions of sustainability (such as ecological, social and economic aspects) were referred to more often (de Haan, 2002; KMK, 2024). When references within the curricula and the textbooks include sustainability or ESD, climate change is sometimes explicit and sometimes remains implicit. The latter allows teachers to include climate change as one sustainability related topic, hence, it depends on the individual teacher if this is going to happen or not (Dawson et al., 2022). The way ESD references are presented in textbooks they would rather contribute to ESD 1 (Vare & Scott, 2007) because they stay on the level of the technical concept, while notions of discussion and participation

are scarce. For the curricula, however, the scope is more open and again, it would depend on the respective teacher which concept of ESD is to be pursued. Eventually the relation between ESD and climate education opens up a twofold opportunity, allowing the inclusion of climate topics in general ESD and transcending climate change when connecting the topic to further challenges.

8.4.3 The interdisciplinary approach

The interdisciplinary approach of climate education merited a theme of its own in study 1. In study 2 and 3 curricula and textbooks from different subjects coming from a scientific and from a social studies background were included in order to provide insights into their different approaches to climate education.

Table 8-2: The experts' assignment of climate education topics and aspects to different subjects from study 1 and as they were found in the curricula and textbooks from study 2 and 3.

Subject	Delphi-Study	Curricula	Textbooks
Biology	Photosynthesis, CO ₂ during evolution, ecosystems and human society, biogeochemical cycles, carbon sinks	Sustainability, climate change	Components and processes, climate change, anthropogenic causes, sustainability (GER)
Chemistry	Radiation, air pollution, greenhouse gases, biogeochemical cycles, carbon sinks	Sustainability, way of living	Space and time (UK), components and processes, climate change, anthropogenic causes, impacts: natural environment (UK), mitigation
Physics	Radiation, atmospheric dynamics, climate models, greenhouse gases, renewable energies	Sustainability, climate change, way of living	Space and time (GER), components and processes (GER), climate change (UK), anthropogenic causes, values, norms, discussion (UK), mitigation
Combined Science	-	Way of living	Space and time (GER), components and processes (GER), anthropogenic causes (GER), mitigation (GER), sustainability (GER)
Geography	Climate system, systems thinking, climate space and time, carbon sinks, natural-human interference, migration, CO ₂ -Costs, climate agreements, impacts on society, human behaviour	Sustainability, climate change, way of living	Space and time, components and processes (UK), climate change, anthropogenic causes, impacts: natural environment (UK), Impacts: human society (UK), values, norms, discussion (GER), mitigation (GER), sustainability (GER)
Social studies	Migration, CO ₂ -costs, climate agreements, impacts on society, human behaviour, climate justice	Sustainability, climate change	Space and time (GER), components and processes (GER), anthropogenic causes (GER), impacts: natural environment (GER), mitigation (GER)
History	Early effects of human actions on climate, cultural history, industrialisation, historic climatic effects on humans	-	-
Further subjects that were suggested by the Delphi-panel: Ethics/religion, arts/music, languages, mathematics Further subjects that were investigated for the curricula analysis: world studies, working life/economy			

Table 8-2 outlines which content was attributed to the specific subjects in the different studies. In the following the significance of different subjects from the conducted studies is referenced to existing literature.

