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Investigating sustainability education in the science capital teaching approach: Competence development and pillar considerations

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ABSTRACT

This research explores the role of the 12 sustainability competences outlined in the European GreenComp and three sustainability pillars within the practice of the science capital teaching approach. This study considers the dimensions constituting an individual's science capital which shape the approach's pedagogical foundation. We conducted a document study of the science capital teaching approach, comprising six modules, by analyzing 208 documents for the presence of the GreenComp sustainability competences and three sustainability pillars: environment, society, and economy. The data revealed a distribution pattern describing the teaching approach's efficacy, indicating eight competence trends differentiated into three extracted levels and four trends related to the pillars. A subsequent thematic analysis of five semi-structured interviews helped to identify decisive categories defining the derived trends. Overall, the results showed a consistent presence of sustainability competences, with some deviations, and the integration of all pillars, despite an irregular distribution unfavorably affecting the economic perspective.

Keywords: science capital teaching approach, sustainability education, sustainability pillars, sustainability competences

INTRODUCTION

The current global educational system appears to be experiencing a significant shift in pedagogical vision and approaches to promote learners' holistic development, enabling them to cope effectively with emergent real-world issues on multiple levels (Bernstein, 2015; UNESCO, 2023). As a response, sustainability education has received considerable attention from a substantial number of stakeholders, varying from concerned individuals up to higher institutions and even entire international parliaments (Bourn et al., 2016; Žalėnienė & Pereira, 2021). These entities pursue the mutual goal of including sustainability as an overarching theme in educational frameworks and teaching approaches. Trends in present teacher training confirm imminent adoption, yet with immense locational differences concerning the sufficient integration of guidelines to equip educators with the ability to incorporate the concept into their practices (UNESCO, 2018).

Overall, sustainability is continually redefined, with varying interpretations across professionals and scientific fields (Moore et al., 2017). Especially in the educational sector, multiple interchangeable terminologies are used to describe the concept while accentuating similar principles and perspectives (Corres et al., 2020; Scalabrino, 2022; Taylor et al., 2015). The main objective, however, is to encourage proactive and self-reflective behavior through transformative learning experiences that foster the essential qualities and attitudes needed to favorably impact the environment for current and future societies (Sterling, 2010). Bianchi (2020) described transformative learning, analyzing previous literature as a holistic personal shift by comprehending existing and new knowledge and experiences through a critical approach and translating this understanding to the real world, especially within one's immediate environment.

In general, effective sustainability education requires a systematic approach, with the literature centrally pointing to three recurring pillars: environment, society, and economy (OECD, 2018a; Purvis et al., 2019; United Nations, 2002). However, previous research has proven that students and educators struggle to fully identify the interconnections and correlating impacts on a broader scale (McFarlane & Ogazon, 2011; Nguyen et al., 2022; Tiana et al., 2018). Research in the field has raised concerns about a one-sided consideration among educators regarding the interactive system and has described it as a primary challenge in supporting the sustainability concept in the classroom (Glavič, 2020; McFarlane & Ogazon, 2011).

Further studies have specified that encouraging scientific engagement, focusing on trans disciplinarity, and fostering holistic competences associated with the three pillars are crucial for understanding sustainability as a concept (Bernstein, 2015; Trott & Weinberg, 2020; UNESCO, 2017). These aspects seem to play a decisive part in students' ability to perceive sustainability as a system, identify root causes, and generate realistic solutions. Research and guidelines regarding sustainability education have emphasized the importance of acquiring cross-disciplinary understanding and essential competences from an early age (Bianchi, 2020; Wiek et al., 2011). A teacher's ability to promote holistic sustainability education appears equally paramount (Redman et al., 2018; Scalabrino, 2022).

In particular, competences are perceived as significant for acting in favor of sustainability and becoming proficient in this field (Bianchi et al., 2022; Wiek et al., 2011). In this regard, the GreenComp framework defines essential sustainability competences in education from a European perspective (Bianchi et al., 2022). Alongside clear definitions and structured learning objectives, GreenComp highlights the application of transformative learning in alignment with the educational guidelines proposed by the European Commission (Bianchi et al., 2022). This proposal underlined that 'interdisciplinary approaches are needed to help learners understand the inter-connectedness of economic, social and natural systems' (European Commission, 2022, p. 1). However, no explicit pedagogical approaches are outlined in the GreenComp framework that potentially support the development of the specified sustainability competences.

In this respect, Leal Filho et al. (2018) explained that utilizing applicable and novel pedagogy is indispensable to achieving sustainability educational principles. The science capital teaching approach appears to align with this educational vision by encompassing multiple holistic qualities and similar conceptual domains (Archer et al., 2016; Chowdhuri et al., 2021). Fundamentally, the approach incorporates the development of multiple competences concerning learners' scientific understanding, personal values and position, background, and social relationships (DeWitt et al., 2016; Godec et al., 2017). It encourages the natural use of scientific thinking skills within learners' immediate surroundings to investigate and evaluate real-world scenarios (Archer et al., 2015; Godec et al., 2017). The pedagogy of the science capital teaching approach promotes the application of comprehensive capital to understand the phenomena and interrelations profoundly (Nomikou et al., 2017).

Recognizing the sustainability competences and pillars in science education, may allow for a more profound approach to understanding complex systems and interconnected factors within the field.

Sustainability Competences in Education

Considering the broad perspectives on sustainability education, researchers have compared and analyzed key competences that shape the backbone of the comprehensive skillset needed to become proficient in the field and to act accordingly (Rieckmann, 2018). A leading study by Wiek et al. (2011) initially identified five broader competence areas focusing on personal traits and ethical stances deeply connected to a systems viewpoint. Over the years, however, further studies have developed the list by employing different perspectives and subsequently redefining areas and adding contemporary competences (Bianchi, 2020; Scalabrino, 2022; Wiek & Redman, 2021; Wiek et al., 2016). Brundiers et al. (2021), for example, approached the topic from a normative point of view by investigating a more value-driven consciousness of sustainability.

Ultimately, collective research compared the most influential findings to generate the GreenComp framework, which embraces a clearly defined set of sustainability competences to direct educators and learners in a European context (Bianchi et al., 2022). As stated by the authors of the framework, 'a sustainability competence empowers learners to embody sustainability values, and embrace complex systems, in order to take or request action that restores and maintains ecosystem health and enhances justice, generating visions for sustainable futures' (Bianchi et al., 2022, p. 12). Although the number of competences outlined in GreenComp diverges from the eight competences proposed by Wiek and Redman (2021), the framework additionally incorporates complementary qualities highlighted by previous studies.

In the GreenComp framework, a total of 12 sustainability competences are defined:

(a) valuing sustainability,

(b) supporting fairness,

(c) promoting nature,

(d) systems thinking,

(e) critical thinking,

(f) problem framing,

(g) futures literacy,

(h) adaptability,

(i) exploratory thinking,

(j) political agency,

(k) collective action, and

(l) individual initiative (Bianchi et al., 2022, **Table 1**).

Despite different focuses, these sustainability competences act as an interconnected system, similar to the whole concept of sustainability, and possess equal significance (Nolet, 2015; Wiek et al., 2011). In other words, their development correlates with every individual competence, contributing to complementing the others (Bianchi et al., 2022; Brundiers et al., 2021). Altogether, these cover four primary areas of sustainability, concentrating on adopting related values, understanding the concept, and envisioning and working towards a desirable future (Bianchi et al., 2022).

Moreover, Scalabrino (2022) stressed the complexity of individual sustainability competences and emphasized gradual but in-depth development over the course of various educational stages for both educators and students. In this regard, GreenComp utilized the knowledge, skills, and attitudes (KSA) approach to define separate learning goals that collectively comply with the standards set for the competences

Table 1. Core dimensions of sustainability competences in education and the science capital teaching approach with a compressed outline of their educational profile elements

Core dimensions of sustainability competences	Core dimensions of the science capital teaching approach
Valuing sustainability (personal values, differentiation, and alignment)	Science-related attitudes, values, and dispositions (identity, interest, engagement, creativity, criticality, innovative thinking, inquiry, and analytic skills)
Supporting fairness (equality, social justice, and intergenerational learning)	Scientific literacy (knowledge, understanding, awareness, reflectivity, comprehensiveness, and potential)
Promoting nature (awareness, respect, and preservation)	Knowledge about the transferability of science (application, adaptation, connection, and creativity)
Systems thinking (multiplex perspective, comprehensiveness, and interconnections)	Participation in out-of-school science and learning contexts (involvement, local and global social justice, systems thinking, and interconnection)
Critical thinking (research, validity, criticality, and background diversity)	Science media consumption (research, criticality, validity, resource variety, digital literacy, and relevancy)
Problem framing (identification, containment, diagnosis, and appropriate decision-making)	Family science skills, knowledge, and qualifications (intergenerational learning, involvement, and interest)
Futures literacy (alternative and forward thinking)	Knowing people in science-related roles (community, network, interaction, relationships, future outlook, and equality)
Adaptability (transition and challenge management, conscious decision-making, and forward thinking)	Talking about science in everyday life (communication, collaboration, discussion, contribution, and involvement)
Exploratory thinking (multidisciplinary growth, creativity, and experimentation)	
Political agency (systems comprehension, problem identification, and adjustment)	
Collective action (collaboration and transformative thinking)	
Individual initiative (potential, agency, contribution, and local and global involvement)	

Note. The information on the left side of the table was adapted from Bianchi et al. (2022) (CC by 4.0) and that on the right side was retrieved from Godec et al. (2017)

and eventually lead to their holistic acquisition (Bianchi et al., 2022). This approach articulates the educational vision of the framework and supports the practical transfer of sustainability competences in the form of more compact proportions (Bianchi et al., 2022). The KSA appears to be consistent with other research findings which elaborated on the scaffold of multiple components and basic skills to develop sustainability competences (OECD, 2018b; Wals, 2015; Wiek et al., 2011).

