Acta electronica Universitatis Lapponiensis 453

Xiaowei Zhang

Art–Science Education

Material Engagement and Learning through Art–Chemistry Integration

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Material Engagement and Learning through Art–Chemistry Integration

Academic dissertation to be publicly defended with the permission
of the Faculty of Art and Design at the University of Lapland
in Mauri hall on 20 November 2026 at 12 noon.

LAPIN YLIOPISTO
UNIVERSITY OF LAPLAND

Rovaniemi 2026

University of Lapland
The Faculty of Art and Design

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Cover Design and Layout
Annika Hanhivaara

Acta electronica Universitatis Lapponiensis, 453

ISBN 978-952-337-586-4
ISSN 1796-6310

Permanent address to the publication:
https://urn.fi/URN:ISBN:978-952-337-586-4

Abstract

Xiaowei Zhang

Art–Science Education: Material Engagement and Learning through Art–Chemistry Integration

Publisher: University of Lapland, 2026, number of pages 154
Acta electronica Universitatis Lapponiensis 453
Doctoral Thesis: University of Lapland, Faculty of Art and Design
ISBN 978-952-337-586-4
ISSN 1796-6310

This dissertation aims to develop interdisciplinary art–science education through art–chemistry integration and material engagement, exploring how pedagogical practices involving materials and natural phenomena support pupils' creativity, scientific understanding, inquisitive thinking, and ecological understanding. The research is conducted primarily in Northern Finland and is a response to the growing interest in interdisciplinary education that connects artistic practices, scientific experiments, and ecological awareness. In recent years, such approaches have gained attention as a way to address complex environmental and educational challenges, particularly in contexts where education is closely connected to local environments and material conditions. The research focuses on how pupils engage with natural materials, environmental phenomena, and interdisciplinary activities, and how these engagements contribute to their meaning-making in school contexts.

This article-based dissertation draws on Art-Based Action Research (ABAR). The research integrates theoretical perspectives on interdisciplinary education, multimodal and embodied learning, and relational approaches to material engagement. The empirical research was organised through three interconnected ABAR cycles conducted in China and Northern Finland. The first cycle was conducted in Changsha, China, while the second and third cycles took place in Rovaniemi, Finland. During the cycles, pupils engaged with materials and natural phenomena through chemical experimentation, observation, artistic creation, storytelling, and collaborative reflection. The activities involved bilberries, snow, recycled paper, and other materials selected according to the focus, season and learning environment of each cycle.

The findings show that material exploration provided a common ground for art and scientific learning. Pupils observed changes in colour, form, and material properties through experimentation, and developed their observations through drawing, painting, storytelling, and other forms of artistic expression. Experimentation and artistic interpretation encouraged questioning, comparison, and responses to unexpected results, connecting creative expression with inquisitive thinking and scientific understanding. As the research expanded from chemistry-based experimentation to forests and recycled materials, pupils also considered connections between materials, environmental processes, and their own relationships with the environment. In the Northern Finland studies, seasonal conditions, local environments, and familiar materials shaped these experiences. The dissertation contributes to the

development of art–science education by showing how material exploration can connect artistic and scientific expression and inquiry within the same educational process. The ABAR cycles supported the revision of pedagogical practices through reflection on earlier activities, while the findings point to possibilities for developing art–science education in relation to materials, environmental conditions, and educational practices in various local contexts.

Keywords: Art Education; Interdisciplinary Education; Art-Based Action Research; Creativity; Arctic Education

Tiivistelmä

Xiaowei Zhang

Taide- ja tiedekasvatus: Materiaalien hyödyntäminen ja oppiminen taiteen ja kemian integroinnin kautta

Julkaisija: Lapin yliopisto, 2026, sivumäärä 154
Acta electronica Universitatis Lapponiensis 453
Väitöskirja: Lapin yliopisto, taiteiden tiedekunta
ISBN 978-952-337-586-4
ISSN 1796-6310

Tämä väitöskirja pyrkii kehittämään tieteidenvälistä taide- ja tiedekasvatusta kuvataiteen ja kemian integraation ja materiaalien käyttöönoton kautta ja tutkimaan, miten materiaaleja ja luonnonilmiöitä hyödyntävät pedagogiset käytännöt tukevat oppilaiden luovuutta, tieteellistä ymmärrystä, uteliasta ajattelua ja ekologista ymmärrystä. Tutkimus toteutettiin pääasiassa Pohjois-Suomessa. Se vastaa kasvavaan kiinnostukseen monialaiseen opetukseen, joka yhdistää taiteelliset käytännöt, tieteellisen kokeilun ja ekologisen tietoisuuden. Viime vuosina tällaiset lähestymistavat ovat saaneet huomiota keinona ratkaista monimutkaisia ympäristöön ja koulutukseen liittyviä haasteita erityisesti tilanteissa, joissa koulutus on läheisesti kytköksissä paikallisiin ympäristöihin ja aineellisiin olosuhteisiin. Tutkimus keskittyy siihen, miten oppilaat toimivat luonnonmateriaalien, ympäristöilmiöiden ja tieteidenvälisten aktiviteettien kanssa ja miten nämä aktiviteetit vaikuttavat heidän merkityksenmuodostukseensa koulukonteksteissa.

Tämä artikkeliväitöskirja pohjautuu taideperustaiseen toimintatutkimukseen. Tutkimus yhdistää teoreettisia näkökulmia tieteidenväliseen koulutukseen, multimodaaliseen ja ruumiilliseen oppimiseen sekä relationaalisiin näkökulmiin materiaalisesta vuorovaikutuksesta. Empiirinen tutkimus järjestettiin kolmen toisiinsa kytkeytyvän toimintatutkimuksen syklin kautta, ja ne toteutettiin Kiinassa ja Pohjois-Suomessa. Ensimmäinen sykli toteutettiin Changshassa Kiinassa ja toinen ja kolmas sykli Rovaniemellä Suomessa. Syklien aikana oppilaat työskentelivät materiaalien ja luonnonilmiöiden parissa kemiallisten kokeiden, havainnoinnin, taiteellisen työskentelyn, tarinankerronnan ja yhteistoiminnallisen reflektion kautta. Aktiviteetteihin liittyivät mustikat, lumi, kierrätyspaperi ja muut materiaalit, jotka valittiin kunkin syklin painopisteen, vuodenajan ja oppimisympäristön mukaan.

Tulokset osoittavat, että materiaalien tutkiminen tarjosi yhteisen pohjan taiteelliselle ja tieteelliselle ilmaisulle ja tarkastelulle. Oppilaat havaitsivat värien, muotojen ja materiaalien ominaisuuksien muutoksia kokeilemalla ja kehittivät havaintojaan piirtämällä, maalaamalla, tarinankerronnalla ja muilla taiteellisen ilmaisun muodoilla. Kokeilu ja taiteellinen tulkinta kannustivat kyseenalaistamaan, vertailemaan ja reagoimaan odottamattomiin tuloksiin yhdistäen luovan ilmaisun uteliaaseen ajatteluun ja tieteelliseen ymmärrykseen. Tutkimuksen laajentuessa kemiaan perustuvasta kokeilusta metsiin ja kierrätysmateriaaleihin oppilaat

pohtivat myös materiaalien, ympäristöprosessien ja oman ympäristösuhteensa välisiä yhteyksiä. Pohjois-Suomessa toteutetuissa tutkimussykleissä vuodenaikojen olosuhteet, paikalliset ympäristöt ja tutut materiaalit muovasivat näitä kokemuksia. Väitöskirja edistää taide-tiedekasvatuksen kehittämistä osoittamalla, kuinka materiaalien tutkiminen voi yhdistää taiteellisen ilmaisun ja tieteellisen tarkastelun samassa koulutusprosessissa. Toimintatutkimuksen syklit tukivat pedagogisten käytäntöjen uudistamista aiempien toimintojen reflektoinnin kautta. Havainnot viittaavat lisäksi mahdollisuuksiin kehittää taide-tiedekasvatusta suhteessa materiaaleihin, ympäristöolosuhteisiin ja koulutuskäytäntöihin erilaisissa paikallisissa konteksteissa.

Avainsanat: Kuvataidekasvatus; Monialainen kouluoppiminen, taideperustainen toimintatutkimus; luovuus; Arktinen koulutus

Acknowledgements

I developed this research as part of my doctoral work at the University of Lapland. From the beginning, my work was oriented towards exploring connections between art and science in education. This interest guided the initial direction of the research. As the work progressed, the focus became more clearly defined through teaching, collaboration, and engagement with practice. Working in school settings in Rovaniemi, together with pupils and teachers, brought new questions and perspectives. Experiences with materials, observation, and creative activities contributed to refining the research direction and deepening its scope.

I am deeply grateful to my supervisor, Mirja Hiltunen. Throughout my doctoral journey, she encouraged me with remarkable generosity and constancy. At every important stage, she helped me see the potential of my work more clearly and guided me in shaping its direction with greater focus. Her comments always went beyond technical advice. Through her thoughtful questions, careful reading, and academic insight, she led me to look deeper, think more critically, and develop my ideas with greater confidence. What has meant the most to me is her trust in both my research and my growth as a scholar. She gave me room to develop my own voice while always being there with support, clarity, and encouragement. Her guidance helped me understand that research involves staying with important questions and working through complexity with patience and commitment. Her belief in my work gave me strength at crucial moments and helped me continue this journey with a stronger sense of purpose.

My sincere thanks go to my second supervisor, Maria Huhmarniemi, whose guidance has been both careful and dedicated. We worked closely together on several articles, and she engaged with each manuscript with remarkable attention and patience. She read my work multiple times, offering detailed comments, suggesting revisions, and helping me refine both the structure and the language with great precision. Our collaboration gradually changed the way I approach academic writing and thinking. Through her feedback, I learned how to clarify my arguments, connect ideas more coherently, and develop a stronger analytical focus. She consistently encouraged me to go further in my reasoning, to look more closely at my data, and to express my ideas with greater clarity and depth. I am grateful to my third supervisor, Annamari Manninen, for the many thoughtful discussions on interdisciplinary education. Through our conversations, I gained a clearer understanding of how to position my research and how to articulate its contribution within the field. She shared her own experiences from her doctoral studies in art education, which gave me a more concrete sense of how such research can be developed in practice.

I would like to express my warmest thanks to my pre-examiners, Hannah Kaihovirta, Seija Kairavuori, and Helena Sederholm, for their insightful comments and pertinent observations. Their feedback has been invaluable in helping me finalize the manuscript. I am also delighted that Seija Kairavuori has kindly agreed to serve as the opponent at my public defence. I am sincerely grateful to my collaborators at the LUMA Centre Finland and the uJunnu Science Center, especially Pieti Tolvanen, Anna-Maija Partanen, Pekka Muotka, Emma Karjalainen and Teppo Kuusela. Working with them played a central role in making this research possible. We designed and carried out a series of teaching experiments that brought art and science into close

dialogue in real classroom settings. They supported planning and implementing the activities, shared their pedagogical and scientific expertise, and contributed ideas that helped refine the workshop structure. During the teaching process, their openness to experimentation created a space where new approaches could be explored and developed. This collaborative environment allowed the research to grow through practice, reflection, and continuous adjustment.

I am grateful to the teachers and pupils at Rantavitikka School, Ounasvaara School, and Korkalovaara School. They welcomed me into their classrooms and made it possible to carry out this research in real teaching situations. The teachers supported the work with openness and flexibility, creating space for interdisciplinary activities and allowing new approaches to take place in their classrooms. Their willingness to engage with experimental teaching helped shape the learning environment. I worked closely with the pupils, whose engagement shaped this research. Their ways of observing, responding, and expressing ideas through materials brought unexpected perspectives and new directions to work. Moments of curiosity, concentration, and shared discussion gave meaning to the teaching process and continuously informed the development of this study. I gratefully acknowledge financial support for this research. I also express my gratitude to Finnish National Agency for Education (EDUFI) for its scholarship support during my doctoral studies in Finland. I am also grateful for the Esko Riepula Grant, which has contributed to the advancement of this research. This support provided important conditions for carrying out the study and sustaining my work throughout the doctoral process.

