frontiers in Education

REVIEW
published: 10 December 2021
doi: 10.3389/feduc.2021.739408

Nature Experiences in Science Education in School: Review Featuring Learning Gains, Investments, and Costs in View of Embodied Cognition

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This review examines the didactic use of nature experiences in science education, in primary and secondary school (7–16 years) globally. From the perspective of embodied cognition the review explores the types of nature experiences used in science teaching. Focus is on returns when we invest in nature-based science learning, such as specific academic achievements in the form of long-term effects on learning and memory and how we maximize those returns. The review also addresses challenges and barriers, such as costs and labour involved when using nature experiences in science teaching. Initially, 3,659 articles were selected, with the initial screening leading to the inclusion of 159 studies. Of these articles, 34 studies forming the corpus in this review investigated the effect of using nature experiences as an intervention. These studies are divided into four themes: content understanding, environmental education, teaching scientific methods, and costs and challenges to teaching science outdoors. Informed by the perspective of embodied cognition, the review addresses the returns in terms of learning and academic achievements, the mode of action of the intervention, the investment, costs in the form of labour, challenges, and gaps in the theoretical underpinning of the field. Based on the review, using nature experiences in science education seems promising regarding increasing content knowledge, insight into science methodologies and pro-environmental behaviours. Interventions exploiting the schoolyard, school gardens, or nearby park areas are particularly promising due to the simultaneous strengthening of local engagement at low costs. However, using nature experiences as an alternative to traditional in-class teaching depends on profound didactic deliberations and preparations, which are difficult for the individual teacher to address single-handedly. The review also reveals an urgent need for research that thoroughly explores the connections between teaching practices and theoretical foundations to consolidate the field. To that end, it is noteworthy that a few studies also reported on prior pilot studies demonstrating the need for testing the entire design before conducting the actual research. Teachers seldom experience the opportunity to preview their teaching strategies before performing in front of their students.

Keywords: nature experience, science education, primary and secondary school education, content knowledge, environmental education (EE), review (article), nature connectedness, embodied cognition

OPEN ACCESS

Edited by:
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Specialty section:
This article was submitted to Educational Psychology, a section of the journal Frontiers in Education

Received: *10 July 2021*
Accepted: *02 November 2021*
Published: *10 December 2021*

Citation:
Schilhab T (2021) Nature Experiences in Science Education in School: Review Featuring Learning Gains, Investments, and Costs in View of Embodied Cognition. Front. Educ. 6:739408. doi: 10.3389/feduc.2021.739408

INTRODUCTION

Science is the term for school subjects that deal with natural phenomena and the scientific exploration of them. Science in school draws on astronomy, physics, chemistry, geology, geography, and biology. Such disciplines share the assumption of a real-world defined by space and time accessible to the senses at large and therefore readily available in direct experiences.

Historically, the so-called scientific revolution in the Renaissance argued for observation and concrete experiences of natural phenomena as a basis for knowledge and theory formation about the world (Chalmers, 2013). Galileo Galilei who is known for his observations of Saturn's rings, and who advocated the modern heliocentric worldview, has been hailed as the promoter of the modern scientific method.

Hence, in the natural sciences, observations of natural phenomena and justifications for scientific finds follow from experiences with the natural world (Føllesdal et al., 2005). Unfortunately, science education in school often happens in built environments like in class or laboratories (Braund and Reiss, 2006; Rios and Brewer, 2014). Why is this the case? Are there no differences between learning from direct experiences in nature and traditional learning, or are the challenges too costly?

The latest advances within the cognitive sciences termed "embodied cognition" emphasise the role of direct experiences in learning and meaning-making, including advanced academic achievements (Barsalou, 2010; Rowlands, 2010); Glenberg, 2015). Also, multimodal activation during learning typically supports improved memories for the particular learning episode.

Accordingly, science learning benefits from natural, authentic environments, affording pupils' direct experiences with scientific content (e.g. Amin et al., 2015). Unfortunately, the embodied cognition inspired use of nature experiences in teaching science in school is currently under-researched, which is a shame since the embodied cognition framework could prove valuable in detailing to what extent learning processes differ between learning in nature and class. A recent review by Ayotte-Beaudet et al. (2017) encompassed 18 articles published between 2000 and 2015 relating to learning science outdoors. The review was primarily concerned with research emphasising proximity and ease of access and therefore concentrated on outdoor science in schools' immediate surroundings, and the results were not related to the embodied cognition approach.

Hence, this review, based on a systematised search strategy that initially involved 3,659 articles, is motivated by the embodied cognition frame and concerned with locating examples on the use of nature experiences in science education in primary and secondary school globally (pupils aged 7–16 years). At the outset, the aim is to scout for the didactic use of nature experiences in science learning to review the extent to which their modes of action harmonise with the percepts of embodied cognition theories. Given the novelty of the embodied cognition approach, it is unlikely that the didactic research on nature experiences in science learning embraces this perspective openly. Hence, the aim is not to search the literature for research adhering to the embodied cognition tradition but to identify research on embodied cognition compatible teaching practices and the benefits and drawbacks in this approach. The embodied cognition compatible teaching practices could contribute to the conceptualisation and theorising of the nature-based learning field (e.g. Schilhab, 2017a; Shapiro and Stolz, 2019). Hence, the research literature is analysed for types of nature experiences in science teaching and thematised and interpreted in terms of the embodied cognition perspective. Focus is on which interventions exist, the modes of actions involved as suggested by the reported results, and the investment, returns and challenges.

Definition of Nature Experiences the Natural Environment and Embodied Cognition Aspects

Following embodied cognition studies (e.g. Barsalou, 2009, 2010; Glenberg, 2015), the understanding of academic material is facilitated when using the surroundings and the body (e.g. Fuchs, 2017); Ionescu and Vasc, 2014) as concrete placeholders for meaning-making; a process known as cognitive offloading (Wilson, 2002). For example, children who interact with concrete entities to simulate the meaning of a text when reading (combing hair when reading "'combs") form deeper and longer-lasting memories of the material (e.g. Kiefer and Trumpp, 2012; Glenberg, 2011).

This method resembles how children acquire language by learning the meaning of concepts from direct experiences (firsthand learning) with the original referent (Klomberg et al., 2022). Unfortunately, most formal learning is not based on direct experiences but on descriptions of experiences (secondhand knowledge), in which pupils interpret descriptions of experiences in the absence of the original referent (e.g. Shapiro and Stoltz, 2019). When using nature experiences to teach science, the teacher uses direct experiences to facilitate meaning-making in pupils. Here, "experience" refers to a combination of all the processes that happen in us in every moment. Barrett (2009) describes the mental "now" as an amalgamation of *1*) the sensory influences such as sounds, colours, temperatures, and events; *2*) our inner sensory experiences such as the experience of hunger, sadness, joy, body position, muscle tension, fatigue, and mood; and *3*) our memories and past experiences.

In every mental now, the number of processes is overwhelming. Imagine for example, how the sound of rain, the smell of soil, the desire to taste, the foot's feeling of the wet sock in the leaky rubber boot, the childhood memory of the blackberry bush in the garden, and the sight of the bee on the flower creates your experience of a blackberry bush (Sheckley and Bell, 2006; Schilhab et al., 2018a). The experience also consists in the social context we participate in when experiencing the bush with parents, friends or teachers and the community's expression of the value of blackberry bushes (Schilhab and Esbensen, 2019).

Hence, a nature experience consists in the many levels from our present and our previous experiences and the natural space and its observable qualities such as biodiversity, types of water bodies, the density of deciduous trees etc. (Schilhab and Esbensen, 2019).

In this review, the nature experiences of interest should typically involve observations of and interactions with concrete natural phenomena, natural processes, and the effects of natural laws, as they occur in natural surroundings such as forests, beaches, lakes, meadows, and parks (Stevenson et al., 2019; Schilhab et al., 2020). However, small animals in a schoolyard, the mixture of cultivated trees and naturally occurring weeds in a distant corner of the school area, the human-made reconstructions of biotopes in a botanical garden, and the life cycle of farm animals are also included. Hence, the term natural environment refers to green or blue surroundings and natural phenomena available to the senses. Of essence, when smaller animals or weeds manage to survive in human-made areas, they do so due to natural processes and life processes. Though a tree is cultivated and pruned in a park or a botanical garden, the short-lived human influence does not remove the tree's character of following the laws of nature. The "natural" appears from the fact that the tree unfolds an autonomous life extensively adapted to the laws of nature. In that perspective, the reason why it grows in a particular location and that it started life in a nursery is unimportant. Central to the concept of nature is the processes that make growth possible in the first place – a mechanism that reaches far beyond any human intervention.

These considerations entail that human-made environments involving natural phenomena such as zoos, public aquariums, green "wedges" in the landscape, farms, and school gardens are included in this review. In a few instances, the location is secondary to the experience of particular natural phenomena such as precipitation, waterfalls, and gravity.