Although GreenComp provided a detailed overview of the essential competences and educational goals that emphasize sustainability, specific pedagogies or teaching techniques to achieve them remained undefined. Instead, the framework referred to recommendations set out by the Council of the European Union (Bianchi et al., 2022). These specifically highlighted a need for 'introducing new and innovative forms of teaching and learning' (European Commission, 2018, p. 2) to support the development of competence proficiency. Further recommendations by the institution also underlined the importance of practitioners establishing lifelong learning experiences in the scientific study field as a pivotal component (European Commission, 2018, 2021), which aligns with other research findings (Wiek & Redman, 2021; Žalėnienė & Pereira, 2021).

Studies within the field have simultaneously stressed the application of appropriate pedagogical approaches, which appear to play a vital part in supporting the process of acquiring sustainability competences with respect to their pillars (Glasser & Hirsh, 2016; Lozano et al., 2017). In fact, Lozano et al. (2019) found a correlation between the utilized pedagogy and sustainability competence development. Nevertheless, some studies have outlined weaknesses in current teaching practices concerning the use of effective pedagogy in line with the vision of education for sustainability; examples of such practices include holistic learning experiences or student-centered approaches and a balanced integration of all three sustainability pillars (Glavič, 2020; Lozano et al., 2019; McFarlane & Ogazon, 2011). Therefore, it seems essential to provide educators with effective pedagogies and teaching approaches that address these challenges to advance sustainability education.

The Potential of the Science Capital Teaching Approach to Sustainability Education

In the context of sustainability, it is crucial to point out that numerous concept-related issues and phenomena are scientific in nature or at least require some understanding of scientific connections (Eilks, 2015; Littledyke & Manolas, 2010). In fact, science literacy has frequently been associated with sustainability education to build a solid foundation for acquiring relevant competences and the ability to comprehend interconnections with socio-scientific issues, such as global warming (Quaban, 2018; Trott & Weinberg, 2020). Therefore, it seems plausible to consider holistic pedagogical practices, such as the science capital teaching approach, that potentially advance the mission of sustainability education and aid students' multidisciplinary growth (Borg et al., 2014).

Principally, the science capital teaching approach utilizes the capital and habitus of individuals and portrays them in environments shaped by setting-specific characteristics (Archer et al., 2015). Godec et al. (2017) defined the concept as 'a way of encapsulating all the science-related knowledge, attitudes, experiences and social contacts that an individual may have' (p. 5) and articulated it using numerous competences unique to learners to explore real-world phenomena and develop their understanding with new findings and impressions. Put differently, students learn to apply and transfer holistic traits to investigate their immediate environments and to generate feasible explanations from diverse angles (Godec et al., 2017). This vision partially resembles the broad objective of sustainability education, which accentuates the development of transdisciplinary skills to develop systems thinking and multidimensional awareness (Bernstein, 2015; UNESCO, 2017).

According to Archer et al. (2016), eight dimensions (**Table 1**) are considered significant in utilizing and developing students' science capital and range from internal to external processes and factors. If successfully incorporated, learners deepen their understanding of scientific topics, including cause and effect, and gain the ability to transfer knowledge from different disciplines to construct appropriate links (Archer et al., 2015; Colucci-Gray et al., 2013). As a foundation, educators appraise relevant topics from students' real-world experiences and scaffold the learning environment to promote ownership and active participation (Chowdhuri et al., 2021; Godec et al., 2017).

Furthermore, the pedagogical science capital approach strongly emphasizes intergenerational learning and social collaboration to maximize holistic growth and encourage engagement through scientific discourses (Archer et al., 2016; Chowdhuri et al., 2021). A student's cooperation with their parents, for example, has shown substantial advantages in increasing learning outcomes and subsequently impacting their engagement with science (Archer et al., 2015). Monroe et al. (2019) described networks within communities and with experts as an essential part of modern educational perspectives for discussing controversial sustainability topics. At the same time, studies have underscored a strong interrelation between

(a) the parents' and educators' educational backgrounds and scientific identities and

(b) learners' competence growth across multiple dimensions (King & Nomikou, 2018; Suortti et al., 2023).

These findings resemble the view on the educator's decisive role in sustainability education and their ability to translate the concept successfully into practice (Lozano et al., 2017; Nolet, 2017).

In addition to the social domain, the science capital approach draws on environmental and economic resources to foster learners' comprehensive development, similar to the pillars of sustainability education (Archer, 2015; DeWitt et al., 2016). This approach also aims to provide uniform policies and incorporate the cultural capital of individuals (Godec et al., 2017; King et al., 2015). Thus, it addresses the concerns raised by previous research regarding the coverage of only three pillars in sustainability education (Astara, 2014; Taylor et al., 2016). Essentially, the vision of science capital connects an individual's identity within various real-world domains and diversifies their scientific understanding accordingly.

At the same time, the methodology of science capital has proven beneficial to learners who lack interest in scientific topics (DeWitt et al., 2016; Nomikou et al., 2017). Instead of focusing solely on knowledge, input is contemplated through individuals' unique holistic qualities and diverse experiences in settings beyond the school environment (Edwards et al., 2018; Godec et al., 2017). In sustainability education, the pure emphasis on the knowledge component is perceived as a misconception; instead, studies outline a web of various factors and competences (Bourn et al., 2016; Vesterinen et al., 2016). The science capital teaching approach materializes these aspects through the profound integration of students' habitus and capital in its fundamental structure while enriching their development through different learning scenarios (Archer et al., 2015). In brief, the concept synergizes with various ideas of sustainability education and may catalyze practical implementation and objective achievement.

Concept Synergy Between Sustainability Competence and Science Capital Pedagogy

The educational profile of the science capital teaching approach seems to align well with the GreenComp framework's sustainability competences. Despite dissimilar subject focuses, which explain some of the differentiating educational elements, the concepts show commonalities in their overarching aims across their dimensions (**Table 1**). **Table 1** provides an overview of the key components of each dimension of the sustainability competences and the science capital teaching approach. In brief, it indicates where relationships could potentially form to explain the frequency of occurrence of each sustainability competence within the science capital teaching approach.

In particular, the recognition of personal attributes in a broader social sense to fully comprehend one's position shows significance in both concepts to continuously grow within the focus areas. The element of interpersonal awareness has profound implications in the science capital teaching approach through the incorporation of a manifold context, drawing on intergenerational connections, alternating learning opportunities, and building an understanding of underlying factors (Archer et al., 2015, 2016). Hence, the teaching approach shows similarities to some of the objectives pursued by the sustainability competences, which additionally incorporate concepts such as social justice and equality beyond a scientific context.

Nonetheless, the social focus of the science capital approach lays the foundation for various opportunities to deepen understanding through discourses and collaborative working environments (King & Nomikou, 2018). In this regard, the GreenComp competences strive to foster learners' responsible citizenship perspectives within global society by, for example, promoting global fairness and action for reasonable and strategic change to mitigate sustainability issues (Bianchi et al., 2022). The science capital teaching approach encourages active engagement through intergenerational knowledge transfer and the exchange of experiences to obtain favorable attributes (Chowdhuri et al., 2021).

In addition, sustainability competences aim to foster multidimensional awareness through systems, critical, and explorative thinking, which appear present in diverse branches of the pedagogical model of science capital. Research-based reflections on daily experiences and scientific phenomena, for example, promote competence growth in students, while communication strategies provide grounds for active participation (Chowdhuri et al., 2021; Edwards et al., 2018). The science capital teaching approach in its format appears to show significant potential to foster a comprehensive development of sustainability competences, connecting crucial subject matters of both science and sustainability through various core dimensions (**Table 1**).

Naturally, some divergences concerning the educational profile elements emerge as the foundation of the sustainability competences built on a different subject concept, including various dimensions, compared to the science capital teaching approach. While the sustainability competences focus on a systematic perspective on sustainability matters, encompassing an integral approach towards holistic development by acknowledging complex systems and addressing interlinked concepts (Bianchi et al., 2022). The science capital approach, according to Godec et al. (2017), incorporates three primary dimensions of an individual (capital, habitus, and field), which nurture by 'personalizing and localizing, eliciting, valuing and linking' (p. 17), respectively, to constitute a wholesome and interdisciplinary teaching practice. Even though some characteristics of the sustainability competence dimensions seem not explicitly apparent in the science capital teaching approach, these may emerge from within the overall structure, educational profiles, and teaching modules.

In sustainability education, it seems essential to promote science-related teaching approaches that encourage active citizenship and construct a comprehensive understanding of sustainability matters, including driving factors, divergent impacts on the global society, and potential future implications (Eilks, 2015; Vesterinen et al., 2016). Simultaneously, the foundation of this understanding rests on a comprehensive set of skills, which develops in consideration of an individual's holistic science capital, in order to act responsibly and appropriately within an applicable context (Sterling, 2010; Trott & Weinberg, 2020).

Present Study

This study explored the potential of the science capital teaching approach to support the development of sustainability competences and to address associated dimensions. By investigating the content and guidelines of a research project as an exemplary case focusing on the science capital teaching approach, this research aimed to provide insight into its suitability for promoting sustainability education. Fundamentally, the purpose was to contribute to advancing sustainability education from a European perspective by analyzing the efficacy of a pedagogical approach used to deliver scientific understanding. In addition, the findings potentially provide suggestions for enhancing the efficiency of the present science capital teaching approach. For this reason, the following research questions guided this study:

1. How does the science capital teaching approach reflect the presence of sustainability competences in education?
2. How are the three sustainability education pillars (environment, society, and economy) positioned in the science capital teaching approach?
3. What is the perspective of fourth-grade Finnish teachers on the representation of sustainability education within the implemented science capital teaching approach?