Regarding the inclusion of climate education topics, geography and science subjects include many focal topics of climate education, according to the curricula analysis of study 2, mirroring the findings of prior works (Chang & Pascua, 2017; Colliver, 2017; Dawson et al., 2022; Field et al., 2023). Similarly, within textbooks study 3 indicates that geography is a main focus subject of content coverage, yet, science subjects include particular focus topics of climate education as well. Indeed, both subject areas are referred to in literature as the typical or appropriate subjects to address climate education (Favier et al., 2021; Johnson et al., 2008). The inclusion of climate change within social studies varied regionally throughout curricula and textbooks according to studies 2 and 3. The subjects' structure is not uniform throughout Germany and also differs between Germany and the UK. Thus, content coverage revealed different focal topics between the investigated countries and regions, but overall climate change content is to be found within social subjects in Germany and rarely in the UK. The implementation of climate education within non-science and non-geography subjects is being proposed in research, as is the relevance of social aspects into climate education (Johnson et al., 2008; Shwom et al., 2017). In line with this, one theme (the interdisciplinary structure of climate education) from study 1 clearly points at the need for an interdisciplinary coverage of the topic, the necessity of connection between separate subjects and the integration of scientific as well as social subjects. Suggestions from the expert panel ranged from assorting specific aspects of climate education to the different subjects to dissolving the separation of subjects generally. Climate change is considered as a trans- and interdisciplinary topic (Ledley et al., 2017). However, an interdisciplinary implementation of climate education in school reality is hampered by constraints for teachers, such as the fact that climate change is missing within the curricula (Sullivan et al., 2014) and that they feel underprepared to teach the topic (Demant-Poort & Berger, 2021). This becomes particularly relevant when considering that science teachers have difficulties with integrating social aspects while teachers in social subjects have difficulties in including the science aspects in their teaching (Beasy et al., 2023). To this end, CuK becomes relevant with respect to the interdisciplinary structure of climate education, whether it is regarded as separate from (Mahler et al., 2017; Shulman, 1986; Tamir, 1988) or part of PCK (Grossman, 1990; Magnusson et al., 1999; Park & Oliver, 2008) in the context of climate literacy. Teachers' professional development for climate education should take into account these particular challenges of an interdisciplinary topic, acknowledging the individual needs of teachers from different disciplinary backgrounds

8.5 Implementation of climate education by means of curricula – linking climate literacy, scientific literacy and ESD

Eventually, the implementation of climate education as it was found by the investigations of curricular materials by study 2 and 3 of this dissertation will be referenced to the existing frameworks of climate education that have been outlined in the theoretical framework of this dissertation. Climate change is being integrated in the investigated curricular materials in a cross-curriculum way according to Eilam (2022) in two ways, concluding from the current state of implementation

reflected by the results from studies 2 and 3: (1) Climate change is being subsumed under sustainability and at the same time (2) the topic is integrated separately into different subjects. Specific aspects of climate change included into the subjects make it easier for teachers to take them from the official curriculum into their intended curriculum (Remillard & Heck, 2014) and therefore, into teaching practice. Overall, the categories from studies 2 and 3 show that the curricula refer to climate education in a broader and shallower way, which leaves much of the specific configuration of climate change teaching up to the teacher. The textbooks, however, show a more differentiated approach. The implementation of climate education is much more specific and exemplary, which allows teachers to take those ideas presented within the textbooks directly into the classroom. Still, a holistic approach to the topic of climate change and especially the connection of humanity and natural systems, is inhibited by the structures of the dispersion across many different subjects (Lehtonen et al., 2018). The complexity of the topic and especially the socio-economic aspects that are elaborated by research, make it difficult to grasp the topic. Hence, the separation that appears throughout an educational biography by the dispersion of the topic hampers the understanding of this complexity (Schreiner et al., 2005). At the same time, the range of focus topics found in curricula and textbooks reflects previous findings (Bhattacharya et al., 2021a; Jorgenson et al., 2019). Yet, recommendations such as personal relevance, discussion about viewpoints, or political decisions (Jorgenson et al., 2019; Kranz et al., 2022; Monroe et al., 2019) are covered by the themes proposed by the experts panel in study 1. In order to transform science education according to Vision II and Vision III of scientific literacy (Roberts, 2010; Sjöström, 2024; Sjöström & Eilks, 2018) and to enable students to meet the challenges of climate change, science education would need to foster students' self-conception as active citizens (Sharma, 2012) and should integrate disciplines as well as values (Hodson, 2003). Thus, the fragmented inclusion of climate change into different subjects does not foster climate literacy, because the single fragments are not connected to each other (Milér & Sládek, 2011). Furthermore, it is not ensured that all necessary aspects are being considered (Eilam et al., 2020). Regarding the discrepancy between the current state of climate education in the investigated curricula and by the experts' suggestions from the Delphi-study, climate literacy, as presented in the relevant concepts including attitudes, justice, societal means and agency (Azevedo & Marques, 2017; Janney et al., 2024; Shwom et al., 2017; USGCRP, 2024), is not being achieved. Yet, the Delphi-study provides a framework that could be used to foster curriculum development and teachers' professional development. To this end, vision I of scientific literacy (Roberts, 2010) and ESD 1 (Vare & Scott, 2007) seem to be implemented in current curricula and teaching practice in the context of climate education. Notions of vision II and ESD 2 might be already underway, perhaps rather implicit and promoted by individual teachers' choices. Yet, climate literacy education should acknowledge vision III of scientific literacy and ESD 3 that embrace citizenship and political aspects, participation and transformation (Guerrero & Sjöström, 2024; Pettig & Ohl, 2023; Sjöström, 2024; Sjöström & Eilks, 2018; Vare, 2014). Here, the results from the Delphi-study add on to the existing frameworks with a practice-oriented approach towards teachers' knowledge and teaching itself.