However, the presented review excludes nature experiences inside school buildings, e.g. school laboratories, with terrariums in the classroom, or computer simulations. Teaching not including the school and for other stated purposes than teaching (e.g. play and social events) are also excluded.

METHODS

Study Design and Review Protocol

This review assumes that teachers use nature experiences to facilitate learning about science by firsthand learning to promote meaning-making. Therefore, the review selects studies seeking nature experiences to enrich the learning episode by sustaining relevant associations of embodied and conceptual processes (Kiefer and Trumpp, 2012; Schilhab, 2017a; Glenberg, 2011). Accordingly, "nature experience" is used in this strict sense, which refers to the embodied cognition literature not usually implied by the nature-based learning literature (Jordan and Chawla, 2019). Hence, the initial search in databases was guided by the following three research questions:

1) How are nature experiences used in science teaching in primary and secondary school?
2) Does the scientific literature describe the types of natural phenomena or topics particularly suitable/effective for science teaching in primary and secondary school?
3) What are the challenges of using nature experiences in science teaching?

The primary goal is to provide an overview of existing research. This involves describing the prevailing assumptions, characterising themes, and the theoretical and methodological approaches. The secondary goal is to identify the interventions' modes of actions in terms of embodied cognition, as well as to describe investment, returns and challenges.

The initial search was conducted by librarian and information specialist Anne-Marie Klint Jørgensen using the EPPI reviewer tool developed and curated by the EPPI Centre, at the Institute of Education, University of London, United Kingdom. At first 3,659 articles were selected based on the following search strings: ("Science learning" OR "Learning science" OR "Learning natural science" OR teaching of Science) and ("informal environments" OR "Outside the Classroom" or "outdoor" OR ("Experiential education and (outdoor or nature or natural")). International searches were conducted in the ERIC database, Education database, Australian Education database, British Education database, Science Citation Index, and Dissertation abstracts. The searches were defined by the following boundaries:

- Publications published exclusively in Danish, English, Norwegian, or Swedish.
- Publications published without specific period requirements before August 1, 2020.
- Publications that deal with comparable school systems (i.e. OECD and EU countries).
- Publications addressing primary and secondary school (pupils aged 7–16 years).

The Scandinavian search was performed in: Bibliotek.dk (DK), The Danish research database (DK), Oria (NO), Norart (NO), Christin (NO), Libris (SE), DIVA Portal (SE), and Swepub (SEE). References derived from references were also included. All abstracts meeting the search criteria were screened based on the following inclusion and exclusion criteria:

Inclusion

I) The study deals with one or more of the research questions, and II) Only peer-reviewed academic documents such as theoretical considerations, conference papers, and empirical studies are included.

Exclusion

I) Wrong document type: Editorials, comments, policy documents, biographies, theses, master's and bachelor's theses; II) Wrong age group: The review only concerns teaching at primary and secondary school level; III) Wrong educational area: The study only examines the use of nature experiences in science teaching in primary and secondary school; IV) Wrong language: The study (full text) was not published in Danish, Norwegian, Swedish, or English; V) Wrong focus: The study does not focus on the use of nature experiences in science teaching in primary or secondary school; and VI) Insufficient information: The study does not clarify which educational area, age group, or country/countries the material is based on.

This screening process and nine references derived from references led to 159 studies, of which 150 was uploaded to EPPI by academic assistant Markus Noach Brauner and read in full by the main researcher. Studies were condensed according to the following categories: I) purpose of the research, II) research questions, III) characterisation/definition of the nature experience, IV) research findings, V) approach used (theoretical, methodical, empirical, other), VI) context in which the work is carried out (country, science discipline), VII) contributions to the field, and VIII) quotes of particular relevance.

Research questions and the protocol were drafted by the main researcher and qualified by Anne-Marie Klint Jørgensen. The studies were not divided based on course duration because that information was not always clear–even though some studies suggest this influences the size of the effects (e.g. Braun and Dierkes, 2017). After a second screening by the main researcher, 45 papers were excluded. Therefore, the review involves a total of 114 studies (see **Supplementary Table S1** for bibliographic details and abstracts).

Analysis

The condensing process revealed that studies of developing practices and theoretical studies dominate the literature. An obvious reason is that the field is somewhat new and therefore preoccupied with proof-of-concept studies (*see* Barsalou, 2010).

Thus, the 114 peer-reviewed studies were categorised into theoretical articles, articles with practical instructions for teaching authored by teachers, and 34 *empirical* studies examining the facilitative effects of nature experiences on science learning. Here, nature experiences are interventions with effects measured qualitatively or quantitatively, and therefore of particular relevance to the embodied cognition interpretation. A fourth category, "other," did not fit the former categories. The review analyses the empirical studies, which are presented in **Table 1**. Following the review by Ayotte-Beaudet et al. (2017) **Table 1** provides information about *authors*, *years of publication*, *geographic origin of data*, *school grades*, *type of data*, *research methodologies*, *instruments*, *participants*, *investigated outcomes, and category*.

Guided by the first and second research question: *How are nature experiences used in science teaching in primary and secondary school?* and *Does the scientific literature describe the types of natural phenomena or topics particularly suitable/effective for science teaching in primary and secondary school?* the studies were divided into three major categories: *content understanding*, *environmental education*, and *teaching of scientific methods.* The third research question *What are the challenges of using nature experiences in science teaching?* guides the analysis of the last category which draws on knowledge from all 114 papers, *Investment, costs and challenges when teaching science outdoors*.

RESULTS AND INTERPRETATIONS

Before presenting the categories in more detail, general themes that emerged from the material on the different cross-national interpretations of the field are presented.

General Overview of the Field

A significant part of the international research in the field originates from the United States, where nature experiences in science teaching commonly take place in "science camps" outside school hours in collaboration with recognised institutions such as NASA (e.g. Barker et al., 2014). Here, the science teacher rarely plans and handles the teaching during the school year. Instead, nature-based science teaching are conducted as short-term collaborations with researchers and science centres during excursions (e.g. Cwikla et al., 2009; Nadelson and Jordan, 2012; Allison et al., 2017). Similar characterisations apply to science teaching in Australia and Europe (Ballantyne and Packer, 2009; Aydede-Yalçın, 2016). One example is an annual school trip focusing on the local area in Flanders, Belgium (Boeve-de Pauw et al., 2019).

These teaching initiatives differ from the Scandinavian outdoor school tradition, defined by repeated teaching led by the same science teacher and organised according to the primary school's curricular goals (Mygind, 2007, 2009; Bentsen and Jensen, 2012; Bølling et al., 2018, 2019; see also Christie et al. (2016) for a similar version in Scotland; Ottander et al., 2015 for the outdoor school tradition in the Swedish context; and Jordet, 2003, for a Norwegian perspective). As research on outdoor schooling often focuses on increasing students' motivation, physical and psychological well-being, and feeling of equality (e.g. Dettweiler et al., 2015; Stevenson et al., 2018; Bølling et al., 2019), these studies are included in this review to the extent that they address the use of nature experiences in the strict sense in science teaching.

In the research literature, a relatively large number of environmental education studies, which examine connections with nature, originate from Turkey, where the environmental education of 4th–8th-grade students in more informal pedagogical arenas has enjoyed great national attention since 1999 (Aydede-Yalçın, 2016). This focus has increased interest in environmental education as a research topic in education science and pedagogy in Turkey (Genc et al., 2018; Çobanoğlu and Kumlu, 2020).

The driving force behind using nature experiences in science teaching also varies by country. In Turkey, as noted above, nature experiences are justified by a national commitment. By contrast, in countries such as the United States and England, it is more often the individual teacher who, driven by enthusiasm and ideals for teaching, initiates using nature experiences to teach science (Scott et al., 2011). In such instances, the teaching develops as the result of passionate souls' insights and inspirations rather than institutionalised teaching goals (e.g. Cwikla et al., 2009). Therefore, many external actors are often needed to implement the initiative, including parents, older primary school students, university students, and local residents (e.g. Cole, 2004; Rye et al., 2012).

TABLE 1 | Nature experiences in science education in school – An overview of the empirical research articles.