Heartfelt thanks go to my family for their support throughout this journey. I am especially grateful to my husband, Feiping Zhao, for his encouragement, practical support, and thoughtful discussions. His perspectives from the natural sciences enriched my interdisciplinary research, while his patience and understanding helped me through the demands of writing and revision. To my son, Alex Zhao, thank you for your companionship throughout these years. Our time together brought warmth and joy, even during the most demanding periods of this work. Your curiosity and imagination reminded me of what lies at the heart of this research.

This dissertation has been shaped by the contributions, conversations, and support of many people. Their generosity helped me develop my ideas and continue through moments of uncertainty. I have learned much from working with others and sharing everyday experiences along the way. As this doctoral journey comes to a close, I look back with gratitude on the years spent learning and working in Lapland. I offer my sincere thanks to everyone who has been part of this journey.

In Rovaniemi, September 22, 2026.
Xiaowei Zhang

List of Original Publications

I

Zhang, X., Huhmarniemi, M., & Hiltunen, M. (2026). Integrating art and science in education: Cultivating creative expression and inquisitive thinking. *International Journal of Education and the Arts,27* (29). CC BY-NC 4.0 http://doi.org/10.59236/ijea27n29

II

Zhang, X., & Huhmarniemi, M. (2026a). The bilberry experiment for Arctic STEAM education. *Scandinavian Journal of Educational Research,* 1–15. https://doi.org/10.1080/00313831.2026.2623292

© 2026 Scandinavian Journal of Educational Research. Article II is available in Scandinavian Journal of Educational Research at the following address
https://doi.org/10.1080/00313831.2026.2623292

III

Zhang, X., & Huhmarniemi, M. (2026b). Trees, forests, and recycled paper: art–science approaches to ecological understanding in Northern Finland. *Environmental Education Research,* 1–19. CC BY 4.0 https://doi.org/10.1080/13504622.2026.2693945

IV

Zhang, X., & Hiltunen, M. (2025). Integrating art into chemistry class: Exploring pH reactions through creative expression. *International Journal of Education through Art,* 21(3), 483–493. https://doi.org/10.1386/eta_00213_3

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Author Contributions

As first author, I designed and carried out the studies, including the development of the research and pedagogical frameworks, as well as the planning and facilitation of the activities. I was responsible for data collection and analysis and led the interpretation of the findings. I wrote the original drafts of the manuscripts and took primary responsibility for revising and finalising the texts. Mirja Hiltunen and Maria Huhmarniemi contributed to shaping the methodological and theoretical framing. They also helped revise the manuscript throughout the revision process.

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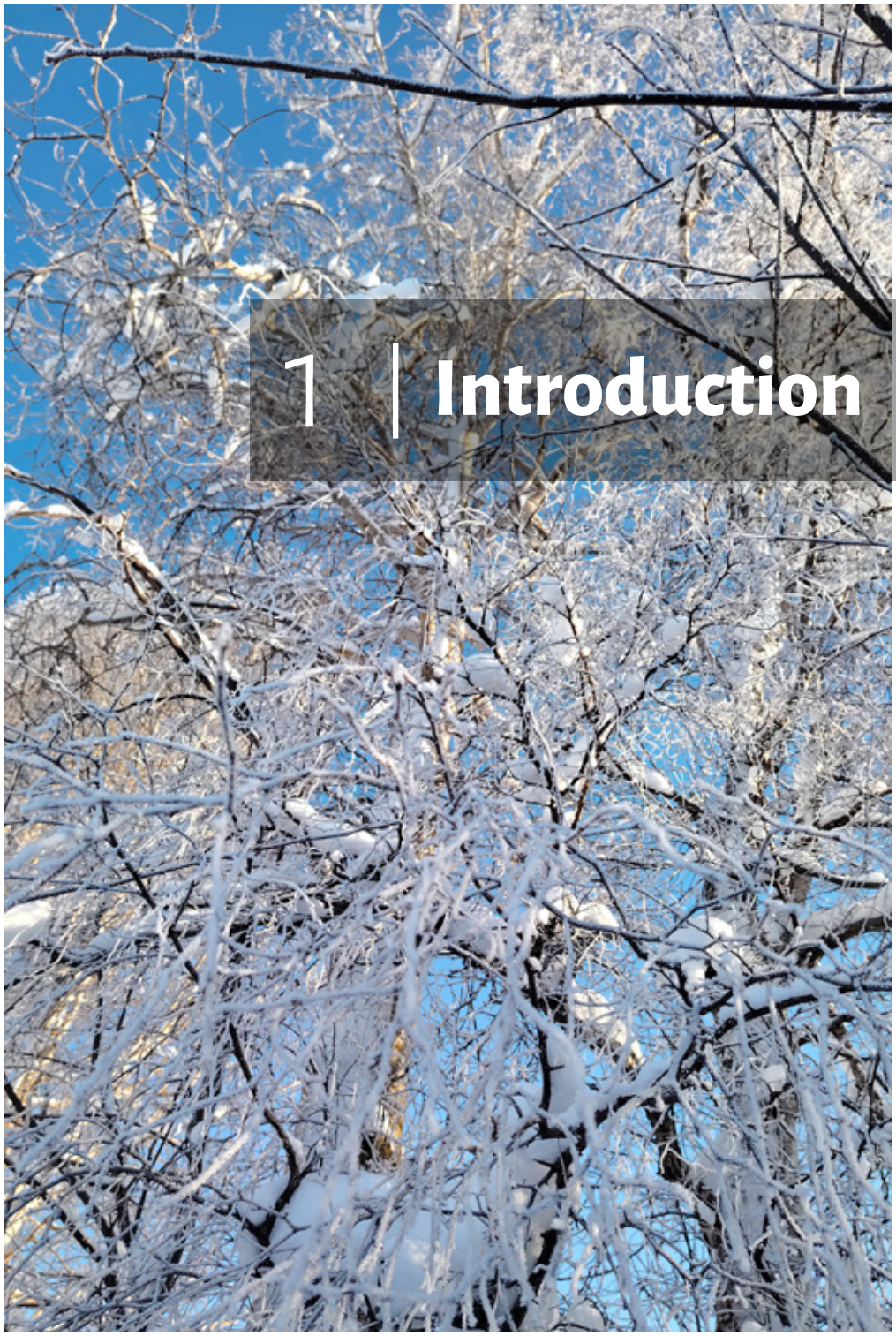
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1 | Introduction

Image 1. Touching the Arctic Winter. Photograph: Xiaowei Zhang, 2026.

1.1 Art and Science Education in Northern Finland

International education research has drawn attention to the need for learners to work with complex ecological and sustainability-related phenomena that extend across subject areas (Lonka et al., 2018). Contemporary approaches emphasise learners' capacity to draw on different modes of inquiry, integrate diverse forms of knowing, and engage creatively and critically with real-world issues (OECD, 2024; UNESCO, 2017). In this context, art–science education has gained attention as a pedagogical approach that links analytical investigation with sensory experience and expressive work (Guyotte et al., 2014; Perignat & Katz-Buonincontro, 2019).

In Finland, phenomenon-based and multidisciplinary modules are supported by national educational policy. The Finnish national curriculum for basic education highlights learning organised around meaningful phenomena (Finnish National Agency for Education [FNAE], 2014). In the dissertation, these approaches are interpreted through the lens of interdisciplinary, with a focus on the integration of artistic and scientific practices. Finnish scholarship has highlighted how these curricular principles aim to foster inquiry-oriented learning, student agency, and interdisciplinary understanding (Drake & Burns, 2004; Lonka et al., 2018). Art–science education provides concrete pedagogical means to approach complex phenomena through observation, experimentation, and creative exploration, allowing learners to engage with knowledge both conceptually and experientially (Kewalramani & Veresov, 2022; Sochacka et al., 2016). My research explores visual art education within the broader field of arts education, focusing on pupils' engagement with visual and material forms of expression (Eisner, 2002; Vecchi, 2010). The term arts-integrated is used to refer to contexts in which artistic practices are combined with other subject areas, particularly science, as part of interdisciplinary approaches (Perignat & Katz-Buonincontro, 2019).

Northern Finland offers a distinctive context for art–science education. The region is characterised by long winters, pronounced seasonal variation, and ecological conditions that shape everyday practices, livelihoods, and cultural traditions. Natural materials, including snow, ice, and berries, are closely tied to local practices and knowledge systems. They also act as cultural resources while offering opportunities for scientific investigation. In this context, environments are closely connected to material and environmental conditions (Hiltunen, 2025; Jokela & Huhmarniemi, 2022). Northern Finland provides a particularly relevant setting for understanding how art–science education develops through engagement with ecological phenomena.

Studies in art education at the University of Lapland have consistently addressed place-based, material-oriented, and community-engaged practices (Hiltunen, 2009). Contemporary Arctic art education has been increasingly conceptualised as responding to changing ecocultural relations and supporting cultural resilience and sustainability in northern regions (Jokela & Huhmarniemi, 2022). New Genre Arctic Art Education is an approach that foregrounds material encounters, ecological relations, and culturally responsive practices, and understands artistic processes as ways of engaging with environmental change, local knowledge, and sustainability concerns.

Bringing science education into dialogue with place-based and community-engaged traditions of Arctic art education opens up new possibilities for art–science education. Research on art–science collaboration and field-based learning suggests that combining scientific inquiry with artistic practices can deepen engagement with phenomena by expanding attention, sensory awareness, and interpretative possibilities (Sandrin et al., 2024; Stoll et al., 2024). In Arctic contexts, such integration allows learners to investigate ecological processes experimentally and to rework these experiences through artistic creation. Sustainability becomes connected to lived experience through material engagement with local environments (Jokela & Coutts, 2021). In Finland, the national curriculum promotes integration, phenomenon-based learning, and holistic approaches across subjects (FNAE, 2014). Despite these aims, the implementation of integrated approaches in schools remains uneven internationally (Gresnigt et al., 2014). Arts education has been described as a "blind spot" within the otherwise highly regarded education system (Juntunen & Anttila, 2019). In primary education, music and visual arts are given limited teaching time, while dance and theatre are mostly absent. Class teachers often teach visual art education, and their training in the arts varies across teacher education programmes.

In Finland, primary education is organised through generalist teaching, where one teacher is responsible for multiple subjects. This structure creates possibilities for interdisciplinary approaches, as disciplinary boundaries are less rigid in everyday classroom practice. It supports connections between different forms of knowledge and enables integration across subjects. Achieving meaningful integration between the arts and other subject areas remains challenging, particularly when teachers have limited confidence or training in artistic practices (Räsänen, 2007). Research has highlighted the potential of the arts within thematic and phenomenon-based learning contexts, where artistic and scientific modes of knowing can be brought into relation (Jokela & Huhmarniemi, 2022). Tensions emerge in how integration is realised in practice. In some cases, arts education is marginalised when interdisciplinary initiatives prioritise technological or engineering outcomes, positioning the arts in a primarily illustrative role (Liao, 2016). These conditions highlight the need to examine how art and science interact in classroom practice and how their relationship supports pupils' meaning-making through sensory, material, and embodied engagement.

The Arctic can be defined through geographical, environmental, political, and sociocultural criteria (Arctic Centre, n.d.). In this dissertation, the term refers primarily to the environmental, educational, and sociocultural context of Northern Finland. Most of the Finnish empirical research was carried out in Rovaniemi, located on the Arctic Circle, within Finland, which officially identifies itself as an Arctic country (Valtioneuvosto, 2021). In this

dissertation, Arctic context is understood through geographical location, seasonal environmental conditions, locally meaningful materials, and place-responsive pedagogical practices. These conditions shaped the selection of materials and natural phenomena explored in the research and provided the setting in which the interdisciplinary art–science practices were developed. Drawing on New Genre Arctic Art Education, the dissertation considers sustainability, creativity, and the relationships among art, people, and the more-than-human environment. Seasonal conditions, local environments, and natural materials influenced the educational activities and pupils' exploration of natural phenomena throughout the research.

1.2 Research Task, Action Cycles and Research Questions

My dissertation aims to develop interdisciplinary art–science education through art–chemistry integration and material engagement, exploring how pedagogical practices involving materials and natural phenomena support pupils' creativity, scientific understanding, inquisitive thinking, and ecological understanding. Situated primarily in Northern Finland, the research focuses on artistic and scientific practices involving observation, experimentation, material exploration, sensory experience, visual interpretation, and creative expression. The Arctic context provides an educational setting shaped by seasonal conditions, locally meaningful materials, environmental phenomena, and place-responsive practices. The dissertation also includes an action cycle conducted in China, which established the initial art–chemistry approach that was subsequently developed through the research in Northern Finland.