8.6 Limitations

There are some limitations to the conducted studies across the dissertation, which will be discussed in the following.

Sample selection: Regarding both, the curricula and textbook analysis, the same challenge occurred with respect to the large and convoluted field of study. The federal organisation of education in Germany leads to an enormous number of inconsistent curricula and adherent textbooks from different publishing houses among the different federal states. The selection of an appropriate sample was done to the best of my knowledge, but still proved difficult. Although the sample came from different federal states in the case of the curricula, the sample might not have been absolute objectively representative and it may thus only provide a small insight into the German curricula structure. In terms of the textbooks one publishing house each was selected from both countries in order to allow an insight into a broad range of subjects and school level. Yet, a sample from different publishing houses would have provided a more representative sample.

Analysis tools: Two of the three conducted studies were based on inductively developed analysis tools and one was based on a deductively developed and inductively revised analysis key. Eventually, the three analysis tools were different from each other which made it more difficult to compare the outcomes of the three studies. Yet, the idea of the Delphi study (study 1) was to compile the existing ideas about climate literacy education from the diverse expert panel, which is why it was reasonable to develop the analysis tool accordingly, which is the common procedure of the Delphi-method. As for the curricula, the idea was to investigate which references to climate education are already there assuming that the scope would be rather small. Thus, the analysis should not have been pushed into a particular direction in advance but it should be open for any content that might be there. Finally, the textbook analysis was meant to be based on the pre-existing analysis tools of study 1 and 2, so for the deductive development of the category system, both existing tools were merged and complemented by an elaborated textbook analysis tool from the literature.

Delineation between teachers' professional knowledge and subject matter: The aim of study 1 was to find out what knowledge aspects experts would consider as necessary for teachers in order to be able to foster climate literacy among students. However, the experts' answers from the interrogation rounds revealed that many experts obviously had problems to delimit teachers' knowledge from teaching content. They sometimes also pointed out the fact that the necessity of knowledge depth and scope may depend on teachers' specification (school level, subject area, students' age groups). As a result, the themes from the Delphi-study represent a full and wide knowledge base that, in individual cases, might be too extensive. Yet, this turned out to be of great value for the dissertation because as such, it can be actually used as a knowledge base for teachers' professional development and as well as for the target setting of teaching about climate change.

Insight into teaching practice: As one idea of the dissertation was to integrate teaching practice in addition to the experts' perspectives and institutional requirements, textbooks were considered as an approximation to teaching. Yet, textbooks are an important step on the way from standards to enactment, but they are not fully congruent to practice. The investigation of teachers' lesson planning would have provided a closer insight into classroom teaching. However, the additional inclusion of such an investigation would have exceeded the framework of this dissertation and to skip the textbooks analysis would have left a gap in the rationale of the dissertation.