MATERIALS AND METHODS

Context

The research paradigm we used was interpretivism, with the exploratory purpose of investigating the efficacy of the science capital teaching approach within a Finnish context to support sustainability education. To achieve this, a qualitative research study consisting of two interconnected parts employing different methods was conducted to answer the above research questions. The study is on the Finnish Science Capital (FINSCI) research project (https://www.finsci.fi). This research project was created in accordance with the guidelines of the pedagogical model of science capital and the vision to support the subsequent development of individuals within a Finnish context (FINSCI, n.d.).

The science capital teaching approach was successfully implemented in five fourth-grade classrooms in the 2022-2023 academic year in Finnish public primary schools. The current study connected to the qualitative part of the empirical research process, specifically the evaluation and reflection phase, in which the implemented content was analyzed alongside the teachers' positions regarding the practical intervention period.

Materials and Participants

The research project provided an example for the fourth grade, including lesson plans and materials that applied the pedagogy of science capital. This teaching approach was created following the guidelines defined by Godec et al. (2017) and the standards of the Finnish national core curriculum (Finnish National Board of Education, 2016).

Overall, the structure of the science capital teaching interventions comprised six primary themes taught within three to eight lessons per module, with one weekly teaching period lasting 75 minutes or two 45-minute lessons. The implemented modules discussed the following themes:

(1) Medical education,

(2) Thermal energy,

(3) Sounds and light,

(4) Climate change and weather phenomena,

(5) Nordic countries and the Baltics, and

(6) Nature, humans, and sustainability.

In total, the researcher examined 208 content-relevant documents, including Word file pages (81), textbook pages (27), PowerPoint presentation slides (38), web pages (43), and video clips (19). However, the file types and numbers employed varied across themes due to the absence of specific guidelines.

The first author utilized the online services offered by the University of Eastern Finland (MOT Sanakirjat) and Google to translate the content from Finnish to English. Missing files or incomplete lesson instructions were supplemented through subsequent collaboration with the other authors and student teachers involved in the intervention process. Additionally, they helped to review and clarify dubious translation results to ensure sufficient validity and credibility for the research material.

To obtain a more comprehensive understanding of the findings and confirm or reject interpretations, 13 class teachers and one teacher assistant were invited to answer interview questions related to the science capital teaching approach and the pedagogical example employed. The participants were selected through a non-probability convenience sampling strategy, given the limited number of Finnish educators who took part in the fourth-grade science capital teaching interventions. However, all of them completed formal teacher education and are qualified teachers for primary schools. Ultimately, five class teachers agreed: three working for a university teacher training school, one at a municipality school, and one teaching/research assistant who was involved in the teaching interventions.

Every interview participant received a brief explanation of sustainability education based on the theoretical background beforehand, including associated sustainability competences and pillars, to ensure an equal initial conceptual understanding. Overall, the interview manuscript contained 14 open-ended questions to explore the science capital teaching approach and its relationship to sustainability education (see **Appendix A**). One of the authors revised and evaluated the interview protocol beforehand to ensure its applicability and enhance the method's validity through triangulation.

Ultimately, the interviews took place in person and virtually, averaging 35 minutes and resulting in 50 transcription pages. Each interview was audio-recorded and transcribed using an intelligent verbatim approach to erase excessive repetitions and linguistic flaws. McMullin (2021) explained that applying such a transcription strategy helps semantically focused analysis methods by reducing the data set to the relevant information without modifying the quality of the evidence. The statements and parts of the interviews conducted in Finnish were translated using the aforementioned translation tools. Additionally, the transcribed files were proofread by an external researcher native to the Finnish language to increase the validity of the data set and were eventually forwarded to the interview participants to verify their accuracy.

Data Analysis

Document analysis

First, a document study of the science capital teaching approach example aimed, through theory-directed content analysis, to connect the competences outlined in GreenComp and the predominant sustainability pillars to the content of each teaching module. For the foundation, the individual lessons of the modules were broken down into sections according to the teaching approach's instructions to assemble a cohesive outline of the separate parts and generate a precise overview of the teaching sequence. The deductive category application model developed by Mayring (2014) was employed for the entire document study, including a second fundamental coding strategy for the sustainability competences, to determine conceptual frequencies (titled as levels) and investigate the content on a nominal system (titled as trends).

In the initial phase, the researcher used the sustainability pillar implications formulated by Scalabrino (2022) and sustainability competence descriptors defined in the GreenComp (Bianchi et al., 2022, p. 14-15) as a priori categories to interpret the modules' summaries regarding their potential correspondence. Each allocation was justified with a brief statement highlighting the link between the competence or pillar and the lesson overview. In reference to the sustainability competences, it is important to mention that the interpretations focused on how each lesson section potentially supports their development and not on their full achievement.

As explained in the GreenComp framework, the sustainability competences are not meant to be acquired in a single lesson due to their complexity but rather through gaining competence proficiency by slowly obtaining sustainability knowledge, skill, and attitude elements represented as the KSA (Bianchi et al., 2022). For this reason, some competences were marked as applicable more than once in an entire session.

Following this guidance, the researcher initiated the second phase by revising the interpretations through a subsequent explicit analysis strategy that used the KSA statements in compliance with their associated sustainability competences. The individual definitions were directly retrieved from GreenComp (Bianchi et al., 2022, p. 40-51) and served as coding guidelines to strengthen the justification of each allocation. Mayring (2014, 2015) pointed out that explication procedures help to analyze the embedded meanings of sentences and to conclude whether they correspond correctly to the established codes.

Ultimately, the supported sustainability competence in each lesson section strategically received coding compliant with the supporting KSA statements. The category revision process using the statements helped to erase initial misinterpretations, minimize errors, and confirm applicable associations between the sustainability competences and the content of the teaching approach example.

Interview analysis

To confirm or reject the interpretations yielded by the document study, the researcher conducted five qualitative semi-structured interviews. The chosen format left room for follow-up questions to further elaborate on and investigate particularly relevant statements concerning the study's purpose (Taylor et al., 2016). With respect to the research questions, the protocol explored three primary themes with four to five questions for each section:

(1) the importance and role of science capital,

(2) science capital to support sustainability education, and

Table 2. Contingency table of the emergent sustainability competences in the content of the modules within the investigated science capital teaching approach

Teaching module	Medical education	Thermal energy	Sound and light	Climate change and weather phenomena	Nordic countries and the Baltics	Nature, humans, and sustainability	Total
Lessons	4	4	6	5	8	3	30
Sustainability competence							
Valuing sustainability	5	1	5	11	12	2	36
Supporting fairness	1	0	1	8	10	3	23
Promoting nature	3	2	5	14	16	7	47
Systems thinking	6	4	2	11	11	3	37
Critical thinking	6	7	3	13	11	5	45
Problem framing	4	2	3	9	5	3	26
Futures literacy	2	0	1	8	6	6	23
Adaptability	2	1	1	12	3	3	22
Exploratory thinking	5	9	5	12	4	5	40
Political agency	3	0	1	7	3	2	16
Collective action	1	3	1	7	7	3	22
Individual initiative	2	4	4	8	4	3	25
Total	40	33	32	120	92	45	362

(3) reflections on the current science capital teaching approach for the fourth grade, including practice-related experiences.

For the analysis, a deductive thematic approach described the findings from the document study utilizing the teachers' impressions and experiences with the science capital teaching approach. The method was oriented based on the six-phase model developed by Braun and Clarke (2006), which is appropriate for educational research purposes (Peel, 2020). However, the extracted codes were used solely to provide further meaning to the already-defined trends resulting from the first analysis procedure.

Following the initial step of the thematic method, the researcher extracted relevant statements from the data set and assigned codes corresponding to their implications for the findings from the document study. For example, 'we thought about the environment, and we did a project on how the children could have a say about their living environment or how they could make a change' (participant 1) was coded as 'mindset' and assigned to the first competence theme, nature perception. The collected extracts were compared to confirm the mutual trend or tendency of the participants concerning the data-driven strategy involving the sustainability competences and pillars. After reassessing the applicability of the derived data to the themes, the researcher defined their implications with respect to the trends developed from the document analyses in more detail and drew conclusions accordingly. Finally, the insights and data from both qualitative methods were considered to determine whether the science capital teaching approach is suitable as a pedagogical approach to foster the vision of sustainability education.

RESULTS

The Presence of Sustainability Competences in the Science Capital Teaching Approach

The document study found that all sustainability competences appeared to some extent throughout the investigated teaching approach. However, the findings showed a significant stretch between individual competences, with some being substantially more present than others. For instance, promoting nature appeared on 47 occasions compared to political agency, with a mere 16. The contingency table (**Table 2**) indicates a complementary inclination towards competence development throughout the science capital teaching example and its modules.

The thermal energy module highly represented the explorative (9) and critical thinking (7) competences, whereas three other competences (supporting fairness, futures literacy, political agency) were completely absent. In contrast, Nordic countries and the Baltics highlighted supporting fairness (10) to fill gaps in previous coverage, yet barely addressed the skill of explorative thinking (4) despite being dedicated the greatest number of lessons (8). In general, module four, climate change and weather phenomena, appeared the most balanced. It also roughly resembled the overall distribution pattern and included all competences.