Authors (year of publication)	Geographic origin	School grades	Research methodologies	Instruments	Participants	Investigated outcomes	Corpus category
Aydede-Yalçın, (2016)	Turkey	Sixth, seventh and eighth grade	Quantitative Qualitative Quasi-experimental pre-/post-test	Surveys Observations	17 pupils	Pupils' perceptions of environmental problems	Scientific process skills Environmental Content knowledge
Boeve-de Pauw et al. (2019)	Belgium	Fifth and sixth grade	Quantitative Pre-/post-test	Surveys	484 pupils 24 teachers	Novelty, preparation and environmental learning outcomes Experienced affective connection	Environmental education Novelty effects
Braun and Dierkes, (2017)	Singapore	First to 11th grade	Quasi-experimental Pre-/post-tests	Questionnaires	601 pupils	Nature connectedness Importance of the duration of intervention	Environmental education
Carrier et al. (2014)	U.S.A.	Fifth grade	Quantitative pre/ post assessments Qualitative	Surveys Interviews Observations	49 Pupils One Principal Two Teachers	Science knowledge Environmental attitudes Outdoor comfort levels	Content knowledge Environmental education
Christie et al. (2016)	Scotland	Eighth to 10th grade	Mixed methods	Observations Questionnaires Focus group interviews	150 pupils 10 teachers	Students' Science learning Teacher perceptions	Critical thinking opportunity Scientific methods
De Dominicis et al. (2017)	Italy	Third to sixth grade	Quasi-experimental Study one between-subjects 2by2research design Study two pre/post research design	Surveys Surveys	497 pupils 248 pupils 92 parents	Promotion of students' pro-environmental attitudes and behaviors	Environmental education
Demirbas, (2017)	Turkey	Seventh grade	Quantitative pre/ post assessments No statistics applied	Word association test	21 pupils	Environmental knowledge	Environmental education
Dhanapal and Lim, (2013)	Malaysia	Third grade	Mixed methods	Quiz tests Questionnaires	24 pupils	Student perceptions of and comparison between the impacts of indoor and outdoor learning	Content knowledge
Dieser and Bogner, (2016)	Germany	Fourth and fifth grade	Quasi experimental pre/post retention assessments	Multiple choice test Questionnaires	289 pupils	Cognitive knowledge achievements	Content knowledge
Djonko-Moore et al. (2018)	U.S.A.	Third to sixth grade	Mixed methods Pre/post narrative inquiry	Tests Focus group interviews Journals Student work samples	34 pupils	Urban children's science knowledge and engagement	Environmental knowledge
Drissner et al. (2014)	Germany	Fifth grade Third and fourth grade	Quantitative Test and control group	Essay Drawings	Study 1 104 pupils Study 2 121 pupils	Knowledge of especially small animals Emotions towards small animals in our own environment	Content knowledge
Fančovičová and Prokop. (2011)	Slovakia	Fifth grade	Quasi-experimental Pre/post retention assessment Control group	Questionnaire	34 pupils	Pupils' attitudes towards and knowledge of plants	Environmental education
Fägerstam and Blom, (2013)	Sweden	Seventh and eighth grade	Mixed methods Quasi-experimental Pre/post retention assessment Control group	Essay-type question about content knowledge Interviews	85 pupils	Cognitive as well as affective effects of outdoor teaching	Content knowledge Environmental education

(Continued on following page)

TABLE 1 | (*Continued*) Nature experiences in science education in school – An overview of the empirical research articles.

Authors (year of publication)	Geographic origin	School grades	Research methodologies	Instruments	Participants	Investigated outcomes	Corpus category
Gencet al. (2018)	Turkey	Seventh grade	Quantitative One group pre-/post-test design Qualitative	Surveys Interviews	30 pupils	Attitudes towards the environment and animals	Environmental education
Ghadiri Khanaposhtani et al. (2018)	U.S.A.	Fifth to eighth grade	Qualitative	Natural inquiry Drawing activities Questionnaires Interview Field-observations	Seven pupils	Cognitive and affective impacts	Content knowledge
Glaab and Heyne, (2020)	Germany	Third grade	Quasi-experimental Pre/post retention assessment Test and control group	Surveys	268 pupils	Pupil's science learning	Content knowledge
Golob, (2011)	Slovenia	Fourth grade	Mixed methods	Surveys Interview	468 pupils 62 teachers	Pupils' attitudes and/or actions towards environmental phenomena	Environmental education
Heras et al. (2020)	Spain	Sixth grade	Qualitative	Focus group interviews	22 pupils	Pupil's perceptions and pro-environmental behavior	Content knowledge Environmental education
Hiller and Kitsantas, (2014)	U.S.A.	Eighth grade	Quasi-experimental Pre-/post-test Test and control group	Surveys	86 pupils	Citizen science project impact on science learning and pupil's career motivation	Content knowledge
Hammarsten et al. (2019)	Sweden	First to third grade	Qualitative	Walk-and-talk interviews	28 pupils	Pupils's perspectives on forest gardens	Environmental education
Jesus-Leibovitz et al. (2017)	Portugal	Second to fourth grade	Mixed methods Pre-/post-test	Surveys Interviews Personal mind maps	164 pupils Nine teachers	Pupils' understanding about biodiversity and scientific procedures	Content knowledge
Kelemen-Finan et al. (2018)	Austria	Third to 12th grade	Quantitative	Surveys	428 pupils	Citizen science project effects on learning outcomes	Environmental education
King and Ginns, (2015)	Australia	Ninth grade	Qualitative	Field notes Audio and video recorded conversations, Interviews Student journals Classroom documents	26 pupils	Environmental education	Scientific methods
Kossack and Bogner, (2012)	Germany	Sixth grade	Quantitative Pre/post retention assessment Test and control group	Surveys	239 pupils	Connectedness with nature	Environmental education
Kärkkäinen et al. (2017)	Finland	Third to sixth grade	Qualitative and quantitative	Annotated drawings	26 pupils	Students' understandings of environmental issues	Environmental education
Lee, (2014)	U.S.A.	Fifth grade	Mixed methods Photography research	Photographs Interviews	27 pupils	Memories *via* photographs during an environmental science field trip experience	Scientific methods
Lehrer and Schauble, (2017)	U.S.A.	First/second, third and sixth grade	Qualitative	Individual Interviews	26 pupils	Pupils' understanding of sampling in science	Scientific methods
Magntorn and Helldén, (2007)	Sweden	Third to fourth grade	Qualitative	Interviews Concept maps	23 pupils	Ecological understanding	Scientific methods
Nadelson and Jordan, (2012)	U.S.A.	Sixth grade	Mixed method Retention test	Surveys Annotated drawings	111 pupils	Pupil's perception of field trip	Content knowledge
Randler et al. (2005)	Germany	Third and fourth grade	Quantitative Pre/post retention assessment Test and control group	Surveys	46 pupils	Pupil's understanding and retention of science learning	Content knowledge

(Continued on following page)

TABLE 1 | (*Continued*) Nature experiences in science education in school – An overview of the empirical research articles.

Authors (year of publication)	Geographic origin	School grades	Research methodologies	Instruments	Participants	Investigated outcomes	Corpus category
Scott and Boyd, (2016)	England	Fifth and sixth grade	Quantitative Pre/post retention assessments Test and control group	Surveys	379 pupils	Pupils' ability to write about ecology	Content knowledge
Smeds et al. (2015)	Finland	Fifth grade	Mixed methods Pre/post retention assessment	Interviews Assessments	106 pupils	Impact of learning environments on science learning	Content knowledge
TaŞ and Gülen, (2019)	Turkey	Seventh grade	Mixed methods Pre/post retention assessment	Multiple choice test Interviews	19 pupils	Students' academic achievement Permanence of information	Content knowledge
Ting and Siew, (2014)	Malaysia	Fifth grade	Quasi-experimental Pre/post retention assessments	Surveys	119 pupils	Pupils' science process skills and scientific curiosity	Scientific methods

The teaching can also be part of a larger initiative led by local foundations that support initiatives encouraging students to gain a greater local knowledge and understanding of nature through teaching based on nature conservation (Bingaman and Eitel, 2010). This partly explains the large proportion of US research literature that arises because researchers have developed and implemented a science course in collaboration with dedicated science teachers.

The purpose of nature experiences in science teaching also differs by country. Typical purposes include to facilitate learning and consolidate content knowledge through multimodal activities, familiarise students with scientific working methods, and support students' affective and emotional processes (Kilty and Burrows, 2020).

In the United States, the use of nature experiences in science may have a clearer political and social justification than that seen in the corresponding Nordic research literature. Here, nature experiences in science education may be used "for establishing culturally relevant experiential learning opportunities to engage underrepresented children in science" (Djonko-Moore et al., 2018, p. 137).

Similar considerations about the importance of social class in connection with nature experiences in science teaching are also found in Turkey (Taş and Gülen, 2019). However, the more politically motivated use of nature experiences in science teaching is beyond the scope of this review. Further, although the use of nature experiences in science teaching varies by country, studies that deal explicitly with physics are scarce (*see* Alberghi et al., 2007; Aspinall, 2016).

Summary of the Corpus

In the empirical studies, nature experiences are typically treated as interventions that can last from half a day to courses extending over several years with multiple experiences (Drissner et al., 2010; Golob, 2011). Such studies tend to measure the effect of the intervention using various qualitative and quantitative methods that test for the learning of scientific content, the attitudes towards nature or nature connectedness, such as multiple choice tests, Likert scale tests, word association tests, personal meaning mapping tests, interviews, observations, student work samples and annotated drawings. In most studies, the performance of the intervention group is compared with that of a similar control group that received instruction on the same content in a more traditional setting (textbook and blackboard instructions, Internet searches, and PowerPoint presentations in the classroom).