8.7 Implications

8.7.1 Implications for practice

This dissertation outlined that the status quo of climate education regarding curricular requirements and material does not meet the demands of addressing climate literacy as proposed by experts from climate and education research, teacher educators and teachers. Limitations were found on several levels: First of all, there is the coverage of related themes. As study 1 points out in line with existing climate literacy frameworks, a broad coverage of themes from the physical science basis towards the way of handling climate change in the social discourse would be needed (Shwom et al., 2017; USGCRP, 2009, 2024). Yet, the coverage currently focuses mostly on the physical science basis, as studies 2 and 3 point out. Curricula, as well as textbooks, lack content including climate science, adaptation strategies, the social debate and ways towards transformation and participation. Connected to this, the implementation of ESD as an overarching task (Buddeberg, 2016; KMK, 2024) is visible within the analysed curricula, but at the same time, the implementation of the ESD into practice remains vague. The idea is to implement this overarching task by a whole-school approach transcending the level of content aspects alone, but rather integrating the concept into school practice and everyday life (KMK, 2024). To this end, an interdisciplinary approach is needed, yet, this is difficult to realise. Arrangements between subjects on a curricular level that ensure linkages between topics of different subjects and that lead to a climate literacy curriculum along an individual's school path, would be helpful. Eventually, teachers' professional development is a significant component on the way to the promotion of climate literacy. The barriers for teachers to include climate change in their teaching include a lack of adequate preparation, the interdisciplinary structure of the topic and the limited curricular alignment (Hestness et al., 2014; Sullivan et al., 2014; Wise, 2010). Therefore, teachers of several subjects would need to be equipped with adequate interdisciplinary CK and PCK for climate literacy. Science teachers in particular would need support regarding the social aspects and social subject teachers would need support for science aspects (Beasy et al., 2023). To start with, the results from study 1 propose an outline for the design of professional development (PD) programmes detached from the range of specific subjects. In fact, a qualification programme for preservice teachers of different subjects has already been developed and tested within the projects that this dissertation was written in (see Supplementary Material). Further programmes could be developed with respect to different phases of teachers' PD. Also, different subject groups could profit from specifically tailored PD courses that could be derived from the themes prepared in study 1. Those should possibly take into account the curricular integration and cross-cutting content concepts from further subjects, in order to facilitate a trans-disciplinary approach.

8.7.2 Implications for research

This dissertation investigated the status quo of climate education by contrasting curricular requirements and material against the perspectives of experts from climate and education research, teacher educators and teachers. It became obvious that the status quo falls behind the experts' perspectives on how to foster climate literacy, which are in line with existing climate literacy frameworks (Shwom et al., 2017; USGCRP, 2009, 2024). This holds true as far as the status quo of curricula documents and material is concerned. However, textbooks were considered as an approximation towards the enactment of classroom teaching, due to the significant role they play in

teaching practice (Bruillard, 2022; Oelkers & Reusser, 2008). Thus, they provide only an idea of what might really be made of climate education within the classroom by the individual teacher. Therefore, it would be necessary to investigate the next step: the operational curriculum as enacted in the classroom (Remillard & Heck, 2014). For that purpose, the analysis of lesson plans prepared by in-service teachers would provide an insight into actual classroom practice. Interviews with teachers would provide an insight into the planning of teaching as well as the worldviews and beliefs of teachers regarding climate education. Finally, the observation of lessons and the analysis of protocols or recordings of lessons would be further options to get an insight into the enactment of climate education in teaching practice. With respect to study 1, the themes could be taken as a starting point to develop a test instrument for the investigation of teachers' current state of professional knowledge in the context of climate literacy. Such investigations could be implemented in different stages of teachers PD but also to evaluate PD programmes.