Furthermore, the contingency table (**Table 2**) shows that the frequency of occurrences differs between the separate modules, with some promoting sustainability competences substantially more often than others. Again, the most prominent module was climate change and weather phenomena, which addressed competences on 120 occasions despite consisting of only the average number of teaching hours (5). In contrast, the module on sound and light featured sustainability competences on only 32 occasions, with six lessons. A similar deviation could be observed when comparing other modules, such as thermal energy (33), consisting of four lessons, and nature, humans, and sustainability (45), consisting of three.

The competence distribution resulted in three levels distinguishable by the frequency of occurrence and significant gaps between the data sets. Put differently, the sustainability competences that occurred more than 35 times in the science capital teaching approach were assigned to the first level, and competences with frequencies between 20 and 35 were assigned to the second level. Everything below 20 occurrences

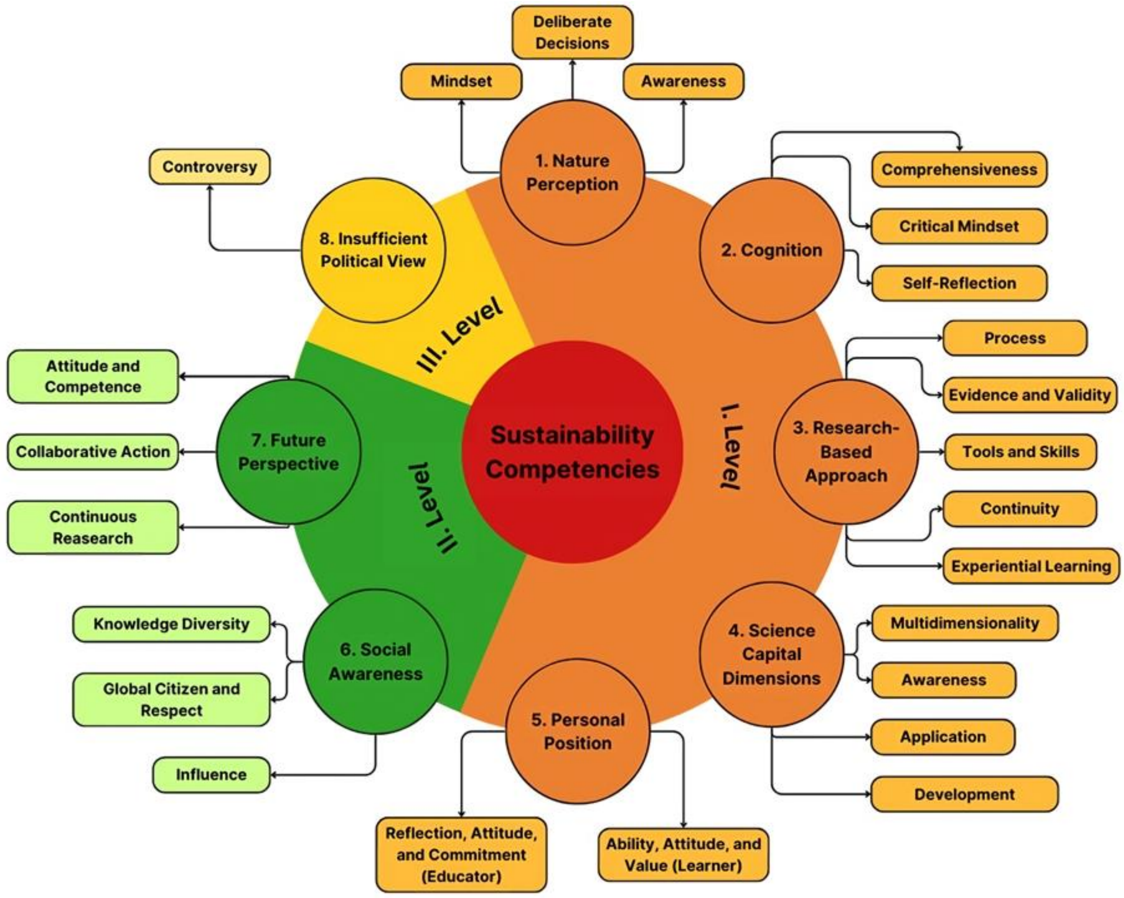

Figure 1. Thematic map of sustainability competences showing eight primary trends (circles) situated in different levels with their associated codes (boxes) (Source: Authors' own elaboration)

was positioned in the third level. Within these levels, sustainability competences were categorized into trends according to their general definition, frequency of occurrence, and representation in the content of the science capital teaching approach. Ultimately, eight trends arose from the data set (**Figure 1**), with each interpretation showing evidence in the interview data to help explain their focus.

First level

Five competences showed the most significant presence and reached 36 to 47 occasions (promoting nature, critical thinking, exploratory thinking, systems thinking, and valuing sustainability). The most frequently recurring competence, promoting nature (47), found connections in all modules, with four showing significant implications, especially in environmentally related modules, such as climate change and weather phenomena (14). Within these modules, the content stretched across topics, from growing a critical awareness of environmental changes and their resulting consequences to acknowledging actions that positively contribute to the local ecosystem. For this reason, nature perception (trend 1) was identified as a major trend, with a particular focus on encouraging environmental awareness, changing students' mindsets, and making deliberate decisions, according to the interview participants. Several statements also pointed towards interactions with nature and growing environmentally favorable attitudes as the foundation for this trend: 'People need to interact with the environment and with the animals [...] we are not just here to make decisions for ourselves on ourselves' (participant 1). Participant 3 stated, 'It works well and even touches on the fact that environmental values and sustainable development are strongly within the scope of its subject studies'.

Aside from how learners perceive nature, the data and interview evidence strongly indicate a connection to their *cognition* (trend 2). In fact, all three thinking-related sustainability competences (critical, explorative, and systems thinking) consecutively formed the second-highest appearance in the teaching approach. These were primarily incorporated to investigate and experiment with different ways of comprehending the driving factors of a phenomenon, such as noise or air pollution, and to subsequently ponder critically about the impacts and interrelationships. Most participants explained this trend through the strong elaboration of the science capital teaching approach on comprehensiveness and developing a critical mindset, including a self-reflective attitude.

> Thinking and learning. How you see the world, how you learn to think and learn to learn. I think it's very much in touch there, and, as I said before, it's not about learning things once, but kind of being critical in the world (participant 5).

The most frequent thinking competence from this set was critical thinking (45), which was identified almost as frequently as promoting nature. In addition, it showed the most balanced distribution of occurrences of each sustainability competence within the modules. Critical thinking is connected to a *research-based approach* (trend 3) to findings and information retrieval procedures in the teaching approach. Learners were frequently encouraged to analyze, evaluate, discuss, compare, reflect, and justify various topics throughout the modules. In the Nordic countries and the Baltics module, for example, instructions included discussing and assessing the current exploitation of resources across this area using collaborative research and evaluating its sustainability over time. The interview evidence suggests that experimental learning and engagement in the entire research process are essential regarding this trend: 'They enjoyed the FINSCI [Finnish Science Capital] lessons a lot, especially the ones where we had hands-on activities and when they could research things' (participant 1).

With respect to the entire research process, several statements underlined the importance of continuity, the application of tools and associated skills, and evidence analysis and validity assessment as substantial factors within the category.

> There must be connections between science capital approach and sustainability education. For example, I think the research is behind both of those. Everything what you, well, what I teach, but what hopefully pupils will be doing in the future will be researched somehow (participant 2).

In contrast, explorative thinking (40) and systems thinking (37) also received significant attention but with alternating integration in each module. Explorative thinking remained somewhat steady in its occurrence, whereas systems thinking was either moderately present–for example, in the Nordic countries and the Baltics (11) module–or barely noticeable–as in the module on sound and light (2). Nevertheless, both skills represented the combined use of the *science capital dimensions* (trend 4), based on the content of the science capital teaching example and competence descriptors, to support holistic growth and scientific comprehension of phenomena. The last module, nature, humans, and accountability addressed the interaction between all three sustainability pillars in terms of biodiversity loss using learners' existing knowledge and experiences, as well as parental and expert insights. At the same time, the lesson instructions aimed to explore realistic initiatives to promote sustainable decisions and actions within a community and how these may be translated into their immediate environment. The interviewees further defined this trend by highlighting awareness, application, development, and the multidimensional aspects of science capital.

> In science capital, we kind of tried to bring science and the [associated] themes to the world of the student. So, they would kind of see their environment and their everyday life through the knowledge. It wouldn't be kind of separate but as a part of their world (participant 5).

Finally, valuing sustainability (36) connected to the *personal position* (trend 5) within the applied teaching approach and incorporated elements such as educational background and interests to create a learning environment. A strong focus was laid on developing an in-depth understanding of one's own attitudes and values and how these may contrast with those of other cultures or contradict sustainability-related values, such as prioritizing environmentally friendly products. This competence was thoroughly considered throughout the modules, except for thermal energy (1) and nature, humans, and sustainability (2). Interestingly, the interview evidence suggests that the learner's and educator's positions appeared equally important. One interviewee explained:

> It helps with the skills that the students and people need in modern and daily lives like the discussions and the social side and the media side, but also it helps teachers to understand how to add those features in their teaching and in their lessons (participant 1).

In other words, the competence's development appeared to depend on both sides, with one difference identified in some of the elements shaping their positions. The data for learners targeted ability, attitude, and value, whereas reflection, commitment, and attitude seemed essential for educators.

Second level

The following set exhibited an equal distribution of competences, with two emergent groups ranging from 22 to 26 occurrences (problem framing, individual initiative, futures literacy, supporting fairness, collective action, and adaptability). The first group comprises individual initiative (25), collective action (22), and supporting fairness (23). Their overall distribution patterns were roughly comparable, aside from minor deviations, except for the latter competence. Supporting fairness received extremely sparse appreciation in the modules of medical education (1), thermal energy (0), and sound and light (1), but it was given more significant consideration in the remaining modules.