According to the literature, students exposed to nature make observations that spontaneously stimulate their wonder – even without encouragement. During longer stays in nature, they gain a greater knowledge of the variation of natural phenomena and can more easily develop expectations and predictions (e.g. Bosse et al., 2009). However, the scientific observation of natural phenomena can still be greatly improved. Some studies therefore describe that the teacher can help sharpen students' observational abilities (e.g. Parrott, 2004; McBride and Brewer, 2010). Although observations constitute an essential aspect of the scientific method, focus is also placed on the formation of hypotheses, ability to reason scientifically, and ability to argue and incorporate background knowledge.

Studies on Content Understanding in the Corpus

A US study of the use of nature experiences in science teaching for a 5th-grade class showed significant differences in students' scientific knowledge and connection to nature after a year (Carrier et al., 2013). The study developed a year long snapshot of one school's science experiences with using the outdoors for science instructions. Here, students' knowledge was measured both before and after the intervention using a 48-question multiple choice test divided into four main areas: ecosystems, weather, force and motion, and landscape forms. The improvements in the content knowledge of experimental students were significant for all four themes compared with 5th-grade students who had only received classroom instruction. Similar cognitive effects were demonstrated in a quasi-experimental study by Fägerstam and Blom (2013). Here, 85 Swedish pupils in four classes (grade 7 and 8) were taught about ecology and diversity of life in several lessons. Half of the pupils were taught outdoors and the other half indoors. 21 pupils were interviewed

5 months later. According to Fägerstam and Blom, pupils taught outdoors would refer differently to the science experience (2013, p. 71): "Five months after the course they could tell a story about themselves doing science, compared with the pupils who were taught indoors who instead talked about what the teacher did." Also, content knowledge between the experimental and the control classes differed to a significant extent. The researchers report (p. 63): "In the outdoor classes the pupils used more course-related words (e.g. plants, animals, leaf, bird, adaption, Darwin, food web, consumers, photosynthesis, carbon dioxide) than in the indoor classes."

The study by Nadelson and Jordan (2012) examines 6th-grade students' memories of nature-related topics 1 month after conducting a day visit to a nearby park with various science activities (presentations, demonstrations, and interactive sessions) organised by a high school teacher and his 3rd-grade students to support students' non-formal science teaching. Using a single-page questionnaire including annotated drawing, the researchers measured the type of activity students most often recalled. Of the activities (tree planting, recycling and waste management, blindfolded walk in a nature area in the park, orienteering, a simulated fox and rabbit game, water quality demonstration, and presentation of animals from a zoo), the orienteering race stood out. The activity was remembered three times more often than the water quality experience, which was remembered the second greatest number of times. The researchers stated that the hands-on element, and situatedness made it particularly easy to remember. Additionally, the orienteering could easily be associated with students' theoretical knowledge of maps and compasses, which anchored the classroom knowledge in concrete experiences. Apparently, the teaching benefitted from pairing the theoretical and embodied approach with the direct experience, including manipulatives such as maps and compasses illuminating the conceptual understanding already introduced in class (Clements, 2000; Hutchins, 2005).

In a Turkish study by TaŞ and Gülen from 2019, 19 pupils from 7th grade were enrolled in an outdoor program consisting of activities to teach them about e.g. the needs of living beings, food chains in nature, and species under threat. The content knowledge was assessed in a pre-/post-/retention test design and pupils were interviewed about their perception of the educational program. Whereas pupils showed significant changes in content knowledge from their pretest to posttest performance, there were no significant difference between posttest and permanence test results assessed 6 weeks after the intervention. However, this study did not involve a comparison group.

The cognitive benefits of teaching content knowledge as part of more coherent experiences were also demonstrated by Randler et al. (2005). In a German study with 3rd- and 4th-grade students and a control group, the researchers investigated how concrete experiences in nature help students understand abstract concepts such as biodiversity. The study focused on five species of amphibians (toads, salamanders, and frogs). The intervention involved a class-based course with the participation of both experimental and control groups. All students were first introduced to the topic through a radio-transmitted story about toads' life cycle. Then, they were divided into groups of four. These groups carried out a series of activities such as using biological identification keys and lifelike plastic models of five toad species. During toads' annual migration to their breeding grounds, the 26 experimental students were guided by college students to count all the toads they encountered. They were then taught about toads' life cycles, habitat requirements, predators, and nature conservation conditions in the classroom. Both before the intervention and 1 week and 6 weeks after, all students were tested on their ability to identify six toads at the genus and species levels using a coloured sheet with the toads. Both the experimental and the control groups showed significant improvements in their ability to identify the toads, but the experimental group performed significantly better than the control group, both 1 week and 6 weeks after the intervention.

The gains of swapping between class-based instructions and experiential hands-on activities outside class compared to the traditional pedagogical approach are reflected in significantly better scores in the follow-up achievements tests. The authors assert that since biodiversity is a rather ill-defined, abstract and complex construct, outdoor ecological education that introduces students to basic knowledge about identification and the life history of a single species is particularly potent in establishing a conceptual understanding of biodiversity.

The didactic framing of nature experiences in a 1-day environmental course was the exact focus of a quasi-experimental German study. 268 pupils in 3rd grade took part in an educational program about the life conditions of wild cats, defined as either teacher centered, guided learning, or free learning. A fourth group attended the wild life park without any instruction and formed the control group. All pupils completed knowledge questionnaires (multiple-choice tests) 1 week before, right after, and 6–8 weeks after the intervention answering questions like "How does the wildcat hunt its prey?" and "which paw print belongs to the wildcat?" In all intervention groups, knowledge scores increased significantly from pre-to post-test and from pre-to retention test compared to the control group. However, pupils who participated in teacher centered or guided learning at work stations showed significantly more content knowledge from pre-to post test. It is noteworthy, that this difference between intervention groups vanished when tested in the retention test months later. The researchers comment that (p. 149–150): ". . . we assume, that the stronger presence of an educator leads to a better cognitive outcome at the out-of-school learning setting, regardless whether the educator guides the whole learning process instructively or just phases . . . Moreover, the short-term learning advance does not persist into the medium term, where no significant differences between all approaches can be discerned. We assume a lack of follow-up instructions within the weeks following our instructional unit to play a role in this outcome."

In a Finnish paper by Kärkkäninen et al. (2017), work at the school before and after the field trip was actually implemented as a major part of the entire intervention. In this study, 26 pupils from 3rd to 6th grade were taught about the complexity of landscape changes in an educational program that spanned both school work, work at a visitor centre in a national park, and a field trip. Before and after the intervention, pupils were asked the question "Which factors shape the landscape" and answered using annotated drawings. There was a significant shift in the amount of depicted non-human induced and human induced landscape changes.

However, compared with the majority of the studies presented, the actual nature experience reported in Kärkkäninen et al. seemed to play a reduced part of the entire intervention. This characterisation also applies to the Malaysian study by Dhanapal and Lim (2013) which compared the impacts of indoor and outdoor learning about a particular science theme in improving students' academic achievements. The study found that indoor and outdoor learning complement each other in improving students' academic performance.

In a Finnish study by Smeds et al. (2015), three learning environments that differed by the degree of authenticity were compared. 106 pupils were to learn about the route of milk and were either taught in the classroom (traditional learning), classroom and the farm (mixing traditional with authentic learning), or farm (authentic learning). The interventions were sequenced into three 2 h sessions including a 15 min break over a period of 14 days. Pupils were tested before, immediately after and 5 months after in assessments addressing five concepts relating to the route of milk. In the post test, classroom + farm group and the farm group scored significantly higher than the pure classroom group but did not differ from each other. Five months after the interventions, both farm groups scored significantly higher than the pure classroom group, while not displaying any internal differences.

Significance of the Intervention Duration

Across studies, the effectiveness of an intervention that aims to build content knowledge seems to some extent to depend on the duration of the educational program. For example, several studies show that short-term courses have fewer desirable effects than longer-term courses. In Turkey, Aydede-Yalçın (2016) examined whether a 5-day course consisting of environmentally oriented fieldwork in two national parks for 6th-to 8th-grade students affected their general science understanding, insights into scientific working methods, and environmental science understanding. Students were tested early on the first and last day of the course. Students showed significant improvements in both their scientific and their environmental knowledge, but not in their understanding of scientific procedures.

Similar results were observed in a study by Braun and Dierkes (2017). Here, students' nature connectedness was measured as a function of an outdoor education program. 194 students participated in a 5-day residential ecology program outdoors, whereas 182 pupils participated in a 1-day program outdoors. The control group of 225 pupils had no outdoor sessions but took ecology lessons using pictures, short films and texts for either 1 or 5 days. All participants were measured for grade of connectedness with nature, 2 weeks before, just after, and 6 weeks after the intervention. Both experimental groups showed a significant rise in their nature connectedness immediately after the intervention, whereas this measure did not change within the control groups. However, when tested 6 weeks after the field trip, participants in the 5-day outdoor learning session demonstrated significantly higher nature connectedness than students who participated for only 1 day.