The research was implemented through three major Art-Based Action Research cycles. Each cycle involved iterative processes of planning, implementation, documentation, analysis, reflection, and redesign. The first cycle introduced art–chemistry integration, the second developed this approach through material experimentation in Northern Finland, and the third extended the research towards ecological understanding through forests and recycled paper. Across the cycles, pupils engaged with colour transformation, microscopic observation, recycled papermaking, snow-based artmaking, storytelling with natural materials, and outdoor art–science activities.

Artistic and scientific practices were connected in different ways across the three cycles. Observation and experimentation directed pupils' attention towards material properties, transformations, and natural phenomena, while artistic practices supported sensory exploration, visual interpretation, imagination, and expression. Reflection and analysis following each cycle informed subsequent decisions concerning materials, activities, educational settings, and analytical perspectives. The research developed through an iterative process in which questions and observations emerging from earlier cycles contributed to the design and analytical focus of subsequent cycles. Based on the overall research aim, the dissertation is guided by the following overarching research question: How do pupils' creativity, scientific understanding, inquisitive thinking, and ecological understanding develop through engagement with materials and natural phenomena in interdisciplinary art–science education? The three action cycles examine specific dimensions of this overarching question through their respective educational contexts, materials, and analytical focuses. The research questions presented in the three peer-reviewed research articles are:

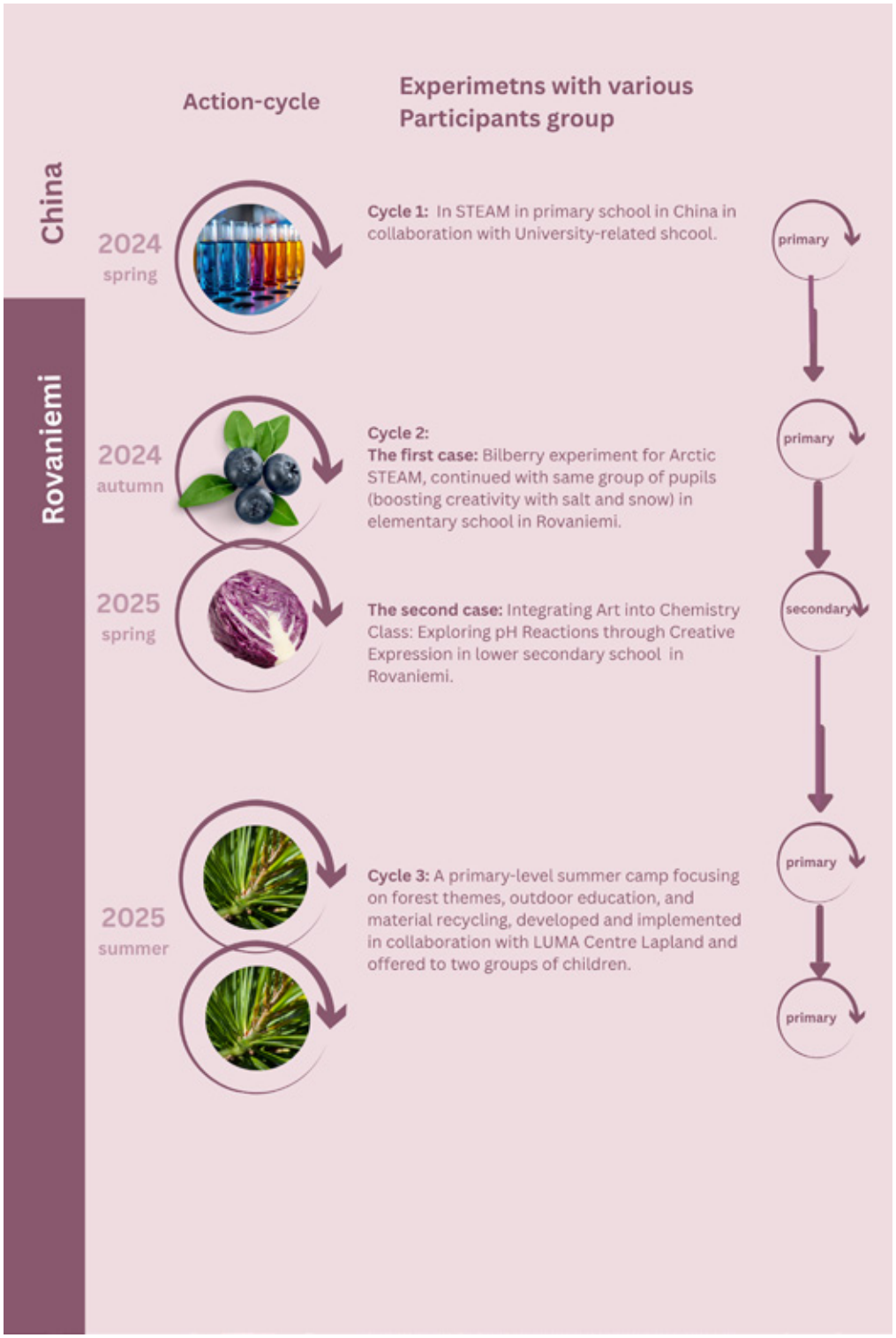


Figure 1. Doctoral research action cycles. Xiaowei Zhang, 2026

1. How does integrating art and chemistry promote students' creative expression, inquisitive thinking, and emotional engagement?
2. What role do artistic modes of expression play in pupils' meaning-making of scientific phenomena when using bilberries as natural pigments?
3. In what ways does the integration of chemistry and visual arts through bilberry-based experiments foster emerging science during classroom-based inquiry?
4. How did children articulate ecological understanding and their own roles in relation to forest environments through embodied, material, and imaginative engagement in art–science activities?

The four study-specific research questions provide complementary perspectives on the overarching research question by examining its creative, scientific, inquisitive, and ecological dimensions across different materials and educational contexts. Their findings are synthesised at the dissertation level to examine how these dimensions develop through pupils' engagement with artistic and scientific practices. Figure 1 presents the three action cycles and the related artistic practices in chronological order. It illustrates the development of empirical studies across the Art-Based Action Research process and their relationship to the overall research task of the dissertation.

1.3 Context of the research: From China to the Arctic

In China, interdisciplinary education and STEM-related initiatives have developed rapidly in recent years, supported by national policies that emphasise innovation and interdisciplinary approaches (The State Council of the People's Republic of China, 2021). I began this research on art–science education through an ABAR cycle that I designed and facilitated alongside primary school teachers, integrating art-making with chemistry experimentation in primary education (Zhang et al., 2026). The research was conducted in a classroom, where pupils observed and experimented with scientific reactions while using visual art to record, reflect on, and express their experiences of scientific phenomena. These pedagogical and methodological experiences shaped my interest in multisensory engagement, arts integration, and how visual expression can support reflection in art–science education. This work helped shape later work carried out in the Arctic context.

The following ABAR-cycles are grounded in the sociocultural and ecological realities of the European Arctic, where environmental conditions, everyday practices, and educational traditions profoundly shape pupils' learning experiences and the possibilities for integrating art and science (Huhmarniemi & Jokela, 2025). The region of Lapland in Finland and the wider Arctic region are characterised by distinctive natural rhythms, including long and cold winters, rapidly changing weather systems, extreme variations in daylight caused by polar night and midnight sun, and ecosystems formed by forests, lakes, wetlands, and permafrost. Arctic art education research highlights that these environmental conditions actively influence how pupils perceive change, materiality, and ecological relations in their daily lives (Hiltunen, 2023; Jokela & Huhmarniemi, 2022).

For pupils growing up in the Arctic, natural phenomena enter experience through direct sensory and bodily engagement. Snow, ice, wind, light, berries, and water are not abstract curricular

topics but materials that can be touched, observed, tested, and transformed. Studies on more-than-human and place-responsive education emphasise that such encounters form the basis for pupils' early ecological understanding and shape their cognitive and affective relationships with the environment (Ingold, 2013). These material encounters provide pupils with concrete reference points for understanding seasonality, transformation, and the properties of matter. This close relationship with nature affords Arctic pupils extensive opportunities for embodied and sensory experience. Through outdoor play and everyday activities, pupils observe ice melting, snow compacting, trees freezing and thawing, and experience these processes through touch, sound, movement, and temperature. Research on embodied and multimodal perception demonstrates that such bodily experiences support both aesthetic sensitivity and scientific sense-making, particularly in early and primary education (Thomas Jha & Price, 2022). Scientific observation and artistic experience are intertwined ways of engaging with the world.

In Arctic educational settings, multimodal activity connects with pupils' lived experience and develops in outdoor, material-rich environments. Studies in outdoor and environmental education suggest that such environments stimulate attention and curiosity, encouraging active participation in educational processes (Ratinen, 2016). Teachers can build on these experiences by linking sensory engagement with scientific concepts and using artistic practices to support reflection, articulation, and consolidation of understanding. Research on integrated sustainability education suggests that the openness of artistic processes and the structuring role of scientific inquiry mutually reinforce each other, enabling pupils to develop integrated understandings of complex phenomena (Stoll et al., 2024). These two educational contexts reflect different pedagogical orientations. In China, interdisciplinary learning is often organised through structured teaching and predefined learning goals. In contrast, in the Finnish Arctic it develops more frequently through open-ended exploration, material engagement, and context-responsive teaching approaches. These differences are also reflected in teacher roles. In China, primary education is typically delivered by specialised subject teachers, with art taught as a distinct subject following national curriculum standards (Ministry of Education of the People's Republic of China, 2022). In Finland, primary education (grades 1–6) relies on general class teachers who are responsible for teaching all subjects, including art (FNAE, 2014). These differences influence how art–science integration is implemented in practice and indicate the capacity of material-based approaches to link structured and exploratory work.

This research is embedded in the concrete educational practices of the Finnish Arctic, where local environmental conditions, community structures, and school cultures shape teaching approaches, material availability, and pupils' ways of making meaning. Learning develops in environmental contexts through bodily engagement, material exploration, and sensory experience. Out of three ABAR cycles, one was conducted in China and two in Finland. Recognising this situatedness clarifies the generative logic of the research materials and informs how teaching practices and processes are analysed.

1.4 Internationalisation of Finnish Basic Education and Its Implications

Over the past decade, Finnish basic education has continuously promoted internationalisation, with schools constantly incorporating concepts and methodologies from international educational research into policy, curriculum design, and collaborative networks (Lonka et al.,

2018; OECD, 2018). International cooperation projects, transnational teacher training, and increasingly close ties between schools and international organisations have made internationalisation a significant driving force for education system renewal (OECD, 2024). In this process, internationalisation is closely linked to curriculum reform, updated teaching philosophies, and the reshaping of learning ability structures. With the deepening of national curriculum reform, schools are placing greater emphasis on openness, innovation, and practical orientation in instructional design, stressing the importance of learners' active participation in understanding complex social and natural phenomena, and enhancing the capacity of education systems to respond to future challenges (FNAE, 2014; Lonka et al., 2018).

This internationalisation process is reflected in curriculum planning (Lonka et al., 2018) and pedagogical approaches (Gresnigt et al., 2014), and is also evident in teacher education, particularly in art teacher education programmes (Manninen et al., 2025). Phenomenon-based learning and inquiry-based learning have been incorporated into the teaching structure of Finnish basic education, allowing classrooms to address diverse learning needs and supporting students in bringing different forms of knowledge into meaningful educational situations (FNAE, 2014). Related research indicates that although Finnish curriculum reform has provided stable institutional support for integrated teaching, the development of classroom practice still depends on teachers' ongoing adjustments to teaching structures and learning processes (Lonka et al., 2018). Teachers often show openness to new teaching approaches and seek to combine artistic expression, scientific observation, and outdoor activities (Bequette & Bequette, 2012; Inwood, 2008; Kuo et al., 2024).