However, these sustainability competences reflected the social dimension of the science capital teaching approach according to the content interpretations and hence were assembled as a group. The modules embodied a collective and equal working environment wherein every individual played a determining role in advancing growth in learning. Subsequently, a trend towards *social awareness* (trend 6) was derived from the evidence. Furthermore, the interview data elaborated on knowledge diversity, global citizenship, and respect regarding this position. One interviewee, for example, portrayed the teaching approach as a vehicle to contribute to a mutual understanding within society:

> Science capital is an important role in kind of like closing the gaps between the knowledge of people. So, we are kind of enhancing equality of the knowledge in one way […] I would say that brings people on the same level (participant 5).

The seventh trend highlighted the future perspective on sustainability matters, focusing on encouraging a long-term attitude and consciousness. This second group comprises the competences of problem framing (26), futures literacy (23), and adaptability (22), which shape a comprehensive picture of

Table 3. Contingency table of sustainability pillars supported by the modules of the science capital teaching approach

	Sustainability pillar			Pillars per module
	Society	Economy	Environment	
Overall distribution	36%	22%	42%	
Module	Frequency of pillar references			
Medical education	8	8	4	20
Thermal energy	5	1	5	11
Sound and light	6	1	15	22
Climate change and weather phenomena	15	12	18	45
Nordic countries and the Baltics	20	10	18	48
Nature, humans, and sustainability	4	3	7	14
Pillar total	58	35	67	160

present sustainability challenges, their future implications, and how adaptation strategies for society help to minimize or avoid unfavorable outcomes. These three competences showed an irregular distribution pattern throughout the modules, occurring more or less frequently, depending on the topics. The interview data connected people's attitudes and competences, collaborative action, and continuous research to the trend of future perspectives. Several participants elaborated on the importance of integrating scientific teaching strategies, such as the science capital teaching approach in modern education, starting from primary school.

> I really think that it's something that you should have more in schools starting from first grade [...] because the world pretty much works around science these days, and science capital is an important part of their future. And I want to believe that in the future, the world works more around science and science capital (participant 2).

Third level

The remaining competence, political agency (16), deviated from its overall support and received considerably less attention throughout the modules, either scoring equal to or consistently lower than the other sustainability competences. The only module that provided comparatively moderate reflection was climate change and weather phenomena (7), which claimed almost half the total number of occurrences. The content in this module addressed the role of the government in enforcing policies and laws to mitigate climate change, as well as the responsibilities of individuals and the current economy. In contrast, this competence received little attention from other modules and was entirely absent in thermal energy. For this reason, an *insufficient political view* was defined as the eighth trend in the analysis. However, the interviews provided limited evidence of this interpretation. A single code, controversy in scientific topics, appeared to match this trend and was elaborated on by only one participant. The interviewee pointed towards the sensitivity of these matters and differences in social acceptance.

> It really comes to like what is the school's role kind of in this like controversial things. It's, yeah, it could potentially be hard. I think that's [...] because we are kind of seeing it from a very, like, scientific perspective. That is, yeah, it has, like, the scientific proof behind it. Yeah, but it has the potential to cause issues, I would say (participant 5).

The Position of the Sustainability Pillars in the Science Capital Teaching Approach

The distribution of competences (**Table 3**) indicates that all three pillars–society, economy, and environment–were somehow incorporated into the teaching approach, with most content tending towards the environmental dimension (42%), followed by society (36%) and economy (22%). Regardless of the frequency, the pillars were present in each module, with climate change and weather phenomena (45) and Nordic countries and the Baltics (48) demonstrating the most balanced spread. Both modules also ranked highest for the total number of pillar references, setting themselves significantly apart from others, such as thermal energy (11).

From a broader perspective, the evidence suggests four emergent trends for the sustainability pillars (**Figure 2**) defined by their frequency of occurrence and general representation in the content of the science capital teaching example. The first pillar trend describes an irregular systems approach to pillar integration. The modules addressed the pillars in an unbalanced manner, resulting in an inadequate focus on one or two perspectives yet disconnected from the entire interrelated system. The interview data confirmed this trend by highlighting separate perspectives, especially the absence of the economy, in the participants' statements, in which at least one pillar regarding their teaching focus was missing. In addition, the irregular approach in teaching practices was justified by the time limitation of delivering the respective sustainability content.

> [...] the teachers are the ones who are deciding what's going on in the classrooms, and they might not have time to think about the sustainable side of it. Or the science capital side of it. So, maybe it comes to the time and place and teachers and the leaders of the school (participant 1).

However, the environmental pillar dominated in four out of six modules–with seven references, for example, in nature, human, and sustainability, and as high as 15 references in sound and light. This mostly materialized by constantly incorporating the natural environment into the learning activities through sensory experiences, such as observations and reflection procedures on topic-related knowledge. Therefore, in the teaching approach example and associated topics, *environmental focus* emerged as the leading pillar-related trend revealed by the data. The interview participants justified this by explaining that the guidelines originated from the Finnish national core curriculum, whereas the general

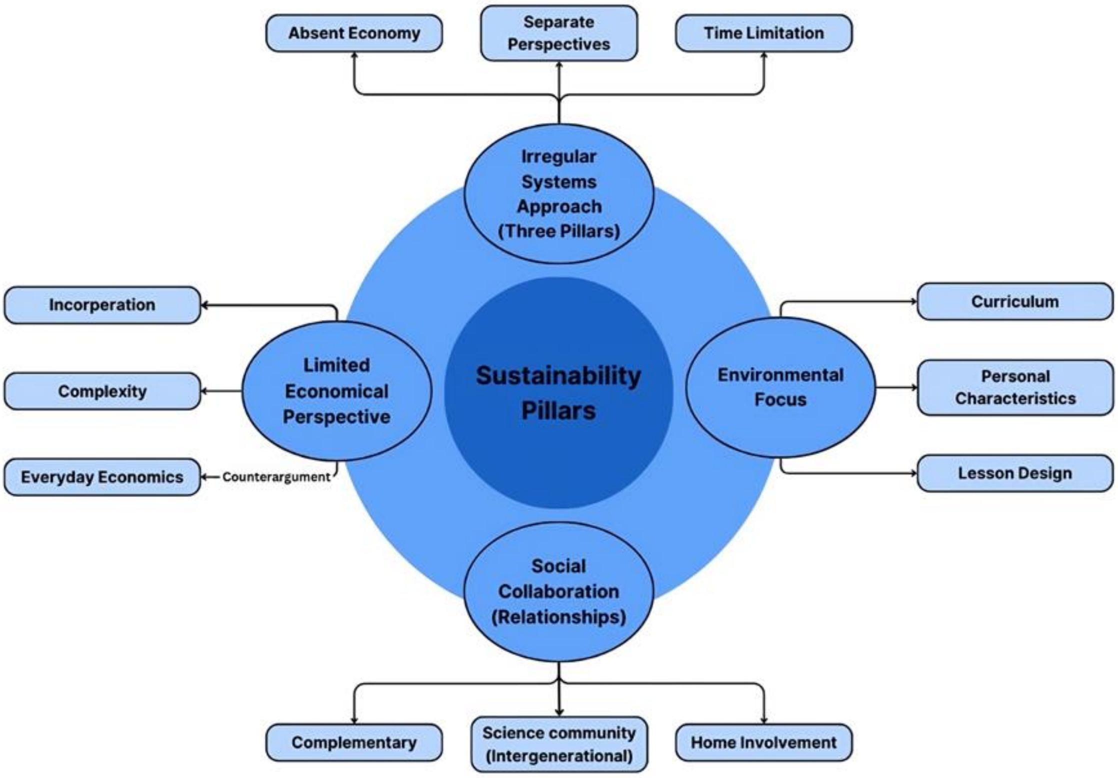

Figure 2. Thematic map of the sustainability pillars showing four associated primary trends (circles) with their associated interview codes (boxes) (Source: Authors' own elaboration)

lesson design was decided by the teacher. However, they elaborated on the importance of personal characteristics, such as engagement, to develop a deeper understanding within this area: 'The units that we had they were all based on our curriculum. So, I don't think we can much change the topics as contents' (participant 1). Participant 2 stated, 'In the future, I can use [expert collaborations] in my own natural lessons. That I have now experienced getting those experts [to give talks], and I noticed that they are more than happy to come talk to the children.'

Nevertheless, the findings for the social pillar implied almost equal support compared to the environmental dimension, with only nine fewer total identified connections. To be precise, the social pillar recorded the highest focus in half of the modules, similar to the leading pillar. In the teaching example, the social dimension often materialized in the expected work formation and communication with external individuals, such as experts and parents. Thus, *social collaboration*, particularly relationship creation, was determined as a trend. The interview data defined this further by highlighting home involvement and the creation of intergenerational science communities as the primary reasons. Additionally, they reflected the subsequent skill and knowledge complementation through effective collaboration: 'One thing is getting the home involved, which we talked about, but also the science communities' (participant 2). Participant 1 stated, 'I think if we want to make sustainable decisions in the future or already right now for a better future, [...] we need to communicate with other people, who have other knowledge'.

In contrast, the frequency of occurrence of the economy pillar was only once, registered similar to the social pillar, but otherwise comparatively underperformed in every single module, with significantly less attention paid to the thermal energy (1) and sound and light modules (1). This finding suggests *limited economic connections* in the content of the science capital teaching approach examined. After further analysis of the interview data, the participants' statements confirmed a lack of integration of this dimension, with some teachers showing unawareness of whether it found support by underscoring the concept's complexity, considering students' age: 'And what was there, the economy? I don't know if there's a connection between the economic side [and the science capital teaching model]' (participant 1). Participant 3 stated, 'It has a lot to do with the student's ability and the current situation, what each person's prerequisites and abilities are at the age of fourth graders.'