A Spanish qualitative study reporting about a 1-day nature field trip to a protected area, used semi-structured interviews of 22 pupils from sixth grade conducted 1 month after to investigate the cognitive and emotional outcomes of the intervention (Heras, et al., 2020). Although all informants liked to participate in the field trip reporting positive emotions, the cognitive effects seemed much less convincing. When asked the question "what have you learnt," the factual answers showed inaccuracies and mistakes, and pupils experienced difficulties in remembering them. The researchers assert, that although the pupils claimed to have learned a lot, it was difficult for them to verbalise or clearly identify the learning.

However, a Portuguese study found that 2nd, 3rd, and 4th graders who worked as marine biologists for a day showed a significantly better understanding of the complexity behind biodiversity (Jesus-Leibovitz et al., 2017). In a so-called "personal meaning map" centred on biodiversity topics, intervention students distinguished far more relevant relationships both between types of living organisms (plants, mammals, and birds) and between specific animal species. The same effect was seen in personal meaning maps focusing on scientific work. After the intervention, the quality of students' personal meaning maps increased considerably, demonstrating more relevant concepts for both people and places (e.g. fieldwork) as well as more concrete examples of scientific procedures (e.g. experiments, exploration, discoveries, observations, learning, study, thinking, and discussion).

Durability of Cognitive Effects. When the primary goal of teaching is to enhance cognitive effects, the durability of the effects becomes particularly interesting. Even short interventions can be efficacious. In the German study by Dieser and Bogner (2016), who examine the cognitive effect of a week-long course in a nature park, 298 4th- and 5th-grade students were tested with a multiple-choice questionnaire before, immediately after, and 4–6 weeks after the intervention. The intervention involved hands-on activities such as a barefoot experience of different types of soil, tracing of tree species, interaction with different types of domestic animals, and ecologically oriented tasks in wetland, forest, and meadow areas such as examining a squirrel's storage strategies and the function of national parks. By comparison, 60 students who instead received classroom instruction were used as control. Both the short-term and long-term test showed that intervention students had significantly more comprehensive content knowledge about the experience-based topics and better memory about it than the control group. Also, Fančovičová and Prokop (2011) reported significant retention of knowledge compared to the control group after 3 months.

A Slovenian mixed method study on what 4th grade pupils remember about school induced nature experiences in earlier periods of their school education, shows that more lasting experiences of observing life in water was significantly linked to better knowledge of smaller organisms like insect larvae, tadpoles, pond skaters, and algae (Golob, 2011). See also Drissner et al. (2014) referring to significant long-term effects (up to 5 years) after an intervention lasting half a day.

Use of Nature Experiences to Support Environmental Education

In a Turkish study (Demirbas, 2017), 21 7th-grade students participated in field studies focusing on environmental education. Before and after the five weekends of fieldwork, students completed a word association test on key environmental education concepts such as air, soil, and water pollution, biological diversity, urbanisation, and recycling. Students were given 1 min to associate new concepts with each word. The number of relevant association concepts increased from 82 before to 1,230 after the intervention. Most increase was seen in the key concept of biodiversity (by 63 words), while the number of associations to air pollution *only* increased by 20 words. However, this study did not apply statistics. Hence, nominal increases of associated words are provided.

Also, studies measuring changes in nature-connectedness and attitudes towards nature as a result of direct experiences can be identified. In a study by Genc et al. (2018) 30 7th grade students were participating in an educational program dealing with the natural environment such as water pollution, natural habitats, recycling and biodiversity in a natural setting over a period af 11 days. The students' attitudes towards nature were tested in at pre/posttest design measuring e.g. attitudes towards living organism and the environment. According to the researchers (p. 333): "At the end of the program, it was revealed that, for the 7th grade students, attitudes towards the environment, and living organisms and the affective tendency were shown to be more highly developed than before the program."

An Italian study by De Dominicis et al. (2017) tested 3rd to 6th grade students proenvironmental attitudes and behaviours after participating in a program that promotes informal activities in natural environments. The research paper reports on two separate quasi-experimental studies involving respectively 419 and 248 pupils. One parameter of interest to the first study was the impact of place of residence. Apparently, effects were larger for children living in large urban context than for children living in smaller cities. The second study was a longitudinal pre-post quasi-experimental aiming at assessing the long-term effects of participating in the environmental program. The study showed that pupils' general pro-environmental attitudes and self-reported behaviours were significantly affected by the intervention.

In a German quantitative study by Kossack and Bogner (2012) 123 6th grade students participated in a 1-day module involving both self-directed indoor and outdoor learning in nearby woods. Hence, the learning swapped between group presentations of seasonal rhythms indoor and "touching trees" outdoor focussing on the individual relationship with forests. Students (116 pupils) and a control group were tested for nature connectedness 2 weeks before, immediately after and 7 weeks after projects participation. The researchers concluded that the 1-day module influenced the significant shifts in connectedness with nature found in the intervention classes, which were not found in the control group.

Citizen Science Projects

Citizen science projects are projects in which students work with researchers to solve real-world problems by, for example, reporting the occurrence of certain species/pollution and solving research tasks locally. Citizen science projects often rely on large amounts of data (Almeida et al., 2006; Rogers and Steele, 2014), which demands that citizens such as science students contribute to the research. Such projects typically strengthen students' local knowledge and connection to their local area (Parrott, 2004; Bingaman and Eitel, 2010). At the same time, it is assumed that students gain self-efficacy and control, which is considered to be essential to enhance their environmental awareness.

This was demonstrated in an Austrian citizen science project (Keleman-Finan et al., 2018) in which 428 students and 21 teachers from 16 primary schools participated in two tasks : *1*) identifying eight key butterfly species and eight other selected butterfly species and *2*) identifying eight key bird species and 12 other selected bird species. Students were tested using a questionnaire that revealed their level of knowledge about biodiversity, assessment of their ability to identify species, and motivation to both learn about animals and contribute to science as well as their self-reporting on helping species in the garden. After the intervention, 309 out of 428 participating students responded to the questionnaire, with the highest number of responses to motivation to learn about animals, while the response level for biodiversity was the lowest. The researchers found that the favourite research activities were the identification of birds and butterflies. The results also showed that the youngest students scored highest on motivation to learn more and helping species in the garden as well as on their assessment of their ability to identify species.

An improved self-assessment of mastery was also observed in a US citizen science study in which two classes of 8th graders were recruited to register daggertails at the beach (Hiller and Kitsantas, 2014). Students were trained, as is often standard for citizen science projects, in data collection. The intervention also provided lectures on the life cycle, form, and function of daggertails as well as their biomedical significance. Students took part in a laboratory activity to test a condensate based on the copper-rich blood of daggertails, which can be used to detect bacteria. After the laboratory visit, they visited a nature centre to learn to handle small daggertails. To facilitate data collection, students were taught how to measure daggertails, assess their age based on colour, and determine their gender. They worked in teams of two or three and were initially monitored by researchers to answer questions and assuage any uncertainty about the task. As the day progressed, students worked more independently and collaborated to calibrate their abilities. Pre- and post-intervention tests revealed their level of knowledge and self-assessment of abilities to perform the task. A control group of students who learned about daggertails in class using the same PowerPoint show as the intervention group was similarly tested. The self-assessment test for skills in science consisted of a questionnaire based on a Likert scale from "strongly agree" to "strongly disagree" and the test of content knowledge was generated from the PowerPoint presentation previously presented to both groups. The results on the knowledge increase and self-assessment of abilities showed a significant difference in favour of the intervention group.

In citizen science projects, the teachers typically rely on the expertise and labour of the involved researchers. In such cases, the workload related directly to the teaching might be less demanding than in traditional school settings since any training of data collection practices with students is the responsibility of the researchers. However, implementing citizen science projects into the science education in school may challenge teachers' balancing of curricular demands in terms of the time spent on the project and its subsequent relevance to the national testing scheme in science (e.g. Carrier et al., 2013).

Garden-Based Science Learning

According to the research literature, when students are asked about ecosystems often plants are underestimated (Carr, 2010) even though plant diversity plays a decisive role in the health of ecosystems both through productivity and through nutrient cycles (Fančovičová and Prokop, 2011). Such "plant blindness" includes the inability to notice plants in the environment, inability to recognise the importance of plants for the environment and human affairs, inability to recognise plants' aesthetic and unique biological properties, and tendency to underestimate plants in favour of animals (Strgar, 2007).