The international value of education is no longer limited to cross-cultural understanding but gradually points to the construction of analytical skills for complex problems, creative problem-solving abilities, and the capacity for cross-disciplinary understanding of the world (UNESCO, 2017). Art and science in education is significant in this shift because it connects different cognitive pathways through material manipulation, sensory experiences, and experimental processes, providing pupils with conditions for inquiry that integrate analytical understanding and creative expression (Sochacka et al., 2016). Recent research indicates that art-science integration offers students a more open and generative structure for understanding complex phenomena, particularly advantageous when addressing ecological and sustainable development issues (Sandrin et al., 2024).

In the Finnish basic education system, an international perspective also fosters collaboration between schools and research institutions. Many schools actively participate in educational research projects initiated by universities, science centers, and cultural institutions, considering curriculum co-creation, instructional experimentation, and reflective assessment as integral parts of instructional development (Jokela & Hiltunen, 2024; Manninen, 2021; Manninen et al., 2025). Schools support teacher participation in research collaborations, enabling the continuous development of experimental and inquiry-based teaching methods in the classroom. Within this educational context, I implemented multiple teaching cycles in primary schools in Rovaniemi. Schools regarded the research activities as an opportunity to deepen curriculum practice and develop teaching that combines art and science.

The aims of phenomenon-based learning, thematic learning units, and ecological understanding in the national core curriculum support combining art and science in classroom

practice (FNAE, 2014). Phenomenon-based learning emphasizes observation and inquiry around real phenomena. This encourages teachers to adopt multi-sensory, multi-material, and multi-contextual teaching methods in curriculum design, allowing artistic expression and scientific observation to naturally intertwine in practice (FNAE, 2014; Lonka et al., 2018). In the Arctic region, this approach builds on easy access to the natural environment, where seasonal changes, natural materials, and ecological phenomena can be used directly in teaching. This was carried out through a series of ABAR action cycles, in which the tasks introduced earlier were progressively refined and the research questions were examined across different educational contexts. This also highlights the need for a more contextualised and theoretically in-depth exploration of teaching practices.

1.5 Networks and Partners of the Research

I carried out this research in collaboration with a network of institutions, schools, research units, and community participants in Northern Finland. The research developed within an educational environment in Rovaniemi where collaboration between schools and universities is well established (Figure 2). Teaching, research, and educational development are closely linked, creating conditions in which experimental pedagogical practices can be carried out in authentic classroom settings. This network enabled the three action cycles of the research to be implemented across different contexts. Two of these cycles were conducted in Rovaniemi, Finland, while one cycle was carried out in a school context in Changsha, China. Across these settings, the research was supported by institutional coordination, professional expertise, and local participation. Figure 2 illustrates the network of partners involved in the research and their relationships within the research process, with the University of Lapland forming the central institutional context connecting research, teacher education, and school collaboration.

University of Lapland: Research and Institutional Framework

This research is based at the University of Lapland, involving the Faculty of Art and Design and the Faculty of Education. It is also part of the Northern Art, Community and Environment Research (NACER) team, which explores art education, community-based practices, and Arctic perspectives. These institutional structures provided the academic framework for the research, including theoretical grounding, supervision, and methodological development.

Ujunnu Science Education Centre: A Platform Connecting Universities, Schools, and Educational Practice

Ujunnu Science Education Centre played an important role in connecting university research, schools, and local educational practices. It provided a collaborative platform that brought together expertise from different disciplines and supported cooperation among researchers, teachers, and external partners. Through Ujunnu, research activities were integrated into everyday school contexts. The centre supported the coordination of teaching schedules, communication with schools, and the organisation of teaching cycles. Its familiarity with school structures, curriculum requirements, and classroom conditions helped align research activities with ongoing

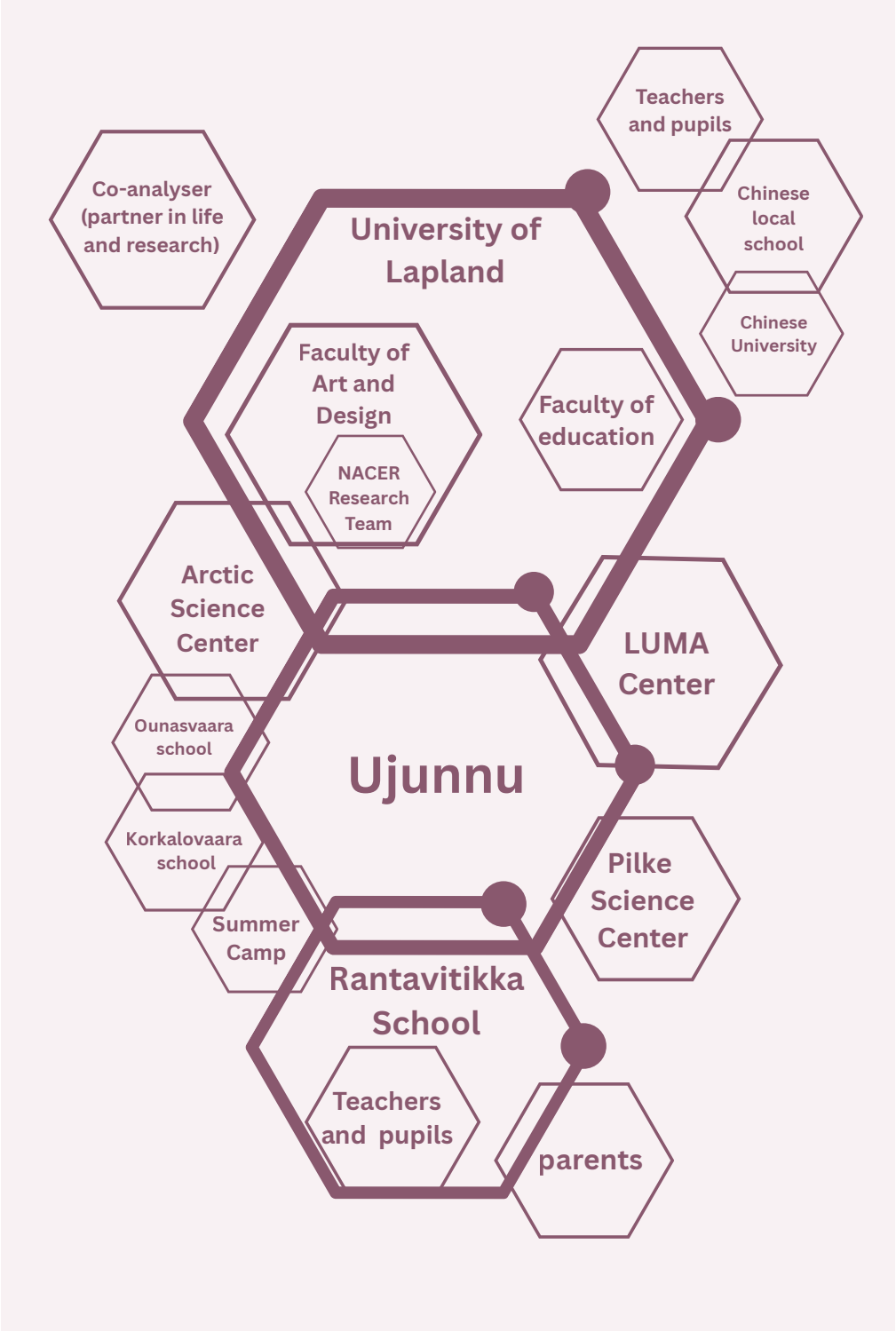


Figure 2. Network of institutional, educational, and research partners in the research. Xiaowei Zhang, 2026.

teaching while minimising disruption to school routines. During the research process, Ujunnu also contributed to the planning of teaching activities, including material preparation, activity design, and safety considerations. Members of the Ujunnu team participated in classroom observations, with attention to pupils' engagement and multimodal expression. Their observations informed reflection on each cycle and contributed to adjustments in subsequent teaching practices.

School Contexts and Participants

Several schools participated in the research, including Rantavitikka School as the main site, as well as Ounasvaara School and Korkalovaara School. These schools provided diverse classroom contexts in which the teaching cycles were implemented. Teachers and pupils were actively involved in the research, contributing to designing, implementing, and reflecting on the activities. Parents were also involved as part of the broader educational context, particularly in relation to pupils' learning beyond the classroom. The research also includes connections with Chinese educational contexts, including collaboration with an affiliated primary school of Central South University, China. These connections extend the research beyond the Finnish setting and contribute to its cross-cultural dimension.

LUMA Centre Lapland and Science Education Support

LUMA Centre Lapland functioned as a key partner in supporting the scientific aspects of the research. As part of the national LUMA Centre Finland network, it promotes engagement with science, mathematics, and technology through research-based educational practices. In this research, LUMA Centre Lapland provided support in experimental design, material selection, and safety guidance. It contributed to the development of activities involving colour change, material transformation, and microscopic observation. Its expertise ensured that scientific processes were accurately represented while remaining accessible and meaningful within school contexts.

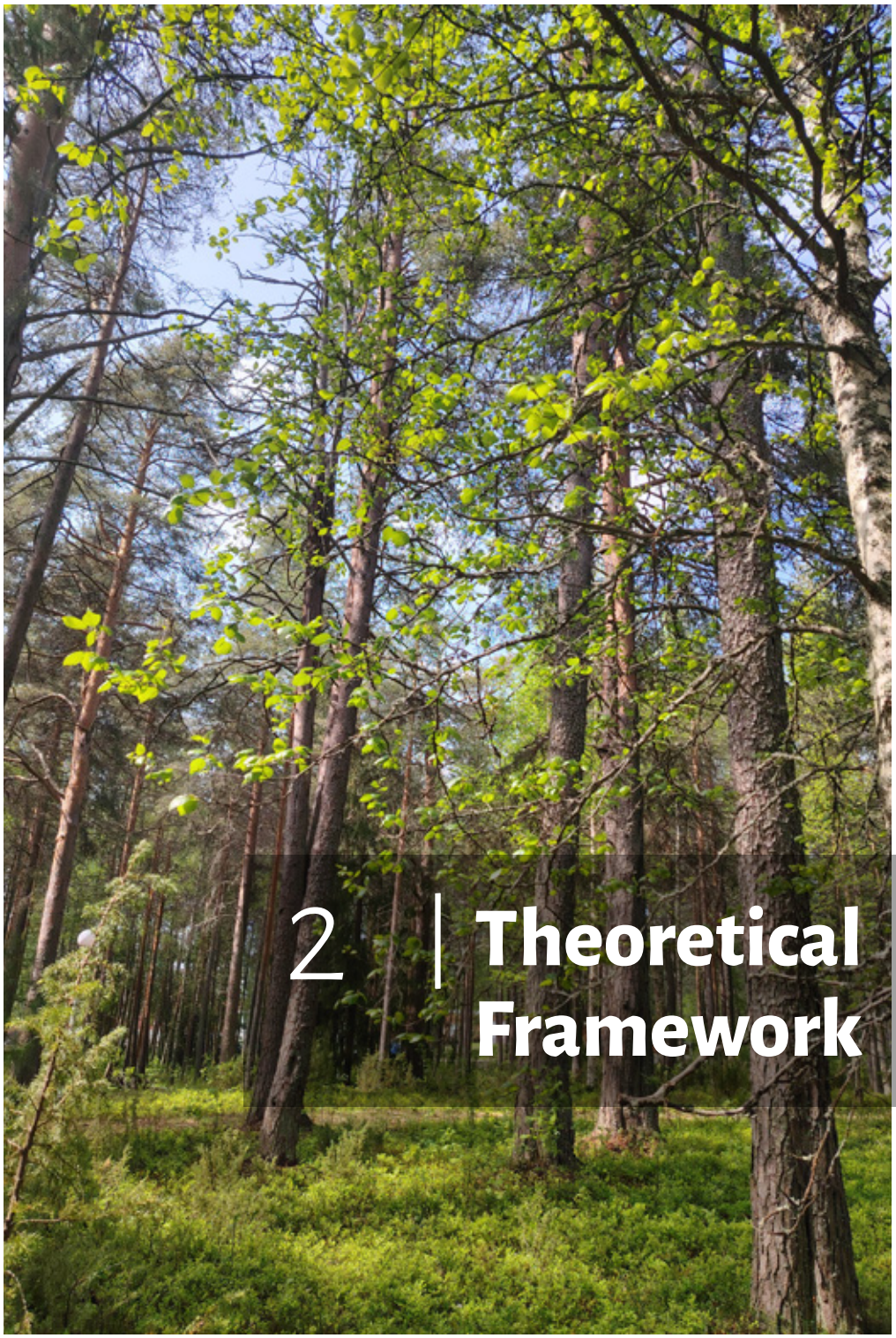
Arctic Science Centre, Pilke Science Centre, and Informal Learning Environments

In addition to school-based settings, the research was connected to informal learning environments, including the Arctic Science Centre and Pilke Science Centre. These institutions provided additional perspectives on science communication, environmental education, and public engagement. Summer camp activities and outdoor education contexts also formed part of the network, supporting the extension of activities beyond the classroom and enabling engagement with natural materials and environments.