In contrast, some statements revealed an underlying connection to everyday economics in the modules, which served as a counterargument to the identified trend. Participant 1, for example, shared classroom experiences concerning thought processes during the lessons despite previously showing unawareness of a connection to the economic dimension: 'You make decisions: Should we build this factory here to make money because it develops products and people buy them? Or should we not make it here because we think about the sustainable side of it?' The interview data showed that thought processes were explored following topic discussions and peer interactions instead of being explicitly incorporated into the lesson content.

DISCUSSION

This study investigated the appearance of various sustainability competences according to the European GreenComp framework and concept-associated pillars (society, economy, and environment) within the science capital teaching approach example. The results suggest that using the science capital teaching approach in line with its pedagogical guidelines and in an appropriate timespan shows substantial potential in addressing sustainability competences. Throughout the investigated example, all 12 competences were present, with the KSA statements highlighting the corresponding components. Supporting the entire set provides an essential foundation for understanding the concept of sustainability, including interrelations and essential constituents (Bianchi et al., 2022; Wiek et al., 2011). However, the distribution of competences across the teaching modules revealed irregularities, with some receiving more coverage than others, especially when considering the six teaching modules separately.

The findings suggest a complementary distribution of the sustainability competences among the teaching modules, in which the absence of competences in some lessons was compensated for in other modules. Bianchi et al. (2022) articulated that sustainability competences must find support at different stages in a learner's educational course. Put differently, this complementary pattern aligns with GreenComp's general vision concerning competence growth. Previous studies have also stressed the necessity for harmony between a student's comprehension ability and a topic's complexity, which ultimately correlates with competence support (Breiting & Mayer, 2015; Scalabrino, 2022). Given the fourth-grade target group and the trends retrieved from the findings, the focus appeared to remain on thinking and social skills, including an emphasis on nature awareness.

Furthermore, the results demonstrated that the holistic perspective of the science capital teaching approach seemed to facilitate the presence of multiple sustainability competences. In particular, competences connected to students' cognition–namely, the habitus according to the approach's pedagogical foundation–received considerable support. This integration ultimately helps scaffold the grounds for multidimensional and deep-learning abilities, such as interdisciplinary skill development and analytical thinking (European Commission, 2021; Holden et al., 2014). Generally, holistic considerations are perceived as essential in sustainability education to move away from purely knowledge-driven pedagogical approaches, which are seen as ineffective in that respect (Bourn et al., 2016; Vesterinen et al., 2016).

Simultaneously, the findings derived trends indicating the ability to transfer skills and knowledge to diverse disciplines and subjects. In combination with the identified focus on a future perspective on the discussed topics, the science capital teaching approach appears to support lifelong learning experiences. In sustainability education, related learning environments and trans disciplinarity are essential to comprehending the entire system (Bianchi, 2020; European Commission, 2018; Wiek et al., 2011).

Further principles emphasized collaboration and interaction within larger science communities and experts as additional fundamental elements to accelerate sustainability education and to address controversial topics, such as climate change (Kidman, 2019; Monroe et al., 2019). The present study's results found support for both aspects, with recurring growth in affiliated competences, such as futures literacy. The teaching approach involved interactions between different generations, as revealed by one of the trends (social collaboration) associated with the sustainability pillars, to broaden the range of experiences and perspectives. Similar to the science capital teaching approach, intergenerational learning is seen as vital to sustainability education to deepen the understanding of pillar interrelations and to comprehend society's role (Bianchi et al., 2022).

In this respect, the findings also underscored the profound incorporation of people's attitudes and viewpoints within the pedagogy of science capital that contributed to addressing competences. These factors have previously been identified as insufficiently supported in sustainability education (Biancardi et al., 2023; Bourn et al., 2016).

For students, this incorporation was achieved through autonomous and research-based learning within personalized educational situations. Providing ownership and responsibility in learning is recognized as necessary in modern teaching practices (Glavič, 2020; Lozano et al., 2019). This perspective of the science capital teaching approach was particularly effective in highlighting the competence of valuing sustainability. At the same time, the evidence pointed towards ability and personal engagement as decisive factors for educators regarding this competence. Overall, sustainability education depends on the successful translation of conceptual underpinnings into practice, actuated by the teacher (Lozano et al., 2019; Redman et al., 2018; Scalabrino, 2022).

Moreover, the complementary relationship between the teaching modules was further defined by analyzing the implications of the distribution of the sustainability pillars. The findings indicated a connection between the science capital dimensions, with a subsequent impact on the coverage of the respective pillars and the frequency of occurrence of related competences. One significant dimension integrated into science capital's pedagogical foundation is society, which promotes learning and experiences (Chowdhuri et al., 2021).

As a result, the science capital teaching example focused extensively on the social pillar and established connections to associated competences, such as collaborative action and supporting fairness, which showed a substantial presence in the content. Kidman (2019) explained that integrating different factors situated in the social pillar helps to advance sustainability education in various respects. As the evidence indicates, the science capital teaching approach appears to positively contribute towards balancing the pillar distribution, specifically through social awareness, inclusion, and relationship creation. This focus may help shift the limited dimensional focus in sustainability education concerning teachers' awareness and practice, as claimed by Nguyen et al. (2022).

In contrast, the science capital approach refers only to the economic pillar in terms of resource availability and the financial means to support learning opportunities (Archer et al., 2015). This explains the limited focus on the economic pillar, with the data demonstrating the lowest distribution throughout the science capital example and the subordinate presence of political agency as an example of an associated competence. In other words, the findings suggest that the science capital teaching approach does not address the concerns outlined by previous research regarding the lack of focus on the economic pillar in sustainability education, especially affecting lower school grades (Biancardi et al., 2023; McFarlane & Ogazon, 2011).

Moreover, the general pillar distribution tended towards the environmental side, with a subsequent effect on a nature-related competence positioning as the most common. This discovery upholds the assumption that most primary science classes focus on environmental topics (Biancardi et al., 2023). Nevertheless, Bourn et al. (2016) argued for the strong dependency of the topics discussed, including their structure, on the guidelines provided by a school's curriculum. In fact, the interview data confirmed this claim and highlighted the Finnish national core curriculum as one of the primary reasons behind the prominent position the environmental pillar claimed.

Regardless, the overall distribution pattern implied a favorable development concerning a one-sided consideration in sustainability education (McFarlane & Ogazon, 2011). The science capital teaching approach showed evidence of all pillars, with an almost equal focus on the social and environmental pillars. According to the interview evidence, the resulting deviation from an overall balanced distribution was explained by an educators' ability to address each sustainability pillar. Žalėnienė and Pereira (2021) stressed that teacher training institutions must integrate adequate sustainability education to establish an awareness of the concept's principles.

CONCLUSION AND IMPLICATIONS

This study's purpose was to provide insight into the efficacy of the science capital teaching approach to support various sustainability competences within a European context while coherently including environment, society, and economy as the three primary pillars. For the most part, the findings demonstrated a consistent presence of each competence, despite noticeable deviations in their levels and frequencies of occurrence. While some competences, such as those related to thinking skills, were relatively evident in each of the six modules, others followed a complementary pattern across the modules. However, the frequency of occurrence of political agency was irregular, being significantly low in all modules except for the unit on climate change and weather phenomena. Hence, the data suggest questionable support for this competence in this science capital teaching example.

Identified as an underlying dimension of political agency, the economic pillar followed a similar trend, showing equally limited recognition in the science capital teaching approach examined. This trend can be justified by reflecting on the pedagogical foundation of the approach, which predominantly focuses on social inclusion, resource availability, diversified settings, and the learner's habitus (Godec et al., 2017). In this respect, the interview data also stressed sensitivity and complexity regarding topics and curriculum guidelines as additional factors contributing to the limited incorporation of these pillars.

Aside from the economy, the environmental and social pillars found almost equal support within the science capital teaching example. Based on the content interpretations and results, the environmental pillar appeared to scaffold the lessons' foundations, whereas broad social collaboration and network creation helped support diverse competences. In summary, the findings suggest that the examined science capital teaching approach has the potential to promote a more even consideration of sustainability pillars and a wide range of associated competences across multiple lessons. Yet, the extent to which the political agency competence and economy pillar were included and the overall balance of all three sustainability pillars appeared moderate in the investigated example. However, it is noteworthy that the selected data analysis method was interpretational and may yield divergent findings when repeated by different experts, despite the application of several triangulation procedures. The small number of interviewees, especially the majority's affiliation with one specific school, limited the potential to formulate a general conclusion on science education.

In addition, the researcher was unable to conclude whether the frequency of competence occurrences was sufficient to build proficiency effectively according to the students' learning stage due to undefined guidelines or measurements in the GreenComp framework. Thus, this study proposes incorporating grade-specific recommendations, including assessment options to measure students' competence growth, based on the defined objectives and KSA statements in GreenComp. In this regard, Redman et al. (2021) examined and formulated tools to adequately assess the development of sustainability competences in practice. Future studies may utilize these tools to measure in more detail the potential of pedagogical methods, such as the science capital teaching approach, to achieve the desired competence growth.