In a school garden project in Slovakia, Fančovičová and Prokop (2011) investigated how teaching a garden course affected 5th-grade students' attitudes towards plant knowledge. They also explored whether student access to their own garden affected learning. Among the topics taught, students learned about organisms such as animals, plants, and fungi in ecosystems such as meadows, forest and water areas, and cultivated fields. The 34 students were divided into an intervention group and a control group. Together with experts, the intervention group planted trees on the school grounds while learning about the life cycle of the forest and amenity value of trees. In addition, they were taught botany on a meadow next to the school. Students worked together in groups of four or five on different tasks such as botanical research methods, the collection of plants, and plant determination using keys as well as discussed plant names and roles in specific ecosystems. The tree planting and botany course lasted 6 months, corresponding to six lessons. The control group did not participate in the tree planting and meadow teaching, but instead received conventional biology teaching in class. However, they were given access to the meadow in which they practiced sports for a period corresponding to the intervention group's stay on site.

Two days before, 3 days after, and 3 months after the intervention, students' knowledge of and attitude towards plants were tested using a questionnaire. In the attitude test, they had to answer 45 statements such as "plants in the city are a problem because they cause allergies," "plants are very important for medical knowledge" and "I enjoy going to plant exhibitions." In the knowledge test, students were asked 13 in-depth questions about the meadow ecosystem such as "what is not an abiotic factor in the ecosystem: temperature, human activity, wind direction?" and "draw all the components of the meadow ecosystem." The responses correlated with age, gender, grades in biology, and access to one's own garden. Significant differences in both the attitude and the knowledge tests were found between the intervention and control groups but there was no correlation with gender or access to one's own garden. The researchers concluded that students' awareness of the importance of plants can increase through carefully planned courses with plants as a focus.

Also an understanding of the insects and smaller mammals found in students' immediate environment is overlooked (Hagevik, 2003; Dominguez et al., 2013; Spring and Harr, 2014). The media generally focus on birds and exotic vertebrates, while small animals, if mentioned at all, often arouse disgust. According to Drissner et al. (2014), this creates major problems for the understanding of environmental problems. The researchers investigated a "green classroom" project in a German botanical garden in which teaching and hands-on experiences sought to sharpen students' attention to invertebrates and insects in their immediate environment. In the botanical garden, the animals live in their natural habitats such as meadows, forests, and lakes, and students from visiting schools received direct answers to their questions while observing the animals. Students were also allowed to handle and physically examine the animals under controlled conditions to learn to treat them with caution and show them respect. The intervention built on the assumption that students only learn to care for insects and smaller mammals if they build concrete relationships that provide emotional attachment to these organisms.

The researchers' study involved 121 3rd- and 4th-grade students divided into an intervention group and a control group. Intervention students visited the botanical garden for 1 day 9 months before, while control students did not (Drissner et al., 2010). Back at school, both groups of students were asked to draw an ordinary forest with the typical plants and animals they knew. The researchers then evaluated the drawings according to the number of *1*) small animals (insects and invertebrates) such as butterflies, beetles, spiders, snails, and millipedes, *2*) large animals (vertebrates and mammals) such as birds, foxes, hedgehogs, and deer, and *3*) different kinds of species (animals only). The intervention group drew twice as many small animals and indicated more different species than the control group. The girls in the intervention group drew almost twice as many invertebrates as the boys as well as more distinct species than the boys. According to the researchers, time spent on drawing could have been the cause of the gender difference observed.

The demonstration of the effect of teaching 9 months after an intervention that lasted half a day is in line with the same researchers' study of 5th–9th-grade students who showed significantly different attitudes and emotions towards small animals several years after the intervention (Drissner et al., 2010). The results of that study are supported by a qualitative forest garden intervention in Sweden in which students highlighted that concrete experience had changed their attitudes towards, for example, spiders and dragonflies (Hammarsten et al., 2019; *see* also; Short, 2013).

Use of Nature Experiences to Support Teaching Scientific Methods

Empirical Studies on Scientific Methods in the Corpus

Spontaneous stimulation of scientific methods was investigated in a Malaysian study of 5th-grade students. Here, the intervention group was taught using an "eco-hunting" task over four to 6 weeks, while the control group received comparable teaching in the classroom using textbooks, smartboards, and presentations (Ting and Siew, 2014). The experimental group practiced their observational skills when asked to look for animals and plants in the schoolyard. They were also introduced to performing prediction and derivation procedures when dealing with themes such as "animals with and without parental care" and "plant dispersal strategies." Before and after the intervention, the experimental and control groups conducted a multiple-choice test consisting of 20 questions on scientific research methods such as observation, classification, the ability to derive, predict, and communicate, and control variables. In subsequent lessons, teachers focused on food chains and the importance of the relationship between the number of primary producers and consumers. Both groups showed significant improvements in their ability to apply scientific methods, but the improvements of the intervention group were significantly greater than those of the control group. Within the intervention group, the main improvement centred on classification and observation skills. The researchers explained that the outdoor environment improves students' senses of hearing, sight, feeling, and taste considerably.

A Scottish qualitative outdoor school study focusing on the subjects of geography and mathematics highlights how nature experiences support students' critical thinking (Christie et al., 2016). The researchers followed 150 11–14-year-old students and 10 teachers for a year to understand their learning processes through the use of nature experiences in science teaching. The researchers observed that students, as a result of their observations of and experience and interaction with the outdoor environment as well as the discussions that the experiences initiated, asked themselves questions such as "why do some rivers freeze in winter when others do not?" This questioning helped students interpret intentions, understand context, recognise hidden values and emotions, clarify motives, detect bias, and conclude concisely and suitably.

Learning in a natural environment can also stimulate conversations (Kirsh, 2010), as demonstrated by an Australian qualitative study in which a class of 9th graders received science lessons at the local stream over an 11-week period (King and Ginns, 2015). The teaching centred on measuring and comparing water quality, flora, fauna, and pollution in three places. Students were divided into groups of five that rotated around different sub-activities. The researchers observed so-called "spontaneous teaching episodes" in which the teacher seized the opportunity for deeper conversations on an environmental topic with students. These were conversations about habitat, the difference between living and extinct species, water quality, organism adaptations, food chains, species populations, native and invasive plant species, plant reproduction, and the erosion of the edges of the stream. The interactions took the form of a spontaneous question/answer dialogue, beginning with the teacher asking 11 students at the stream if they had seen water insects. The teacher and students brainstormed together in such a way that different students first provided examples such as water striders and dragonflies and then began to discuss their observations of larger animals. The teacher seized the opportunity to ask the group if they expected to see fish in the area. One student said that the water was not sufficiently clean to see fish. In response, the teacher used the concept of pollution and then introduced the concept of habitat. The teacher then asked students what habitat they expected the fish in the area would prefer.

In this way, he made students grasp the concept, reason, direct their attention towards stones, and at the same time point to places in the stream where the fish accumulated. As the next step in the ongoing dialogue at the stream, the teacher asked if there is anything else behind which fish prefer to hide. Another of the students mentioned seaweed and pointed to the stream to illustrate. "Yes, seaweed," the teacher replied and then asked "What about along the edges?" One student answered, "Plants hanging down in the creek." The teacher confirmed and continued the brainstorming by commenting that plants hanging down the stream are probably also a good area, thus encouraging students to search for small animals around the vegetation as they put on waders and moved around in the stream. In conclusion, he summed up that "things not only live in the water; they also live in the area around and above it."

The spontaneous teaching episodes that frequently occur during fieldwork are an expression of a special class and teacher–student dynamic. Such an environment both encourages and supports longer dialogues in which the teacher can make students familiar with scientific hypothesis formation, derivative thinking, and reasoning based on what they have in common (Rennie et al., 2003; Eshach, 2007; Lewis and O'Brien, 2012; Heras et al., 2020).

Scientific Systematics

The scientific method also involves a special systematics in relation to the collection and handling of empirical data (Çapkınoğlu and Yilmaz, 2018). In a project on nature conservation in the United States, 5th-grade students acquired basic and essential fieldwork skills (e.g. updating a logbook; Bingaman and Eitel, 2010). They also learned to introduce date, time, and location, organised measurements on sheets with appropriate headings, outlined observations, found precise names for them, and categorised information.

Some parts of the science approach are not intuitive for elementary school students. In a US study, 26 1st-, 3rd-, and 6th-grade students from a rural area were interviewed about the relationship between sampling and the possibility of deriving causal relationships (Lehrer and Schauble, 2017). Over a year, the students had collected data and conducted comparative studies of nearby local ecosystems, including ponds, prairies, and forests. Through their experiences with sampling in the field, they became indirectly aware of biodiversity and began to associate species variation with variations in biotopes. The researchers aimed to uncover students' understanding of the concept of sampling, ways of collecting sensible samples, potential sources of error in sampling, the relationship between cause and randomness in explanations of variability, ideas about larger sample sizes, how a single sample can represent the whole ecosystem, and variations in sample quality.