Collaborative Roles and Knowledge Development

The research involved multiple roles, including the researcher, teachers, pupils, project members, and a co-researcher who contributed to the interpretation of the data. The co-researcher was an experienced researcher in the natural sciences, whose expertise supported the interdisciplinary analysis. These roles reflect the collaborative nature of ABAR, where knowledge develops through shared engagement with practice. Across this network, research developed through connections between institutional structures, educational practices, and local

environments. Collaboration among partners supported the design and implementation of interdisciplinary art–science activities, while also helping to shape context-sensitive pedagogical knowledge.



2 | Theoretical Framework

Image 2. Interconnected ecologies of learning and environment. Photograph: Xiaowei Zhang, 2025.

2.1 Art–Science Education: Conceptual Orientation

Art–science education provides a way to examine how knowledge is produced, experienced, and communicated across disciplinary boundaries in contemporary education (Ingold, 2013; Sederholm, 2017). Increasing attention has been given to approaches that connect artistic and scientific ways of knowing, particularly in response to complex phenomena that involve ecological, material, and cultural dimensions (Kairavuori & Knif, 2016; Liao, 2016). Within these discussions, art–science education highlights how understanding develops through perception, material engagement, creativity, and conceptual inquiry (Bequette & Bequette, 2012; Land, 2013). This perspective provides the conceptual foundation for understanding how artistic and scientific practices can be brought together in interdisciplinary learning.

School subjects are typically organised into clearly defined disciplinary areas (Komulainen et al., 2020), each with its own methods, traditions, and forms of assessment (Gresnigt et al., 2014). Science education is associated with observation, explanation, hypothesis formation, and analytical reasoning, while art education places greater emphasis on perception, expression, interpretation, and material exploration (Eisner, 2002; Dewey, 1934). Despite these differences, research has shown that both domains share important epistemic practices, including close attention to phenomena, experimentation, and the interpretation of change (Bequette & Bequette, 2012; Drake & Burns, 2004). Previous research shows that these shared processes make it possible to examine learning across disciplinary boundaries and to support more connected forms of understanding (Gresnigt et al., 2014; Macdonald et al., 2022). Art–science education extends beyond combining subjects by emphasising shared ways of knowing developed through inquiry and experience (Ingold, 2013).

Within art–science education, chemistry offers particular possibilities for integration with visual art because chemical processes often involve observable changes in colour, texture, form, and material properties. Earlier studies have explored connections between chemistry and art through artistic materials, chemical processes, and classroom experimentation (Greenberg, 1988; Greenberg & Patterson, 2007). Art-based chemistry activities can support conceptual understanding by allowing students to approach chemical phenomena through experimentation and visual representation (Danipog & Ferido, 2011). Research with science teachers has also shown that art can be integrated into science education through visualisation, creative activities, and inquiry, although the forms and depth of integration vary in classroom practice (Turkka et al., 2017). More recent work has extended art–science approaches in chemistry

education towards sustainability and community-based environmental engagement (Blatti, 2025). These studies position art–chemistry integration as a pedagogical field in which scientific inquiry and artistic practice can develop through shared engagement with materials and observable transformations.

In my research, I use interdisciplinary as the key concept to describe the relationship between art and science. This choice requires clarification in relation to multidisciplinary and transdisciplinary approaches, which are often used interchangeably in discussions of integrated STEAM education (Perignat & Katz-Buonincontro, 2019). Multidisciplinary approaches typically organise disciplines around a shared theme while maintaining their boundaries, allowing each subject to contribute from its own perspective (Drake & Burns, 2004). Interdisciplinary approaches involve a higher level of integration, where concepts, methods, and perspectives from different disciplines contribute to more integrated forms of understanding (Kairavuori & Knif, 2016; Klein & Newell, 1997; Newell, 2007). Transdisciplinary approaches extend beyond disciplinary structures and often address complex real-world problems through broader forms of knowledge production (Liao, 2016).

Interdisciplinarity is adopted as the central concept in this dissertation because my dissertation examines how pupils develop understanding through artistic and scientific engagement with shared phenomena (Bequette & Bequette, 2012; Macdonald et al., 2022). Visual arts and science retain their distinctive disciplinary perspectives while creating opportunities for pupils to connect artistic and scientific ways of knowing through shared practices, including observation, experimentation, material engagement, interpretation, and creative inquiry (Kairavuori & Knif, 2016; Klein & Newell, 1997; Newell, 2007). Through these practices, pupils connect sensory experience with conceptual understanding and creative expression, supporting the development of creativity, scientific understanding, inquisitive thinking, and ecological understanding (Land, 2013; Perignat & Katz-Buonincontro, 2019). In my dissertation, interdisciplinarity serves as the conceptual framework for analysing pupils' learning across artistic and scientific ways of knowing. The focus is on how pupils construct creativity, scientific understanding, inquisitive thinking, and ecological understanding through interdisciplinary learning experiences organised around shared phenomena.

The organisation of these interdisciplinary learning experiences also requires attention to pedagogical design. Integrated curriculum design involves decisions about disciplinary aims, learning activities, materials, and how different forms of knowledge are connected within a shared educational situation (Drake & Burns, 2004; Gresnigt et al., 2014). In art–science education, pedagogical design can involve selecting shared phenomena and materials, sequencing activities, and creating opportunities for pupils to move between scientific observation and experimentation and artistic exploration, interpretation, and expression (Bequette & Bequette, 2012; Perignat & Katz-Buonincontro, 2019). Teacher guidance influences these processes by directing attention, supporting inquiry, and providing time for experimentation and reflection. In this dissertation, pedagogical design refers to the organisation of disciplinary aims, materials, activities, learning environments, and teacher guidance that creates conditions for pupils' interdisciplinary engagement.

2.2 Material Engagement as a Way of Knowing

New Genre Arctic Art Education (AAE) provides the art educational framework for this dissertation. It responds to the ecological, cultural, and social conditions of northern regions (Huhmarniemi & Jokela, 2025; Jokela & Hiltunen, 2024). It builds on earlier developments in Arctic art education, where artistic practices are closely connected to local environments, seasonal cycles, and community life (Hiltunen, 2009; Jokela et al., 2019; Jokela & Huhmarniemi, 2022). Art is approached as a situated and relational practice shaped by people, materials, and environments. Artistic practice is situated within everyday life and environmental processes, reflecting broader shifts in contemporary art education towards contextual and place-responsive approaches (Huhmarniemi, 2016). Similar approaches to art–science integration in Arctic contexts have also been explored in Arctic education research, where interdisciplinary practices connect artistic processes with ecological inquiry and sustainability education (Stoll et al., 2024; Sørmo et al., 2024).

Art education in Arctic contexts highlights how environmental conditions, seasonality, and material variability shape artistic processes and educational experiences (Hiltunen, 2009; Huhmarniemi et al., 2021; Jokela & Huhmarniemi, 2022). Materials such as snow, ice, wood, and natural fibres change over time, requiring learners to respond to material behaviour and environmental conditions (Stöckell & Jokela, 2024). Such encounters create opportunities for artistic exploration and scientific observation to develop around shared materials and natural phenomena (Sørmo et al., 2024). Within Arctic educational contexts, knowledge develops through engagement with material and environmental conditions (Huhmarniemi et al., 2021). Art-based action research highlights how knowledge develops through practice, where bodily activity, material processes, and environmental contexts are closely intertwined (Jokela et al., 2019; Jokela, 2019). Within AAE, artistic knowing develops through material exploration, interpretation, participation, and place-responsive practice (Jokela & Huhmarniemi, 2022; Huhmarniemi & Jokela, 2025). Within interdisciplinary education, scientific knowing develops through observation, experimentation, inquiry, and the interpretation of natural phenomena (Bequette & Bequette, 2012; Macdonald et al., 2022). Artistic practice is also understood as place-responsive, participatory, and materially grounded, extending discussions of art beyond individual self-expression (Jokela & Huhmarniemi, 2022). Artistic and scientific ways of knowing retain their distinctive characteristics while becoming connected through shared engagement with materials, environments, and natural phenomena.

Creativity in art education has been associated with imagination, perception, interpretation, experimentation, and the capacity to transform experience into new forms of representation (Eisner, 2002; Vecchi, 2010). Artistic creativity involves processes of noticing, exploring possibilities, making decisions, revising ideas, and responding to emerging situations. In interdisciplinary contexts, creativity can also connect artistic exploration with inquiry as learners move between observation, experimentation, interpretation, and representation (Land, 2013). Material and place-responsive practices further situate creative processes within encounters with materials, environmental conditions, and emerging situations, where materials can redirect intentions and open new possibilities for interpretation and making (Ingold, 2013; Jokela & Huhmarniemi, 2022). Within this conception of art, creativity extends beyond individual self-expression and emerges through exploration, interpretation, and responsiveness

to materials, environments, and changing conditions. Imagination, emotional response, and expression remain integral dimensions of this creative process.

This understanding also situates artistic practice within collective, cultural, and ecological contexts. AAE engages with varied ways of knowing, including artistic, cultural, ecological, and, in some cases, Indigenous perspectives (Hiltunen, 2009; Jokela & Hiltunen, 2024). Its orientation reflects a movement from individually oriented artistic production towards collective and socially engaged practices in which participation occurs through shared activities and communal contexts. Knowledge develops through participation, dialogue, and the exchange of experiences, connecting artistic practice with broader social and cultural processes. Environmental conditions, material properties, and ecological processes also influence artistic practices and the situations in which they take place (Jokela & Huhmarniemi, 2022). New materialist perspectives further emphasise that learning develops through relationships among pupils, materials, and environments (Barad, 2007; Bennett, 2010). These perspectives provide a broader theoretical understanding of material engagement within AAE. This framework also connects artistic practice with ecological awareness and sustainability in Arctic contexts, where environmental change, resource use, and human–environment relations form part of educational experience (Jokela & Coutts, 2021).

Within New Genre Arctic Art Education, the Arctic is approached through environmental, sociocultural, and pedagogical conditions that shape artistic practice, material engagement, place-responsive processes, and ways of knowing (Jokela & Hiltunen, 2024; Jokela & Huhmarniemi, 2022). Finland's Arctic context also carries geographical and societal dimensions that extend beyond a strictly latitudinal understanding of the region (Valtioneuvosto, 2021). In Northern Finland, seasonal environmental conditions, local ecological knowledge, and material availability provide a situated basis for place-responsive artistic and educational practices. These contextual conditions informed the selection of materials, the organisation of activities, and the interpretation of pupils' engagement across the action cycles. AAE provides a framework for examining pupils' artistic engagement as a process that includes imagination and expression while remaining connected to material exploration, environmental phenomena, participation, and place. This perspective also supports the interdisciplinary orientation of the dissertation by providing a basis for examining how artistic and scientific ways of knowing become connected through pupils' engagement with materials and natural phenomena.

2.3 Pupils' Multimodal and Embodied Learning

In art–science education, pupils' learning develops through active engagement with their surroundings, where perception, action, and social participation shape how they make sense of natural phenomena (Anttila, 2015; Kewalramani & Veresov, 2022; Vygotsky, 1978). In early and primary education, pupils rarely approach knowledge through abstract reasoning alone. Learning often begins with pupils observing, touching, moving, comparing, and manipulating materials within specific situations. These activities involve multiple modes of engagement, including visual, tactile, kinaesthetic, and verbal processes, which together shape how meaning gradually emerges (Vygotsky, 1978).