Ultimately, through the investigated science capital teaching example, the findings of this study provide reference points for modifying the current version to achieve a more balanced distribution of sustainability pillars and address less-considered competences more frequently. For instance, the thermal energy module encourages students to identify natural and alternative heat sources together with their parents in the home environment in one lesson. This example may serve as a foundation to explore the industrial purposes (economic pillar) of utilizing natural resources (environmental pillar) to generate thermal energy for production or broader heating purposes with respect to demands (social pillar). At the same time, this exercise provides opportunities to reflect on sustainability matters, such as resource exploitation and soil impoverishment (political agency, futures literacy, problem framing, and valuing sustainability).

Based on the adjustments, replicating this study could help reassess the updated science capital teaching approach and determine whether the pillar distribution became more balanced, and the coverage of different competences increased. However, the interview data also suggest noticeable limitations driven by curriculum guidelines and topic controversy. Previous studies have proposed opening science education and scientific discussions in school environments to controversial sustainability topics and issues (Leal Filho et al., 2018; Monroe et al., 2019). Pedagogical methods, such as the science capital teaching approach, can help provide grounds for effectively tackling these topics through research-based pedagogy.

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Data sharing statement: Data supporting the findings and conclusions are available upon request from the corresponding author.

REFERENCES

Archer, L., Dawson, E., DeWitt, J., Godec, S., King, H., Mau, A., Nomikou, E., & Seakins, A. (2016). Science capital made clear. *King's College London*. https://kclpure.kcl.ac.uk/portal/files/49685107/Science_Capital_Made_Clear.pdf

Archer, L., Dawson, E., DeWitt, J., Seakins, A., & Wong, B. (2015). "Science capital": A conceptual, methodological, and empirical argument for extending Bourdieusian notions of capital beyond the arts. *Journal of Research in Science Teaching, 52*(7), 922-948. https://doi.org/10.1002/tea.21227

Astara, O. H. (2014). Culture as the fourth pillar of sustainable development. *Sustainable Development, Culture, Traditions, 2*, 93-102. https://doi.org/10.26341/issn.2241-4002-2014-2a-1

Bernstein, J. H. (2015). Transdisciplinarity: A review of its origins, development, and current issues. *Journal of Research Practice, 11*(1), 1-20. http://jrp.icaap.org/index.php/jrp/article/view/510/412

Biancardi, A., Colasante, A., & D'Adamo, I. (2023). Sustainable education and youth confidence as pillars of future civil society. *Scientific Reports, 13*(1), Article 955. https://doi.org/10.1038/s41598-023-28143-9

Bianchi, G. (2020). *Sustainability competences: A systematic literature review (JRC123624)*. Publication Office of the European Union. https://doi.org/10.2760/200956

Bianchi, G., Pisiotis, U., & Cabrera, M. (2022). *GreenComp–The European sustainability competence framework (EUR 30955 EN)*. Publications Office of the European Union.

Borg, C., Gericke, N., Höglund, H. O., & Bergman, E. (2014). Subject-and experience-bound differences in teachers' conceptual understanding of sustainable development. *Environmental Education Research, 20*(4), 526-551. https://doi.org/10.1080/13504622.2013.833584

Bourn, D., Hunt, F., Blum, N., & Lawson, H. (2016). Primary education for global learning and sustainability. *Cambridge Primary Review Trust*. https://discovery.ucl.ac.uk/id/eprint//7/Blum__N_Bourn-report-160311-final.pdf

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology, 3*(2), 77-101. https://doi.org/10.1191/1478088706qp063oa

Breiting, S., & Mayer, M. (2015). Quality criteria for ESD schools: Engaging whole schools in education for sustainable development. In R. Jucker, & R. Mathar (Eds.), *Schooling for sustainable development in Europe* (pp. 31-46). Springer. https://doi.org/10.1007/978-3-319-09549-3

Brundiers, K., Barth, M., Cebrián, G., Cohen, M., Diaz, L., Doucette-Remington, S., Dripps, W., Habron, G., Harré, N., Jarchow, M., Losch, K., Michel, J., Mochizuki, Y., Rieckmann, M., Parnell, R., Walker, P., & Zint, M. (2021). Key competencies in sustainability in higher education–toward an agreed-upon reference framework. *Sustainability Science, 16*, 13-29. https://doi.org/10.1007/s11625-020-00838-2

Chowdhuri, M. N., King, H., & Archer, L. (2021). *The primary science capital teaching approach: Teacher handbook*. University College London.

Colucci-Gray, L., Perazzone, A., Dodman, M., & Camino, E. (2013). Science education for sustainability, epistemological reflections and educational practices: From natural sciences to trans-disciplinarity. *Cultural Studies of Science Education, 8*, 127-183. https://doi.org/10.1007/s11422-012-9405-3

Corres, A., Rieckmann, M., Espasa, A., & Ruiz-Mallén, I. (2020). Educator competences in sustainability education: A systematic review of frameworks. *Sustainability, 12*(23), Article 9858. https://doi.org/10.3390/su12239858

DeWitt, J., Archer, L., & Mau, A. (2016). Dimensions of science capital: Exploring its potential for understanding students' science participation. *International Journal of Science Education, 38*(16), 2431-2449. https://doi.org/10.1080/09500693.2016.1248520

Edwards, R., Kirn, S., Hillman, T., Kloetzer, L., Mathieson, K., McDonnell, D., & Phillips, T. (2018). Learning and developing science capital through citizen science. In S. Hecker, M. Haklay, A. Bowser, Z. Makuch, J. Vogel, & A. Bonn (Eds.), *Citizen science: Innovation in open science, society and policy* (pp. 381-390). UCL Press. https://doi.org/10.14324/111.9781787352339

Eilks, I. (2015). Science education and education for sustainable development–justifications, models, practices and perspectives. *EURASIA Journal of Mathematics, Science and Technology Education, 11*(1), 149-158. https://doi.org/10.12973/eurasia.2015.1313a

European Commission. (2018). *Council recommendation of 22 May 2018 on key competences for lifelong learning (2018/C189/01)*. https://eurlex.europa.eu/legalcontent/EN/TXT/PDF/?uri=CELEX:32018H0604(01)&from=EN

European Commission. (2021). *Council resolution on a strategic framework for European cooperation in education and training towards the European education area and beyond (2021-2030) (2021/C66/01)*. https://eurlex.europa.eu/legalcontent/EN/TXT/PDF/?uri=CELEX:32021G0226(01)

European Commission. (2022). *Proposal for a council recommendation on learning for environmental sustainability (2022/0004/NLE)*. https://eurlex.europa.eu/legalcontent/EN/TXT/PDF/?uri=CELEX:52022DC0011

Finnish National Board of Education. (2016). *National core curriculum for basic education 2014*. Opetushallitus.

FINSCI. (n.d.). *FINSCI research project*. https://www.finsci.fi/en

Glasser, H., & Hirsh, J. (2016). Toward the development of robust learning for sustainability core competencies. *Sustainability: The Journal of Record, 9*(3), 121-134. https://doi.org/10.1089/SUS.2016.29054.hg

Glavič, P. (2020). Identifying key issues of education for sustainable development. *Sustainability, 12*(16), Article 6500. https://doi.org/10.3390/su12166500

Godec, S., King, H., & Archer, L. (2017). The science capital teaching approach: Engaging students with science, promoting social justice. *University College London*. https://discovery.ucl.ac.uk/id/eprint/10080166/1/the-science-capital-teaching-approach-pack-for-teachers.pdf

Holden, E., Linnerud, K., & Banister, D. (2014). Sustainable development: Our common future revisited. *Global Environmental Change, 26*, 130-139. https://doi.org/10.1016/j.gloenvcha.2014.04.006

Kidman, G., Chang, C. H., & Wi, A. (2019). Defining education for sustainability (EfS): A theoretical framework. In G. Kidman, C. H. Chang, & A. Wi (Eds.), *Issues in teaching and learning of education for sustainability* (pp. 1-14). Routledge. https://doi.org/10.4324/9780429450433-1

King, H., & Nomikou, E. (2018). Fostering critical teacher agency: The impact of a science capital pedagogical approach. *Pedagogy, Culture & Society, 26*(1), 87-103. https://doi.org/10.1080/14681366.2017.1353539

King, H., Nomikou, E., Archer, L., & Regan, E. (2015). Teachers' understanding and operationalization of 'science capital'. *International Journal of Science Education, 37*(18), 2987-3014. https://doi.org/10.1080/09500693.2015.1119331

Leal Filho, W., Raath, S., Lazzarini, B., Vargas, V. R., de Souza, L., Anholon, R., Quelhas, O. L. G., Haddad, R., Klavins, M., & Orlovic, V. L. (2018). The role of transformation in learning and education for sustainability. *Journal of Cleaner Production, 199*, 286-295. https://doi.org/10.1016/j.jclepro.2018.07.017

Littledyke, M., & Manolas, E. (2010). Ideology, epistemology and pedagogy: Barriers and drivers to education for sustainability in science education. *Journal of Baltic Science Education, 9*(4), 285-301. https://oaji.net/articles/2014/987-1405172734.pdf

Lozano, R., Barreiro-Gen, M., Lozano, F. J., & Sammalisto, K. (2019). Teaching sustainability in European higher education institutions: Assessing the connections between competence and pedagogical approaches. *Sustainability, 11*(6), Article 1602. https://doi.org/10.3390/su11061602

Lozano, R., Merrill, M. Y., Sammalisto, K., Ceulemans, K., & Lozano, F. J. (2017). Connecting competences and pedagogical approaches for sustainable development in higher education: A literature review and framework proposal. *Sustainability, 9*(10), Article 1889. https://doi.org/10.3390/su9101889

Mayring, P. (2014). *Qualitative content analysis: Theoretical foundation, basic procedures and software solution*. Klagenfurt. https://doi.org/10.1007/978-94-017-9181-6_13

Mayring, P. (2015). Qualitative content analysis: Theoretical background and procedures. In A. Bikner-Ahsbahs, C. Knipping, & N. Presmeg (Eds.), *Approaches to qualitative research in mathematics education: Examples of methodology and methods* (pp. 365-380). Springer. https://doi.org/10.1007/978-94-017-9181-6_13

McFarlane, D. A., & Ogazon, A. G. (2011). The challenges of sustainability education. *Journal of Multidisciplinary Research, 3*(3), 81-107.