The researchers expected that the repeated opportunities to collect, interpret, and reason about data would increase children's understanding that samples acquired in the same place vary, that some phenomena in the sample occur more often than others, and that one's opportunity to predict what appears in subsequent samples increases with the number of samples. The results varied by age. The 1st-grade students perceived samples as concrete parts of the ecosystem and expected that more samples would better describe species diversity because they gained an overview of a larger concrete part of the system. Those students placed less emphasis on the fact that methods of obtaining data affect which data one has access to. By contrast, 3rd-grade students were more aware that the systematic implementation of the same method, maintained in the same place, is necessary for sample reliability. The significance of occasional coincidences for the outcome of a sample was rarely included in the interviews. In the 6th grade, on the contrary, there was a strong presumption that samples varied over time. The explanations, however, were most often backed up by concrete experiences with sampling and only rarely with considerations of the principled randomness in sampling. During the ecology course in mathematics teaching, both 3rd- and 6th-grade students had been taught the concept of chance without having it explicitly related to data collection. Only 30% of the younger students referred to ideas of randomness to account for variations in random sampling, while this figure increased to 43% in the older students.

In a Swedish qualitative study by Magntorn and Helldén (2007), 23 3rd to 4th grade pupils were taught ecology by focussing on individual specimens of a species such as the freshwater shrimp to help students *read nature* in a river ecosystem. From the ecology of the freshwater shrimp, the students' perspective was broadened to focus on interrelations between organisms and the relationship between biotic and abiotic factors. During the intervention, seven lessons of a duration from 80 to 200 min, pupils were interviewed three times when they were presented with a tray of objects from the ecosystem. The task was to name and describe the objects and potential links between them. The researchers report how the progression of the course supported the concept development and students' understanding of the complex notion of ecosystem.

Technology-Based Nature Experiences in Science

The scientific emphasis on observations is traditionally linked to the use of technology (e.g. magnifying glass, binoculars, microscope, telescope, oscilloscope, seismograph), which either expands or amplifies the senses (Lewis and O'Brien, 2012).

The ability to stimulate scientific attention through sensory-expanding technology is described in the US study by Ghadiri Khanaposhtani et al. (2018). The qualitative study examined the effect of a 4-day stay in a so-called soundscape ecology camp that recorded and processed the sound of nature areas on the ability of seven 5th–8th-grade students to ask scientific questions and prepare research projects. Students learned to "*see*" the surroundings through soundscape technology. They learned how to compare and contrast sound universes in different ecosystems, how soundscape ecologists record sound universes and analyse them to answer research questions, and how the students themselves could answer questions by collecting and analysing acoustic data. The researchers conducted a drawing and writing activity with the seven students in a questionnaire with six open-ended questions such as "why do animals make sounds?" After the intervention, students showed signs of a deeper understanding of sound universes and how they can be used as a scientific tool to investigate both the state of an ecosystem and the importance of human activity for this ecosystem.

Similar observations about mixing nature experiences and use of technology to teach science are found in the British study conducted by Scott and Boyd (2016). Here, 379 pupils from 5th and 6th grade took part in an intervention in which their class teacher chose a local habitat for a half-day fieldwork session. Selected habitats were the school playing fields and gardens, a school pond, a local woodland, and local rocky shore. Children were encouraged to thoroughly explore the area and use charts to identify all the plants and animals they encountered, and encouraged to photograph species of their own choice, write down field notes about appearance and location, and to write down questions that the encounter with the organism had inspired.

The day after the fieldwork session, pupils were asked to use computers to construe a field guide targeting other children visiting the site based on their photographs and field notes. They were encouraged to look up the answer to their questions on the internet and to add wow facts that had amazed them while learning. The comparison classes did not participate in the field work session but were taught in the classroom about the same habitat and types of organisms.

Two weeks before and 6 weeks after the intervention, pupils' scientific knowledge was assessed. For example, pupils were asked to identify a herbivore, or from drawings of organisms describe which was a predator of which, or provide an answer to a question like "Some children collected animals from a pond. They found a lot of animals amongst the water plants, why was this?"

The study results show that pupils who took part in the intervention scored significantly higher in the mean level of academic achievement. However, the researchers add that the intervention classes also scored higher in the pretest assessments. They hypothesise that the better pretest scores are the result of the intervention classes being told beforehand that they were to participate in ecological fieldwork, and may have started to "think like a scientist" (Scott and Boyd, 2016, p. 668).

In a US study focusing on ecosystems, Lee (2014) describes how categorising 5th-grade students' experiences with photo documentation from fieldwork benefitted their recall and understanding of the subject. In the project, each student was encouraged to photograph what they found interesting. The excursion involved longer walks in wild terrain and teaching at several museums. After the intervention, students were interviewed about their pictures. The photographs were classified into "documentation images," where the student documented a view or something beautiful, and "observation images," where the student zoomed in on a phenomenon or characteristic of what was observed. Others were classified as "cause-and-effect images," where the student illustrated a cause-and-effect relationship (e.g. images of the location of rocks as a result of being pushed from a glacier), and "wonder images," where the student found the photographed image mysterious and in need of explanation (e.g. what an animal skeleton could reveal about the living animal). The study revealed that students photographed far more documentation images on museum visits than on walks (72.8 versus 50.1%) and far more cause-and-effect images on walks than at museums (26.1 versus 2.6%). The researchers conclude that nature experiences stimulate the need to ask questions and predict events whereas museum visits support scientific curiosity (*see* also Hammarsten et al., 2019).

INVESTMENTS, COSTS AND CHALLENGES WHEN USING NATURE EXPERIENCES IN SCIENCE TEACHING

According to the research, there are administrative, financial, and practical challenges to conducting science teaching in nature.

Excursions and longer stays require financial support and more teachers. For example, outdoor teaching is often carried out in collaboration with nature centres, researchers, students, and volunteers.

Also, teaching in a natural environment typically follows a more open course because the outdoor space varies in terms of its organic environment. If organisms are not in the pre-planned location, this might obstruct the teaching (Schilhab and Lindvall, 2017; Glaab and Heyne, 2020). However, this open-ended quality allows teachers to stimulate students' commitment and curiosity. It could be argued that thise lack of control creates the different teacher–student interactions that make the natural environment valuable (King and Ginns, 2015). The teacher may decide to grasp spontaneous learning opportunities, but at the same time feel pressured because they are supposed to strengthens students' abilities when tested. In the study by Carrier et al. (2013), two US teachers remarked that too tight a timeframe is allowed for science teaching and pointed out that science teaching should be the equivalent of mathematics and reading from a political standpoint. They also demanded more subject-related courses that could equip them to teach outdoors. The perception of time constraints and heavy content demands are shared by the Scottish teachers in the study by Christie et al. (2016).

Pupils' attitudes towards the environment also constitute a barrier. Children unaccustomed to being outdoors require more attention to behave appropriately. A typical problem is inappropriate clothing that makes the stay cumbersome. Students often need to be instructed in how to behave during their stay. Articles on examining plant and animal species in school gardens or nearby areas emphasise that caution with poisonous, stinging, and burning plants is necessary (Magiante, 2009; Dominguez et al., 2013). At the same time, the importance of teaching students' etiquette in connection with their stay in nature is highlighted. Students must develop responsibility and care and learn to treat the environment with respect (Drissner et al., 2010, 2014). The teacher's attitude also affects nature experiences (Carrier et al., 2013). Eshach (2007) posits that the teacher's personal interests, preparation, actions in the field, and handling of the fieldwork after the course is completed all affect students' attitude towards the course, both immediately after and in the long run (*see* also Strgar (2007) for the importance of the teacher in emphasising the importance of plants).

The literature points to another barrier that teachers typically encounter. School leaders, school politicians, and parents may be sceptical about the learning potential of completing science subjects in nature. Most inspirational articles therefore have a section that deals with the importance of convincing the pedagogical leader and gaining permission for the project.

DISCUSSION AND CONCLUDING REMARKS

Across the studies in the corpus, typical research methodologies are mixed methods, quasi-experimental, pre-/post- and retention test setups, compared to those of a control group. Exceptions exist. In one study, using measurements statistics is not applied, and in few others, the number of participants is limited, or control groups are missing. The measurements are typically based on instruments like questionnaires and multiple-choice tests to assess the level of knowledge from the number of correct answers. However, quantitative measures of students' knowledge acquisition and retention also encompass probing memories in interviews based on student photos, annotated drawings, personal meaning maps, word association tests, essays, and student work samples. The effects that are measured include cognitive and emotional changes as well as attitudes towards nature and living organisms, and degree of nature connectedness.

In a handful of studies, methodologies are purely qualitative relying on interviews, observations, student work samples or annotated drawings.

Thus, the majority of scientific content knowledge studies, environmental studies and scientific systematics studies (the three categories used here) all assume and are primarily interested in demonstrating quantitatively that cognition, emotions, and attitudes are influenced by nature experiences to a significant extent.

Unsurprisingly, the empirical literature consists of articles written by the researchers affiliated with the intervention projects, implying that projects with less researcher involvement may face difficulties getting published. The researcher involvement likely impacts how to organise the courses and which elements to develop. For example, researchers could be biased towards designing interventions that favour effect measurements. However, school teachers would design interventions governed by pedagogical criteria of quality (e.g. Rennie et al., 2003).