9 Conclusion

Climate change is one of today's main challenges of the Anthropocene. Climate education can be considered as teaching about the phenomenon but also as teaching towards counteracting climate change and in fact towards living with it. Climate education could be incorporated into recent concepts of ESD as well as scientific literacy that are advanced in research. They have in common that they embrace transformative learning that enables learners to become participatory citizens as they relate social and political aspects to science education (Pettig & Ohl, 2023; Sjöström & Eilks, 2018; Vare, 2014). Similar aspects have been highlighted by recent reviews with the scope of climate education, transcending the responsibility of the individual towards a public responsibility (Jorgenson et al., 2019; Kranz et al., 2022).

This dissertation first of all developed a compilation of specific aspects of teachers' professional knowledge (CK and PCK) taking into account the scientific and social aspects of climate education, since teachers are key actors in education. In the same time these aspects provide a comprehensive content coverage for teaching (study 1). Secondly, the dissertation investigated how climate education is currently implemented and how the interdisciplinary nature of climate change is being met especially with the dichotomy of science and social studies. To this end curricular materials were considered in the form of official curricula providing the standards for teaching content (study 2) and in the form of textbooks providing a preliminary view into teaching practice by their role in the curricula enactment (study 3).

Regarding the compilation of knowledge aspects (teachers' CK and PCK) and content coverage by an expert interrogation, a broad view of CK and PCK aspects incorporating science and social aspects was developed. As of the current implementation of climate education, the physical science aspects of climate change (the climate system, the greenhouse effect and its anthropogenic enhancement, impacts of climate change mainly to the natural environment) appear adequately covered by the investigated curricular materials. The curricula provide overarching sections and an open kind of content coverage with a broader approach. The textbooks provide more specific and differentiated content coverage varying among different subjects. Both acknowledge the social aspects by including anthropogenic causes of climate change and mitigation strategies as possible reactions to climate change. They fall short on adaptation strategies as well as on the societal discussion which is mainly limited to climate conferences and miss to take into account the levels of individual and societal action. PCK aspects including students' conceptions and teaching strategies are either crosscutting the content- and CK aspects of climate education or related to the societal aspects of climate education.

The subject transcending nature of the topic and the adherent PCK is a challenge for teachers who are prepared for one or two subjects (Beach, 2023; Beasy et al., 2023; Demant-Poort & Berger, 2021). The interrelation with sustainability allows a twofold opportunity to include climate change within other sustainability topics and to relate climate change to further global challenges. Yet, the interdisciplinary nature of climate education poses challenges on curricula and teachers. As the results from study 2 and 3 indicate, the topic remains fragmented across different subjects and is dispersed across the curricula. The connection between the single fragments is currently missing. These challenges make it necessary that teachers are prepared for climate education by

adequate PD programmes. Climate literacy can currently not be achieved, due to the fragmented dispersal across curricula. In order to meet the objectives of transformative learning, participatory citizenship, the social aspects of climate change would be needed to be much more included into curricula and teaching practice. Therefore, the results of study 1 could be used as a blueprint for teachers' professional development as well as for curricular development, since they represent a comprehensive compilation of content coverage for climate education taking into account climate education specific notions of CK and PCK. With further developed curricular materials and well equipped teachers, climate literacy education could eventually contribute to an informed and participatory society that is enabled to meet the challenges of climate change.

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Supplementary materials

Preservice teacher qualification programme

A qualification programme for preservice teachers in climate education and education for sustainable development was developed as part of the project EnergieweltenPLUS, based on the results from study 1. The qualification programme consists of several modules including CK and PCK aspects that were tested (in an online format), evaluated and revised before being tested (in a face-to-face format) again. The final version of the programme consists of eight modules that can be used for teachers' professional development in online or face-to-face programmes. They are stored at IPN for further use. Supplementary Table 1 provides an overview over the final module-programme.