A multimodal perspective provides a useful lens for examining how these processes operate in practice (Wright, 2010). When pupils encounter new phenomena, they often move

fluidly between drawing, gesture, speech, and material manipulation. A line drawn on paper may represent movement, a hand gesture may express change, and spoken language may accompany both. These modes function in coordination, allowing pupils to organise perception and explore relationships within what they experience (Kewalramani & Veresov, 2022). Meaning-making develops through the connections established across different representational modes (Wright, 2010). Within this interplay, visual forms often take on a central role. Research on visual literacy has shown that meaning-making develops through interpretive engagement with images, where learners connect perception, representation, and personal experience (Qureshi et al., 2022; Qureshi, 2023).

This multimodal process becomes particularly visible (Anttila, 2015; Sederholm, 2025; Vecchi, 2010). Pupils use drawing, colour, composition, and modelling to externalise what they notice and to reshape their ideas over time. These activities are part of a continuous process in which observation, interpretation, and revision remain closely connected (Vecchi, 2010). When pupils revisit their own work, they adjust forms, refine details, and reconsider relationships, allowing understanding to evolve through visual and material engagement. In art–science contexts, these processes support pupils in approaching phenomena that involve transformation, variation, and movement, which may be difficult to stabilise through language alone (Arcadias et al., 2020). Attention to embodiment brings further depth to this discussion. Pupils' engagement with their surroundings is always mediated through the body. Movement, posture, gesture, and sensory coordination influence how they approach materials and how they interpret change (Anttila, 2015). When interacting with substances such as water, snow, clay, or pigment, pupils adjust pressure, direction, distance, and speed in response to material conditions. These adjustments guide attention and shape perception. Learning emerges through these continuous shifts between action and response, where bodily experience and material feedback remain closely intertwined (Thomas Jha & Price, 2022; Wilson, 2002).

This embodied engagement is also closely linked to early scientific understanding. Observing change, recognising patterns, and making comparisons often develop as learners engage directly with materials and their surroundings (Beery & Jørgensen, 2018; Ernst & Burcak, 2019). Pupils may follow the movement of liquid, observe changes in colour, or notice differences in texture before these observations are articulated in conceptual terms. Gestures, action, and visual representation precede verbal explanation and support later conceptual development (Thomas Jha & Price, 2022). Scientific meaning begins to take shape within these sensory and bodily encounters (Dewey, 1934; Malafouris, 2013). Pupils' learning is shaped by affective and emotional engagement (Cheung et al., 2019; Kuo et al., 2024). Experiences of curiosity, enjoyment, surprise, and concentration influence how pupils participate in activities and how long they remain involved (Cronqvist, 2021). These affective dimensions are closely connected to sensory and material experiences, particularly in contexts where colour, movement, rhythm, and transformation are present (Anttila, 2015; Beery & Jørgensen, 2018). Emotional engagement can support sustained attention and creative exploration, contributing to deeper involvement in learning processes (Eddy et al., 2021).

Natural and outdoor environments provide important contexts for multimodal and embodied learning, where pupils engage with changing materials, environmental conditions,

and natural phenomena through sensory exploration and physical activity (Beery & Jørgensen, 2018). Engagement with natural materials such as water, soil, plants, or snow enables participants to observe processes of change while also participating in them through embodied action (Huhmarniemi & Lande, 2025; Yläjoki & Huhmarniemi, 2025). These environments invite movement, experimentation, and attention to subtle differences, supporting the development of perception and imagination (Dewey, 1934; Ingold, 2013).

Therefore, pupils' learning develops through perception, bodily engagement, material exploration, and expression. In art–science education, these dimensions are often activated simultaneously. Pupils draw what they observe as well as what they imagine, move in response to change, manipulate materials to test ideas, and communicate their experiences through multiple forms. This interweaving of modes provides a foundation for examining how learning develops across the ABAR cycles of this dissertation. It focuses in particular on material processes and environmental engagement in Arctic educational contexts.

2.4 Material Engagement in Learning Processes

Material engagement plays a central role in learning processes in art–science education. In classroom practice, materials actively participate in directing attention, influencing action, and shaping the development of understanding (Malafouris, 2013). When learners work with pigments, water, snow, clay, fibres, or other substances, they encounter processes of change that exceed prior expectations. Encounters with materials introduce variation, resistance, and transformation into situations, guiding how learners observe, respond, and interpret interpret emerging processes (Malafouris, 2013). From the perspective of material engagement, learning develops through learners' engagement with materials as they observe, manipulate, test, and interpret changing material conditions (Ingold, 2013). As learners mix, press, pour, stretch, or layer materials, they encounter changing colours, textures, forms, and movements. These material changes invite further observation, adjustment, and experimentation, encouraging learners to refine their actions and interpretations. Understanding develops gradually as learners attend to these changing material conditions (Tang, 2022).

In art education, material processes often guide the direction of creative work (Hood & Kraehe, 2017; Ingold, 2013). The behaviour of materials can redirect intention, introduce unexpected outcomes, and open new possibilities for exploration. A change in viscosity, a shift in colour intensity, or the instability of a surface may lead learners to reconsider their approach and develop new forms of expression. Creative decisions are frequently shaped through engagement with changing material conditions, where materials influence both the process and the emerging form of the work (Marshalsey, 2023). This engagement supports artistic knowing through creative exploration while simultaneously supporting scientific knowing through observation, experimentation, and comparison (Bequette & Bequette, 2012; Eisner, 2002; Macdonald et al., 2022). Learners observe reactions, compare outcomes, and recognise patterns as they work with substances and natural phenomena. Processes such as diffusion, phase change, and structural transformation become perceptible through material variation, allowing learners to construct explanations grounded in observation and comparison. In this way, sensory experience becomes increasingly connected with emerging conceptual understanding (Macdonald et al., 2022; Tang, 2022).

Material engagement also shapes the temporal structure of learning processes. Materials introduce rhythms into practice through processes that unfold over time. Colour spreads gradually in liquid, ice melts at varying speeds, and fibres respond differently to tension or moisture. These temporal qualities influence the pace of activities and encourage learners to observe processes as they develop. Attention shifts from fixed outcomes towards ongoing change, allowing learners to remain engaged with the unfolding of phenomena (Marshalsey, 2023). Learning becomes closely tied to duration, repetition, and variation within material processes. Materials contribute to the organisation of environments. Their properties influence how learners position themselves, how they move within space, and how they collaborate with others. A large surface may invite collective work, while small-scale materials may focus attention on detail. Fluid substances encourage movement and adjustment, while more stable materials support precise manipulation. These spatial qualities shape how pupils participate in shared learning activities and how learning experiences develop.

Materials also connect pupils' experiences with environmental and ecological conditions. Material behaviour is shaped by factors such as temperature, humidity, light, and seasonal variation, making these conditions part of the learning process when natural materials are used. Through engaging with such changes, learners begin to relate material transformations to broader ecological processes, linking classroom activity with environmental awareness (Firth et al., 2016). In art–science education, materials provide a shared ground for creative exploration and scientific inquiry. Observation, experimentation, and expression become interconnected as learners respond to material behaviour and develop interpretations through practice. These perspectives highlight the importance of material engagement for understanding creativity, scientific understanding, and inquiry in interdisciplinary art–science education.

2.5 Relational Perspectives in Art–Science Education

Relational perspectives in contemporary educational research offer a way to understand learning as emerging through connections among learners, materials, environments, and cultural contexts (Ingold, 2013; Jokela & Hiltunen, 2024; Jokela & Huhmarniemi, 2022). Within this orientation, knowledge develops in relation to surroundings, where perception, action, and interpretation evolve in situated conditions (Malafouris, 2013). Learning processes can be examined through the relations that shape them, including material conditions, spatial arrangements, temporal rhythms, and environmental dynamics. These relations provide the conditions through which pupils develop creativity, scientific understanding, and ecological understanding in interdisciplinary learning.

New materialist approaches extend relational perspectives by emphasising that learning develops through relationships among learners, materials, and environments (Barad, 2007; Hood & Kraehe, 2017; Jokela et al., 2019). These perspectives recognise that material properties shape how learning unfolds by influencing attention, action, and interpretation. The concept of intra-action describes relationality as emerging through ongoing relations among people, materials, and environments, where these elements become meaningful through their mutual constitution (Barad, 2007). From a practice-oriented perspective, the concept of material engagement explains how learning develops through learners' engagement with changing material conditions (Malafouris, 2013). In this view, thinking is distributed across bodies, tools, and

environments, with action and perception closely intertwined. In Arctic educational contexts, such approaches are informed by New Genre Arctic Art and Art Education, which has its roots in environmental education through art. Relations to place, materials, and ecological conditions are emphasised, with understanding developing through engagement with changing environments and material processes (Huhmarniemi et al., 2021). Engagement with materials enables learners to externalise thought, test possibilities, and reorganise perception. Through these processes, thinking becomes closely connected to material engagement and environmental experience.

Bennett's (2010) notion of vibrant matter draws attention to the capacities of materials within these relational processes. Materials exhibit tendencies that influence movement, attention, and engagement. Their behaviour contributes to the direction of activity, guiding how learners respond and adjust in real time. Variations in texture, temperature, movement, and resistance can redirect exploration and open new possibilities. Material dynamics shape engagement with practice, with an emphasis on process, participation, and experience in art education research. Art education situates learning within relationships among bodies, materials, and environments, where meaning develops through making, observing, and reflecting (Barone & Eisner, 2012; Leavy, 2009).

Artistic processes often involve iterative engagement, where each action leads to further adjustments and reinterpretations (Jokela et al., 2019). These processes support forms of understanding that develop gradually, shaped by sensory experience and material exploration. In art–science education, such perspectives support forms of integration that develop through activity, where artistic and scientific approaches become connected as learners engage with materials, observe transformations, and construct interpretations grounded in experience. Scientific observation and artistic exploration are closely intertwined, guided by attention to material change and environmental conditions. Within these processes, artistic knowing develops through creative exploration and interpretation, while scientific knowing develops through observation, experimentation, and inquiry.

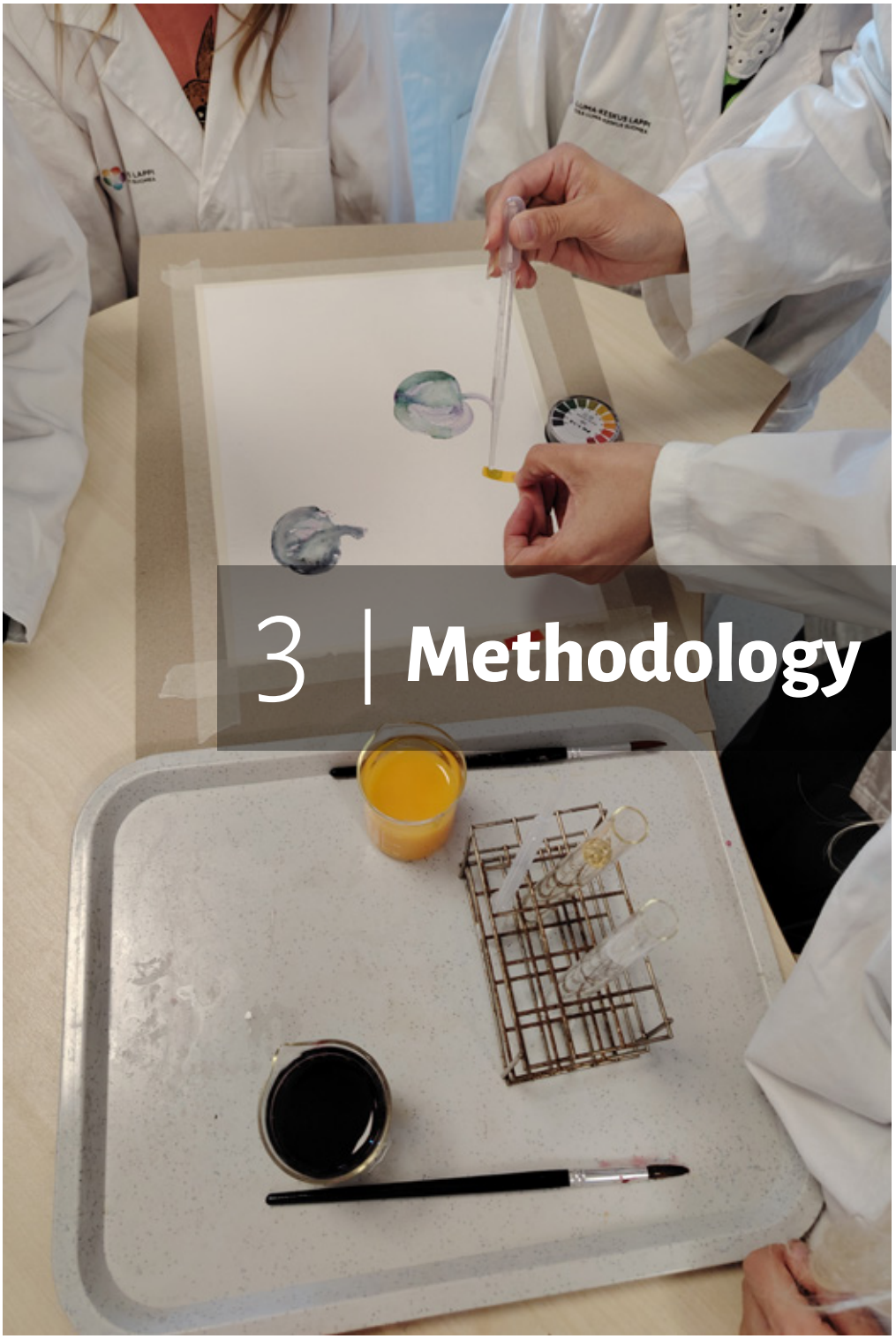
Relational perspectives also connect with approaches that situate education within ecological and environmental contexts. Materials carry traces of these conditions, and engagement with them brings ecological relations into focus. In this dissertation, relational perspectives provide a framework for analysing how processes develop in art–science education. The analysis focuses on pupils' engagement with materials, environments, and one another, together with the conditions that shape these engagements. These perspectives provide the theoretical basis for examining how creativity, scientific understanding, inquisitive thinking, and ecological understanding develop through interdisciplinary engagement with natural materials.