McMullin, C. (2021). Transcription and qualitative methods: Implications for third sector research. *VOLUNTAS: International Journal of Voluntary and Nonprofit Organizations, 34*, 1-14. https://doi.org/10.1007/s11266-021-00400-3

Monroe, M. C., Plate, R. R., Oxarart, A., Bowers, A., & Chaves, W. A. (2019). Identifying effective climate change education strategies: A systematic review of the research. *Environmental Education Research, 25*(6), 791-812. https://doi.org/10.1080/13504622.2017.1360842

Moore, J. E., Mascarenhas, A., Bain, J., & Straus, S. E. (2017). Developing a comprehensive definition of sustainability. *Implementation Science, 12*(1), 1-8. https://doi.org/10.1186/s13012-017-0637-1

Nguyen, L. H. P., Bui, N. B. T., Nguyen, T. N. C., & Huang, C. F. (2022). An investigation into the perspectives of elementary pre-service teachers on sustainable development. *Sustainability, 14*(16), Article 9943. https://doi.org/10.3390/su14169943

Nolet, V. (2015). *Educating for sustainability: Principles and practices for teachers*. Routledge. https://doi.org/10.4324/9781315867052

Nomikou, E., Archer, L., & King, H. (2017). Building 'science capital' in the classroom. *School Science Review, 98*(365), 118-124. https://discovery.ucl.ac.uk/id/eprint/1560142/

OECD. (2018a). The future of education and skills: Education 2030. *Organisation for Economic Cooperation and Development*. https://www.oecd.org/education/2030/E2030%20Position%20Paper%20(05.04.2018).pdf

OECD. (2018b). Preparing our youth for an inclusive and sustainable world: The OECD PISA global competence framework. *Organisation for Economic Cooperation and Development*. https://www.oecd.org/pisa/Handbook-PISA-2018-Global-Competence.pdf

Peel, K. L. (2020). A beginner's guide to applied educational research using thematic analysis. *Practical Assessment, Research, and Evaluation, 25*(2), 1-15. https://doi.org/10.7275/ryr5-k983

Purvis, B., Mao, Y., & Robinson, D. (2019). Three pillars of sustainability: In search of conceptual origins. *Sustainability Science, 14*(3), 681-695. https://doi.org/10.1007/s11625-018-0627-5

Quaban, A. (2018). Building capacities of educators and trainers. In A. Leicht, J. Heiss, & W. J. Byun (Eds.), *Issues and trends in education for sustainable development* (pp. 133-156). UNESCO Publishing.

Redman, A., Wiek, A., & Barth, M. (2021). Current practice of assessing students' sustainability competencies: A review of tools. *Sustainability Science, 16*, 117-135. https://doi.org/10.1007/s11625-020-00855-1

Redman, E., Wiek, A., & Redman, A. (2018). Continuing professional development in sustainability education for K-12 teachers: Principles, programme, applications, outlook. *Journal of Education for Sustainable Development, 12*(1), 59-80. https://doi.org/10.1177/2455133318777182

Rieckmann, M. (2018). Learning to transform the world: Key competencies in education for sustainable development. In A. Leicht, J. Heiss, & W. J. Byun (Eds.), *Issues and trends in education for sustainable development* (pp. 39-59). UNESCO Publishing. https://unesdoc.unesco.org/ark:/48223/pf0000261445

Scalabrino, C. (2022). *European sustainability competence framework background document (JRC130849)*. Publications Office of the European Union. https://doi.org/10.2760/378627

Sterling, S. (2010). Learning for resilience, or the resilient learner? Towards a necessary reconciliation in a paradigm of sustainable education. *Environmental Education Research, 16*(5-6), 511-528. https://doi.org/10.1080/13504622.2010.505427

Suortti, E., Havu-Nuutinen, S., & Kärkkäinen, S. (2023). Finnish parents' science capital and its association with sociodemographic issues. *International Journal of Science Education, Part B, 14*(3), 257-276. https://doi.org/10.1080/21548455.2023.2263607

Taylor, N., Quinn, F., & Eames, C. (2015). Why do we need to teach education for sustainability at the primary level? In N. Taylor, F. Quinn, & C. Eames (Eds.), *Educating for sustainability in primary schools: Teaching for the future* (pp. 1-11). Sense Publishers. https://doi.org/10.1007/978-94-6300-046-8

Taylor, S. J., Bogdan, R., & DeVault, M. L. (2016). *Introduction to qualitative research methods: A guidebook and resource (4th ed.)*. John Wiley & Sons. https://doi.org/10.1002/9781394260485

Tiana, S. A., Raméntol, S. V., & Morilla, M. F. (2018). Implementing the sustainable development goals at university level. *International Journal of Sustainability in Higher Education, 19*(3), 473-497. https://doi.org/10.1108/IJSHE-05-2017-0069

Trott, C. D., & Weinberg, A. E. (2020). Science education for sustainability: Strengthening children's science engagement through climate change learning and action. *Sustainability, 12*(16), Article 6400. https://doi.org/10.3390/su12166400

UNESCO. (2017). *Education for sustainable development goals: Learning objectives*. United Nations Educational, Scientific and Cultural Organization. https://doi.org/10.54675/CGBA9153

UNESCO. (2018). Progress on education for sustainable development and global citizenship education: Findings of the 6th consultation on the implementation of the 1974 recommendation concerning education for international understanding, co-operation and peace and education relating to human rights and fundamental freedoms (2012-2016) (ED-2018/WS/43). *United Nations Educational, Scientific and Cultural Organization*. https://unesdoc.unesco.org/ark:/48223/pf0000266176

UNESCO. (2023). Transforming education together: The Global Education Coalition in action. *United Nations Educational, Scientific and Cultural Organization*. https://unesdoc.unesco.org/ark:/48223/pf0000384812?mc_cid=f6e8a6918f&mc_eid=UNIQID

United Nations. (2002). Report of the World Summit on Sustainable Development: Johannesburg, South Africa, 26 August-4 September 2002. (A/CONF.199/20). *United Nations*. https://digitallibrary.un.org/record/478154?ln=en

Vesterinen, V. M., Tolppanen, S., & Aksela, M. (2016). Toward citizenship science education: What students do to make the world a better place? *International Journal of Science Education, 38*(1), 30-50. https://doi.org/10.1080/09500693.2015.1125035

Wals, A. E. (2015). Beyond unreasonable doubt. Education and learning for socio-ecological sustainability in the Anthropocene. *Wageningen University*. https://edepot.wur.nl/365312

Wiek, A., & Redman, A. (2021). Competencies for advancing transformations towards sustainability. *Frontiers in Education, 6*. https://doi.org/10.3389/feduc.2021.785163

Wiek, A., Bernstein, M. J., Foley, R. W., Cohen, M., Forrest, N., Kuzdas, C., Kay, B., & Keeler, L. W. (2016). Operationalising competencies in higher education for sustainable development. In M. Barth, G. Michelsen, M. Rieckmann, & I. Thomas (Eds.), *Routledge handbook of higher education for sustainable development* (pp. 241-260). Routledge.

Wiek, A., Withycombe, L., & Redman, C. L. (2011). Key competencies in sustainability: A reference framework for academic program development. *Sustainability Science, 6*, 203-218. https://doi.org/10.1007/s11625-011-0132-6

Žalėnienė, I., & Pereira, P. (2021). Higher education for sustainability: A global perspective. *Geography and Sustainability, 2*(2), 99-106. https://doi.org/10.1016/j.geosus.2021.05.001

APPENDIX A: INTERVIEW QUESTIONS

Theme: Importance and Role of Science Capital

1. Please briefly describe your experience of participating in the FINSCI research intervention.

   Focus areas:

   - Content (e.g., activities, lesson focus, organisation, etc.)
   - Learning outcomes
   - Personal engagement and challenges
   - Student reactions/feedback
2. What is your attitude towards science, and how is it represented in your daily life?
3. How would you describe the students' use of their science capital during the lessons?
4. How relevant do you think is a teacher's own science capital in teaching?
5. How important do you see science capital teaching as part of modern-day education?

(*Note to interviewees: In this context, modern day education means an increased use of technology and real-world related science in all school-subjects taught in an inclusive and wholesome student-centered learning environment.*)

Theme: Science Capital to Support Sustainability Education

1. Do you see any connections between the science capital approach and sustainability education? Please explain your answer.
2. How does the science capital approach contribute to developing the broader competence areas of the Finnish National Core Curriculum (e.g., communication, critical thinking, etc.)?
3. How effective do you think is the science capital approach in supporting the social, economic, and environmental dimensions of sustainable development?
4. How relevant/necessary do you see science capital in sustainability education?

Theme: Reflection on the Current Science Capital Teaching Approach for the Fourth Grade, Including Practice-Related Experiences

1. What worked well, and what challenges did you face during the FINSCI interventions? Why?
2. How did you experience conducting research in the classroom? Please justify your answer.
3. How effective would you describe the taught content (e.g., lessons) in supporting sustainable development? Please justify your answer.
4. If there is something you would change in the content, what would it be and why? (How could it be made more relevant to sustainability education?)
5. What would you suggest to further develop sustainability education and science capital in schools?