Supplementary Table 1: Outline of the modules for a professional development programme for (pre-service) teachers:

Modules
Klimawandel – Betroffenheit empfinden und vermitteln <i>Klimabildung im eigenen Unterricht verorten/Betroffenheit bei SuS erzeugen/Umgang mit Bedrohung und Ängsten</i> [Climate Change – to become concerned and how to teach about concern] <i>Climate change in your own classroom/students' concern/how to deal with threats and fear/causes, impacts of climate change and relation to other problems]</i>
Klimawandel im Unterricht – an ein komplexes Thema herangehen und das eigene Wissen einordnen <i>niedrigschwelliger Zugang zu einem komplexen Thema/nicht-Wissen und fachfremdes Wissen</i> [Teaching about climate change – how to approach a complex topic and how to apply your own knowledge] <i>Low-threshold approach to a complex topic/not-knowing and knowledge from other subjects/knowledge in society]</i>
Wissenschaft, Klimawandelleugner, G20? Ein Thema, viele Perspektiven <i>Nachrichten, (soziale) Medien/Politik und Klimawandel/Informationen bewerten/Argumentationsstrategien entwickeln</i> [Science, climate change deniers, Group of 20? One topic, many perspectives] <i>News, social media/politics and climate change/assessing information/developing argumentation strategies]</i>
Umgang mit Fehlvorstellungen und Informationen zum Klimawandel <i>Welche Fehlvorstellungen gibt es und wie geht man damit im Unterricht um?</i> [How to deal with misconceptions and information about climate change] <i>Which misconceptions are there/information and climate science/formation of opinion]</i>
Klimawandel als Querschnittsthema – Anknüpfen an verschiedene Fächer und unterschiedliche Zielgruppen <i>Lehrpläne unterschiedlicher Fächer/kreative Anknüpfungspunkte/Zugang zum Thema für unterschiedliche Altersgruppen und Schulformen</i> [Climate change as cross-cutting issue – Relation to different subjects and different focus groups] <i>Curricula of different subjects/creative focus points/approaches to the topic for different age groups and school types]</i>
Klimabildung und BNE im außerschulischen Lernort – fächerübergreifend vermitteln <i>Besuch in den Saerbecker Energiewelten</i>

Modules
<p><i>[Climate education and sustainability education in an extracurricular learning venue – interdisciplinary teaching</i></p> <p><i>Visit to Saerbecker Energiewelten]</i></p>
<p>Klimabildung – Wo will ich meine Schule hinbringen?</p> <p><i>Whole-School-Approach: Schulleitbilder/RoleModels/eigene Visionen</i></p> <p><i>[Climate education – Where do I want to guide my school?</i></p> <p><i>Whole-School-Approach: School visions/Role models/Own visions]</i></p>
<p>Die Agenda 2030 und Bildung für nachhaltige Entwicklung</p> <p><i>Anknüpfen an verschiedene globale Themen und Herausforderungen</i></p> <p><i>[Agenda 2030 and education for sustainable development</i></p> <p><i>Links to various global topics and challenges]</i></p>

Associated Master theses

Five Master theses have been written in association with the dissertation project. Supplementary Table 2 provides an overview over the Master projects and their relevance for the dissertation.

Supplementary Table 2: Outline of the Master theses associated to the studies of the dissertation:

Title of the Master thesis (Submission)	Objective and relevance for the dissertation
<p>Einstellung von Biologie-Lehrkräften zu Climate Literacy und Hindernisse bei der Behandlung im Unterricht</p> <p><i>Biology teachers' attitudes towards climate literacy and barriers towards teaching</i></p> <p>[02/2022]</p>	<p>Interview-study with in-service teachers about their intention and possible barriers to teach about climate change</p> <p><i>Side issue of study 1</i></p>
<p>Relevanz von Fachwissen und fachdidaktischem Wissen von Biologie-Lehrkräften für die Vermittlung von Climate Literacy – eine vergleichende Analyse normativer Vorgaben und der Ergebnisse einer Befragung von Expertinnen und Experten aus Klimaforschung und Bildung –</p> <p><i>Relevance of CK and PCK of Biology teachers for teaching about climate literacy – a comparison of normative standards and results from an expert interrogation from climate research and education –</i></p> <p>[06/2022]</p>	<p>Comparison of CLEP (USGCRP 2009), NGSS Science and Engineering Practices and KMK Bildungsstandards (Biology) for secondary education and results from the first interrogation round of the Delphi Study.</p> <p><i>Side issue of study 1, preliminary to study 2</i></p>
<p>Eine Fallstudie zur Umsetzung der zielgruppengerechten Klimabildung als Querschnittsaufgabe in der Biologie aus Sicht angehender Lehrkräfte im Rahmen eines Qualifizierungsprogramms</p> <p><i>A case study about the implementation of target group oriented climate education as a cross-cutting task in Biology</i></p>	<p>Development of one teacher education module and interview study about teachers perception of the conducted module</p> <p><i>Contribution to the preservice teachers qualification programme in climate education and ESD (Project EnergieweltenPLUS)</i></p>

Title of the Master thesis (Submission)	Objective and relevance for the dissertation
<i>from preservice-teachers' perspectives during a qualification programme</i> [06/2022]	
Wie können Lehrkräfte Unterricht zur Vermittlung von Climate Literacy gestalten? Validierung einer Befragung von Expertinnen und Experten aus der Perspektive von Schülerinnen und Schülern <i>How could teachers design lessons for the promotion of climate literacy? A validation of an expert interrogation from students' perspectives.</i> [07/2022]	Questionnaire study based on the results from study 1 with students about lessons on climate literacy education <i>Add-on survey to study 1 of students as an expert group</i>
Entwicklung und Pilotierung eines Kategoriensystems zur Klimabildung für die qualitative Inhaltsanalyse von Schulbüchern <i>Development and piloting of a category system about climate education for the qualitative content analysis of textbooks</i> [07/2023]	Development of a category system for textbook analysis of biology textbooks from different publishing houses for climate education <i>Basis for the category system of study 3</i>

Collaboration

Collaboration with Orit Ben Zvi Assaraf (Ben Gurion University of the Negev, Isreal) and Efrat Eilam (Victoria University, Australia)

One appendix chapter of a Green Paper by Efrat Eilam was written in **first-authorship** as a preliminary work of the curricula analysis in study 2 including the analysis of the curricula from all subjects of the federal state of Saarland with a preliminary analysis key:

Leve, A.-K.; Garrecht, C.; Harms, U. (2023): Climate change in German curricula. In: Eilam, E. (2023): Green Paper Prepared for Chief Scientist's office and Pedagogic Secretariate of the Ministry of Education, Israel: Climate Change Education in National Curricula: A Scoping Review of Climate Change Epistemology, Educational Policies and Implementation

Book Chapter

One chapter of the Handbuch Klimabildung was prepared in **co-authorship** related to the implementation of climate education in German curricula. Findings from study 2 were incorporated into the arrangement of the chapter:

Harms, U.; Garrecht, C.; **Leve**, A.-K. (*in Press*): Curriculare Integration der Klimabildung – Herausforderungen der Umsetzung und Lösungsansätze. In: Höttecke, D.; Heinicke, S.; Martens, H.; Rabe, T. & Nehring, A. (*in Press*): Handbuch Klimabildung

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Declaration

I hereby declare that the work presented in this dissertation, apart from the advice given by my supervisor, is my own in both format and content. This is my first dissertation and the work has never been used in any other dissertation attempts. The dissertation complies with the standards for good scientific practice proposed by the German Research Foundation (DFG). As indicated at their respective beginnings, the three research articles presented within this dissertation have been published in, or submitted to scientific journals. No academic degree has been revoked.

Location and date

Anna-Kathryn Leve