2.6 Arctic Contexts in Art Education

Arctic art education is shaped by specific ecological, cultural, and geographical conditions, with educational processes closely connected to local environments and knowledge systems (Huhmarniemi et al., 2021; Manninen et al., 2025). In northern regions, educational practices often engage with seasonal changes, natural materials, and community traditions. These ecological and cultural conditions provide the context for interdisciplinary learning in which pupils engage with natural materials, local environments, and seasonal phenomena (Jokela

& Huhmarniemi, 2022). Ecocultural art education provides an important pedagogical orientation in these contexts by connecting artistic practice with environmental awareness and sustainability concerns (Knif & Kairavuori, 2020). Grounded in engagement with nature, it emphasises ecological processes through creative activity, encouraging attention to natural systems, material transformation, and environmental change (Inwood, 2013). Understanding emerges through observation, experimentation, and interpretation, as students work with natural materials and respond to environmental conditions. In ecocultural art education, artistic exploration and scientific observation are understood as complementary ways of engaging with ecological phenomena. Engagement with land and ecosystems supports forms of perception that move beyond representational approaches and open up ways of exploring ecological relationships through artistic practice (Huhmarniemi & Jokela, 2025).

Place-based education further strengthens this orientation by situating educational practices within local environments and emphasising cultural and ecological specificity (Inwood, 2008). In Arctic ecological art education research, educational practices are developed to draw on local traditions, seasonal cycles, and relationships with the Land, shaping how knowledge is experienced and transmitted (Huhmarniemi et al., 2021). These practices connect cultural heritage and environmental awareness and help develop a connection to place and community. By engaging with nearby environments, knowledge is integrated into cultural practices and ecological systems. Sustainability has become a central concern in Arctic art and art education, particularly in response to environmental change and ecological uncertainty (Knif & Kairavuori, 2020). Educational practices address issues related to climate change, resource use, and cultural resilience, reflecting broader developments in sustainability education (Jokela & Coutts, 2021). Artistic processes provide ways of engaging with these issues through sensory and material exploration, supporting reflection on human–environment relationships. These perspectives support interdisciplinary learning by connecting creativity, scientific inquiry, and ecological understanding through engagement with place and natural materials.



3 | Methodology

Image 3. Experimental practices in art-science. Photograph: Xiaowei Zhang, 2025.

3.1 Art-Based Action Research

My dissertation adopts Art-Based Action Research (ABAR) as its overall methodological framework. The research is organised around three major action cycles, each consisting of iterative processes of planning, implementation, observation, reflection, and redesign. Several successive classroom implementations are conceptualised as iterative phases within a broader action cycle. This organisation better reflects the cyclical nature of ABAR, where pedagogical decisions continuously evolve through reflection on previous implementations (Jokela & Huhmarniemi, 2025; Jokela et al., 2019). The first action cycle established the pedagogical foundations for interdisciplinary art–science education through chemistry-based classroom practice. This cycle consisted of a series of interconnected classroom implementations in primary education. The second action cycle formed the starting point, and reflections from each implementation informed the design of the subsequent activities. The third action cycle extended this line of inquiry through recycled papermaking, examining how material transformation and ecological processes support interdisciplinary art–science learning. These three action cycles constitute one continuous ABAR process and form the empirical basis for the four publications included in this dissertation. The second action cycle resulted in two publications through successive classroom implementations: one research article and one visual essay.

Artistic activities, pedagogical actions, and research reflection are understood as interwoven processes. The research advances from within practice itself, with its direction and guiding questions continuously emerging in response to participants and contextual conditions (Jokela & Huhmarniemi, 2025). ABAR offers a methodology suited to complex educational contexts, allowing understanding to develop through evolving practice. Reflection on each action cycle informed subsequent pedagogical decisions, including the selection of materials, learning activities, and educational contexts. Through repeated cycles of action and redesign, the research traces how change accumulates over time and contributes to the formation of situated knowledge (Jokela, 2019). This temporal continuity enables close attention to subtle variations in teaching practice.

In educational research, action research is recognised as a key methodology for developing educational practices through iterative cycles of planning, action, observation, and reflection in authentic school settings (Kemmis et al., 2014). Contemporary studies describe action research as a participatory and practice-oriented approach that supports the development of teaching and learning through collaboration among researchers, teachers, and learners in response to local educational contexts (Francisco et al., 2024; Lynch et al., 2024). This tradition provides the methodological foundation for ABAR, which extends educational action research by integrating artistic practice, material exploration, and multimodal forms of inquiry into the research

process. Within this approach, pedagogical development, classroom practice, and research are closely interconnected, enabling educational knowledge to emerge through iterative cycles of implementation, reflection, and redesign (Kemmis et al., 2014).

ABAR has been applied in previous studies as a methodological approach for examining such processes, enabling the documentation and analysis of non-verbal and process-oriented experiences in practice (Härkönen, 2021; Korsström-Magga, 2025). Traces of artistic processes, temporary structures created during experimentation, and small-scale collaborative actions in classroom settings are all regarded as meaningful research materials (Heinonen, 2025; Jokela et al., 2019). Within the ABAR, the researcher takes on a fluid position, participating in artistic and pedagogical processes while remaining reflective towards practice (Hiltunen et al., 2020). This dual positioning requires ongoing judgment in action, allowing the research process to develop in parallel with teaching. This positioning also enabled findings from one action cycle to inform the redesign of subsequent cycles, supporting the cumulative development of the research.

The cyclical structure of ABAR, organised through planning, action, reflection, and re-planning, forms the basis for each action cycle in this research. Each cycle develops earlier experiences and involves adjustments to materials, experimental design, and chemistry-based experimental procedures. Through this continuity, it becomes possible to trace how pedagogical ideas take shape in practice and how they are refined across successive cycles (Jokela & Huhmarniemi, 2022).

The research develops as an interconnected process in which pedagogical practice, data generation, analysis, and academic output are closely related. Teaching activities, reflective work, and research dissemination evolve together, allowing the research to grow through continuous

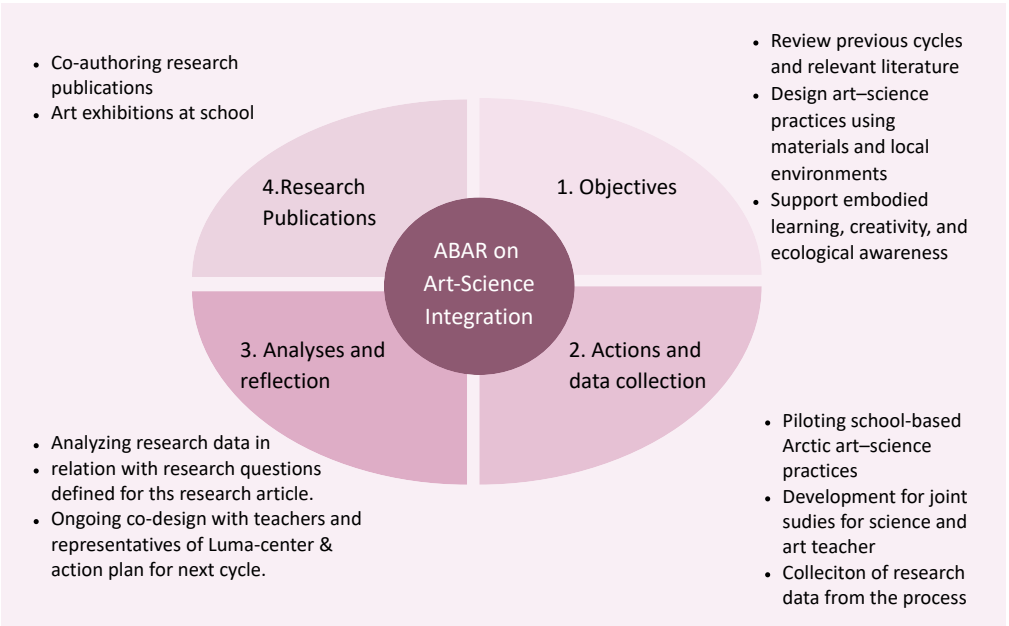


Figure 3. Overall structure of the ABAR process, including objectives, actions, data creation, analysis, and research outputs. Xiaowei Zhang, 2026

engagement with educational situations. Throughout the process, the research aims, classroom intervention, and outcomes remained closely connected, with experiences from practice shaping subsequent action cycles and their interpretation.

Figure 3 presents the overall organisation of the ABAR process in this research, showing how objectives, pedagogical actions, data creation, analysis, and research outputs are connected. This figure illustrates how research moves across several interrelated phases. The research begins with the formulation of research objectives, which guide the design of pedagogical activities in school contexts. These activities generate empirical materials through observation, documentation, and participation. Analytical and reflective work then examines these materials and informs further development of teaching practices. The process also extends to research dissemination, including academic publications and public engagement. The phases remain connected throughout the research process, as developments in one phase continue to influence the direction and interpretation of the others.

3.2 Data collection

The empirical material presented in this dissertation was generated across three action cycles conducted in different educational contexts in China and Finland. Data collection combined qualitative and arts-based research methods to document pupils' artistic and scientific engagement across the action cycles. The empirical material included classroom observations, process photographs and videos, pupils' artworks, group discussions, interviews, reflective diaries, and documentation generated through pupils' participation in the teaching activities. These data were collected across multiple sites, including classrooms, outdoor school environments, nearby forests, and other natural settings shaped by seasonal variation.

The three action cycles involved participants from different age groups and educational contexts (Figure 4). The research began with primary school pupils in China and later extended to primary and lower secondary education in Finland. Teachers and parents also contributed to selected parts of the research, providing contextual perspectives on pupils' experiences and educational settings. Altogether, the research involved 98 participants across the three action cycles.

Each form of empirical material served a specific purpose in the research. Pupils' artworks provided insights into artistic interpretation and meaning-making, while classroom observations, field notes, photographs, and video recordings documented participation, material processes, and experimental changes. Pupils' dialogues and oral reflections captured their observations and emerging ideas, complemented by teachers' contextual perspectives on the educational activities. My reflective diary recorded pedagogical decisions and adjustments across the action cycles.