Relatedly, the expectations of this review study were to find the application of nature experiences across several scientific disciplines ranging from physics and chemistry to geology, and astronomy. In the field as such - the 114 studies – a number of articles fall within this broader scope. Surprisingly in the corpus, almost all studies are concerned with the biological sciences, such as the interconnectedness of nature, adaptational issues, and sustainability issues.

It would be interesting to investigate the effects on learning of for example the demonstrating of watersheds in students' own environments (described by Endreny, 2007). Here, the teacher invited students to walk through the landscape right outside the door. They had access to both a stream and a larger wetland and learned to recognise the relevant physical phenomena. They were also shown their connection with the landscape and taught how to read topographical maps of watersheds as graphic tools and symbolic representations of the phenomena. Hence, it could be argued that observations of actual phenomena and nature experiences could be implemented in a much wider ranges of natural science disciplines (e.g. Townsend, 2010).

In terms of embodied cognition, the research on content knowledge does reflect an appreciation of learning being both embodied and immersed. When content knowledge is gained exclusively through linguistic constructions, its success depends on how well the student works with and imagines linguistic information (Schilhab, 2007; Schilhab, 2011; Schilhab, 2017a; Schilhab, 2017b; Schilhab, 2018; Shapiro and Stolz, 2019)). However, the didactic choice of swapping between firsthand learning and secondhand learning (concepts and theories) are present in many of the studies. Concretisation through direct experience clarifies the meaning of the concepts at two levels (King and Ginns, 2015; Allison et al., 2017; Schilhab and Lindvall, 2017) by *1*) adding experiential content to the conceptual understanding (i.e. something in the world which feels in a particular way corresponds to the concept), and *2*) identifying aspects essential to the concept through the action practices of which the phenomenon is part (Hasse, 2016). At the second level, content knowledge includes knowledge about how to talk and reason about science and nature, contextualised through the experience of these phenomena, related practices, and the theoretical concepts one uses about them (Schilhab and Esbensen, 2019).

The bias towards environmental issues mentioned above, explains why a large part of the research is categorised as environmental education. Here, the research is primarily concerned with environmental issues measuring students' attitudes towards nature and organisms and their feelings of attachment to nature, e.g. their nature connectedness. In several of these studies, the underlying assumptions are that when students gain knowledge about nature, they feel more connected to nature. This may not necessarily be the case.The studies may find a concurrent increase in measures of academic achievements and nature connectedness. However, measures of correlations are not measures of causality.

In terms of embodied cognition, the environmental studies endorse the idea that meaning-making is situated. According to the embodied cognition approach, learning and knowledge formation cannot be dissociated from lived life. On the contrary, cognisers' minds are always embodied, embedded, enacted, and extended (Rowlands, 2010; Menary, 2010; see also; Rietveld et al., 2018), and an adequate understanding of cognitive processes in meaning-making activities is therefore concerned with cognisers' bodies, surroundings, and continuous exchanges with those surroundings (Walter, 2009; Fuchs, 2017). These factors pertained to the experience of the blackberry bush in the introduction. Along those lines, as students *experience* nature, nature starts making sense. That nature experiences related to science in childhood can have long-term effects that may even show up in the choice of a science-related profession has been demonstrated with field geologists (LaDue and Pacheco, 2013). For over half of respondents, early nature experiences in geological areas in which informants lived or had visited in childhood were a decisive reason why they pursued a career as a geologist as adults. Hence, disregarding effect measures, nature experiences have life-long impacts affecting who studies nature professionally.

Research on how the natural environment creates an optimal backdrop for eliciting observations and derived reflections central to scientific inquiries relates to the gains of the formative swapping between instructions and experiential hands-on activities (discussed in relation to content knowledge). With very little investment, such as exposing students to investigating birds at a feeding board or plant development in a select plot, and encouraging spontaneous teaching episodes, teachers tune their students to observe the natural world and through that explore the essence of scientific thinking and reasoning.

Among these studies, some argue for the use of technology in conjunction with nature experiences in science, systematically investigated in a recent review by Kilty and Burrows (2020). The study uncovered how science teachers typically use mobile devices for teaching purposes. Of the 45 selected peer-reviewed articles, the researchers found that mobile devices are most often used to support observations, data collection, and knowledge sharing (44%) and gain content knowledge (49%). However, the use of mobile devices to support observations and hypothesis formation were less well represented.

Contemporary students already use digital learning tools and the Internet as part of their daily lives (Schilhab, 2017c; Schilhab et al., 2018b). The Danish project Natural Technology has demonstrated how smartphones engage disadvantaged children in nature experiences and explorative investigations of natural phenomena (Schilhab et al., 2020; Schilhab and Esbensen, 2021).

In terms of embodied cognition, it could be argued that studies using nature experiences to stimulate pupils' understanding of scientific procedures and methodologies assumes that cognisers' minds are always enacted, and extended (Rowlands, 2010). Also, when using smart technologies in observations and note taking we extend the mind with the tool as thinking-aid. This claim also pertains to notebooks with PIN codes and telephone numbers, road signs, and chalk lines on the wall indicating how many times the sun has risen. When we use objects and surroundings as a placeholder for our thinking - we externalize thought processes that would otherwise taxour cognitive resources.

Though most studies in the corpus were not discussing the investments, costs and challenges, the teacher papers among the 114 papers did. An exception is Randler and colleagues who comment that (2005, p. 50): "…residential outdoor programs are expensive and often linked with traveling…", therefore "Schools should provide their students with local outdoor ecological programs."

Obviously, not every school has access to or can afford to send their students to nature parks, the seaside or wetlands. In this regard, interventions exploiting the schoolyard, school gardens, or nearby park areas are particularly promising. First, the closeness of the empirical site reduces the costs in terms of time, extra helpers and expenses spent on transportation. Also, projects based on easy access can support science teaching on an ongoing basis. This point seems noteworthy since all learning activities seem to benefit from prolonged interventions and subsequent repetitions.

Second, in local areas the science learning effortlessly pivots around the importance of insects, plants and smaller mammals often neglected at the expense of more "attractive" however non-local species. Learning to care about commonly underrated organisms and environments nearby, because they belong to your neighborhood, seem to stimulate pro-environmental behaviours. In local areas, students are also already familiar with the environment, reducing the risk of a negative impact of novelty, and making it safer for younger students to navigate without supervision.

An insight gained from studying the corpus worth emphasising is that the gains from using nature experiences in science learning fundamentally depends on the educators' preparations and didactic reflections. Albeit nature experiences appear "natural" the framing of these within an educational context is far from given. This factor became apparent from the fact that many of the studies included in class preparations and postintervention debriefing in the learning module. The swapping between firsthand and secondhand experiences and the shift between free learning and teacher centered learning needs to be organised by didactic goals. Hence, when considering the gains and costs of implementing nature experiences in science learning, it is important to address the extra working hours on the part of the teacher involved in conceptualising the interventions as useful didactic alternatives to class-based education. To that end, it is remarkablethat a few studies also reported on prior pilot studies demonstrating the need for testing the entire design before conducting the actual research. Teachers seldom experience the opportunity to preview their teaching strategies before performing in front of their students. What this suggests is the necessity to develop educational programs that allow teachers to seamlessly adopt these practices in their everyday routines.

An extremely important metafinding from this review is that science education seems central for remedying the extinction of experience in students, and if exposure to nature is a prerequisite for learning to care abot nature, for providing opportunities for students to learn to care about nature (e.g. Soga and Gaston, 2016). Provided, that time is allowed to develop courses, and that extra manpower is made available, science education seems to be *in a unique position* for incorporating nature experiences into the curriculum. Such actions will boost students' understanding of and maybe also attitudes towards nature. Hence, science educators in primary and secondary schools should be made aware of the gains of using nature experiences in science learning and receive support to reduce the obvious costs if they were to explore this educational approach further.

Very few studies in the present review have touched upon the effect of using nature experiences in science learning regarding disadvantaged children or youth, children of color, children from low-income households, and children with emotional, behavioral, or cognitive disabilities. Results reported by De Dominicis et al. (2017) seemed to suggest that particularly for children living in urban environments like Rome, nature experiences proved useful for developing pro-environmental attitudes and behaviors. Future research should further elaborate on the potential of nature experiences to include disadvantaged children and youth in science education.

Regardless of these limitations, importantly, the material suggests that using nature experiences in science education increases content knowledge and nature-connectedness, and expands insight into scientific methods and inquiry strategies for students in primary and secondary school and that embodied cognition theories are helpful in explaining why and how nature experiences work.

AUTHOR CONTRIBUTIONS

The author is responsible for the work in its entirety.

FUNDING

This research was supported by a grant from Nordea-fonden to TS to the research project Natural Technology (02-2017-1293).

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/feduc.2021.739408/full#supplementary-material

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