In arts-based research, data emerge through artistic processes and function as forms of meaning-making that develop in practice. Artistic practices are understood as both modes of inquiry and forms of knowledge production (Barone & Eisner, 2012; Leavy, 2017). Pupils' artworks, process documentation, and multimodal expressions are approached as epistemic forms that reveal how knowledge develops through sensory experience, material exploration, and creative expression. In ABAR, data collection is embedded in iterative cycles of planning, action, observation, and reflection (Jokela & Huhmarniemi, 2025; Jokela, 2019; Jokela et al., 2019). Artistic processes remain responsive to materials, environmental conditions, and participants' actions, allowing these elements to shape what becomes visible during the research process.

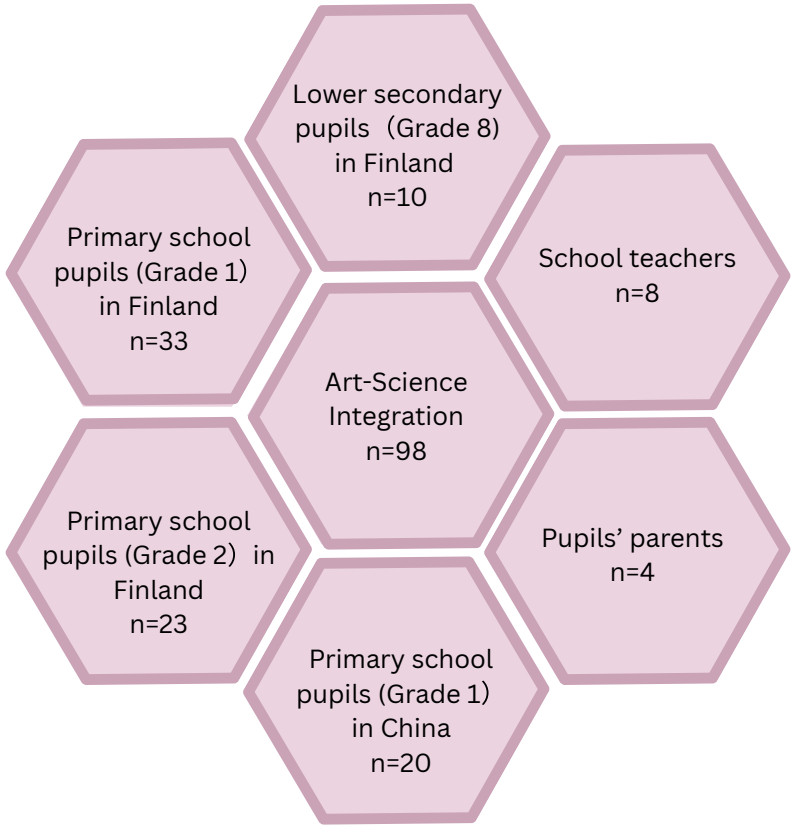


Figure 4. Overview of participants. Xiaowei Zhang, 2026.

Each action cycle generated a substantial body of empirical material. Data collection developed iteratively across the three cycles, as reflections from earlier activities informed subsequent decisions concerning the selection of materials, pedagogical activities, research settings, and forms of documentation. The three action cycles generated the empirical basis for the three peer-reviewed publications, and one visual essay included in this dissertation.

3.3 Data Analysis

Data analysis was guided by the research questions, empirical material, and educational context of each study, with analytical approaches selected according to the characteristics of each dataset and the aims of the individual publication. Table 1 summarises the research questions, empirical material, and analytical approaches used in the three empirical studies. The findings were synthesised to address the overarching research question and examine the development of interdisciplinary art–science learning across the three action cycles. These publications provide the basis for the cross-publication synthesis presented in this dissertation.

The analytical approaches differed across the three empirical studies according to their research questions and empirical material. Publication I employed inductive content analysis together with inductive visual coding of pupils' artworks. Publication II employed inductive content

Publication	Research question	Empirical material	Analytical approach
I. Integrating art and science in education: Cultivating creative expression and inquisitive thinking. (IJEA)	How does integrating art and chemistry promote students' creative expression, inquisitive thinking, and emotional engagement?	Researcher observation diary, students' artworks, oral reflections, and documentary photographs of the teaching process	Inductive content analysis; inductive visual coding of artworks.
II. The bilberry experiment for Arctic STEAM education (SJER)	1. What role do artistic modes of expression play in pupils' meaning-making of scientific phenomena when using bilberries as natural pigments? 2. In what ways does the integration of chemistry and visual arts through bilberry-based experiments foster emerging science during classroom-based inquiry?	Pupil paintings, documentary photographs of some collaborative snow artworks, classroom observation notes, video recordings and informal pupil dialogues during the creative process. Classroom teachers and parent interviews.	Inductive content analysis; thematic analysis.
III. Trees, forests, and recycled paper: art–science approaches to ecological understanding in Northern Finland. (EER)	How did children articulate ecological understanding and their own roles in relation to forest environments through embodied, material, and imaginative engagement in art–science activities?	Children's drawings, photographs, field notes, reflective records, and semi-structured interviews with four teachers.	Inductive content analysis; close looking.

Table 1. Overview of the Research Questions, Empirical Material, and Analytical Approaches Used in the Three Empirical Studies. Xiaowei Zhang, 2026.

analysis and thematic analysis, while Publication III combined inductive content analysis with close looking. Despite differences among the analytical approaches, the analyses shared several common stages. The analytical process began with repeated reading and review of the empirical material in relation to the research questions of each study. Verbal, observational, and visual materials were then examined and coded to identify recurring patterns, responses, and interpretations. Related codes were compared and organised into broader categories or themes according to the analytical approach used in each cycle. Visual materials were examined in relation to their material, visual, and contextual features and compared with observational and verbal material from the same activities. Then, the emerging categories and themes were interpreted in relation to the research questions and theoretical perspectives of each publication. The findings from the three empirical studies were compared and synthesised in relation to the dissertation-level research questions.

Across the dissertation, analysis was informed by arts-based research (Barone & Eisner, 2012) and visual methodology (Leavy, 2009), with attention to pupils' sensory and multimodal expression (Vecchi, 2010; Wright, 2010). The analytical procedures drew on thematic analysis (Braun & Clarke, 2012), close looking (Brooks, 2009), and principles of inductive coding outlined by Saldaña (2021). The visual essay employed visual documentation and arts-based reflection. Reflexive interpretation formed an integral part of the analytical process (Finlay, 2002).

As both educator and researcher, I documented pedagogical decisions and analytical reflections throughout the three action cycles. These reflexive records informed the interpretation of the empirical material and supported transparency in the analytical process. The synthesis presented in this dissertation extends beyond the findings of the individual publications by identifying recurring patterns in artistic engagement, material exploration, interdisciplinary learning, and ecological understanding across the three action cycles. This cross-publication perspective makes it possible to examine how these themes developed throughout the research process.

As the dissertation followed an ABAR methodology, data analysis formed an integral part of the iterative research process. Reflection and analysis undertaken after each action cycle informed the planning, implementation, and analytical focus of the subsequent cycle. Insights generated during one cycle were used to refine activities, materials, research design, and analytical perspectives in the following cycle. Consequently, the three action cycles were connected through successive processes of planning, action, observation, reflection, and redesign (Kemmis et al., 2014), enabling both continuity and variation in interdisciplinary art–science learning to be developed across the dissertation.

The credibility and trustworthiness of the research were strengthened through methodological triangulation (Denzin, 1978; Patton, 2002). For example, in Publication II, pupils' artworks were interpreted in relation to their verbal reflections and classroom observations to examine how artistic expression contributed to their understanding of colour transformations. In Publication III, children's drawings were considered together with field notes and reflective records to explore their emerging ecological understanding. These comparisons helped me distinguish between imaginative expression and interpretations supported by multiple forms of empirical material. Interpretations were developed by comparing multiple forms of empirical material, including pupils' artworks, classroom observations, verbal reflections, interviews, documentary photographs, and my observation diary, as appropriate to each publication. Continuous reflexive writing documented pedagogical decisions and analytical development throughout action cycles, supporting transparency and consistency in the interpretation of the empirical material.

3.4 Ethics

Prior to conducting the research in China, the affiliated school approved the study, and school administrators and pupils' guardians provided informed consent. Consent was obtained in coordination with the school, and participation was voluntary. In Finland, I consulted the school principals and collaborating teachers to clarify the research aims, procedures, and ethical responsibilities, and obtained their agreement to conduct the school-based research. The study followed the research ethics guidelines of the University of Lapland and the Finnish National Board on Research Integrity (TENK, 2019). Written informed consent was obtained from participating teachers and pupils' guardians. Children received age-appropriate explanations of the research and were informed of their right to decline documentation or withdraw from the study at any stage. Pupils could choose whether to be documented and could request the removal of their images or artworks from the dataset. Careful attention was given to anonymity and data protection. During data processing, identifiable details were removed, and pseudonyms were applied where needed. When working with visual materials such as photographs and artworks, separate permissions for publication were obtained, and these materials were handled with particular care.

The research was conducted in a multilingual context. Pupil interviews were carried out in Finnish and transcribed verbatim. My native language is Chinese. I am fluent in English and have basic proficiency in Finnish. I was able to engage with participants in the school context while recognising the limitations of working across languages. To ensure linguistic accuracy and preserve cultural nuance, a Finnish classroom teacher involved in the project, proficient in both Finnish and English, cross-checked the translations. This process supported the faithful representation of participants' meanings and reduced the risk of misinterpretation. Interviews with teachers and parents were conducted in English and did not require translation. To minimise disruption, activities were integrated into the participating schools' teaching arrangements and the summer camp programme. The research was conducted in a respectful, transparent, and ethically responsible manner, taking into account the vulnerability of child participants and the relational nature of school-based research.

3.5 Academic Writing as a Process of Research Exploration

In this research, academic writing developed with the research process. I used writing to record planning decisions, describe classroom situations, and trace how ideas changed across different action cycles. The articles included form the main body of the research. Early drafts primarily described activities and observations. As the teaching experiments progressed, writing gradually shifted towards analysis, helping me identify recurring patterns and connections across visual materials, field notes, and classroom dialogue. Writing supported my understanding of how art and science activities developed in specific educational settings. Collaboration also influenced how I wrote and revised this summary. Discussions with class teachers often led me to reconsider classroom observations, particularly pupils' engagement and responses during the activities. Working with the Ujunnu project and the LUMA Centre Lapland shaped both the activities themselves and the way I articulated the relationship between artistic practice and scientific exploration.

The writing and collaboration processes were closely linked to how the articles in this dissertation developed. I held primary responsibility for the four articles (Zhang & Hiltunen, 2025; Zhang & Huhmarniemi, 2026a; Zhang & Huhmarniemi, 2026b; Zhang et al., 2026), including designing the research, analysing data, and writing the manuscripts. Mirja Hiltunen and Maria Huhmarniemi contributed to conceptual development, supervision, and critical revision of the texts. Through sustained writing, I organised and connected theoretical perspectives related to art–science integration, material-based learning, embodied experience, Arctic education, and sustainability. Writing helped me clarify how these perspectives related to specific empirical situations and how they informed my methodological positioning. The articles developed in response to shifts in materials, participant groups, and pedagogical aims across action cycles.

Across the three action cycles included in my dissertation, writing helped me interpret changing pedagogical situations and empirical material. Revisiting field notes, pupils' artworks, classroom observations, and reflective journals enabled me to identify recurring patterns related to artistic engagement, material exploration, ecological understanding, and interdisciplinary learning across the studies. Writing also helped me connect the findings of the individual publications and develop the cross-publication synthesis presented in this dissertation.



4 | Implementation

Image 4. Experimental materials and the setup of art-science environments. Photograph: Xiaowei Zhang, 2025.

4.1 Cycle One: Art–Chemistry Education in China

Integrating art and science in education: Cultivating creative expression and inquisitive thinking, examined how interdisciplinary teaching can support young pupils' creative expression, inquisitive thinking, and emotional engagement through the integration of art and chemistry (Image 5). The study was conducted by me in collaboration with two teachers at a university-affiliated elementary school in southern China in spring 2024. The participants were 20 first-grade pupils (aged 6–7) who took part in an extracurricular interdisciplinary programme. The course formed the first action cycle of the research presented in this dissertation. The aim was to create an interdisciplinary environment in which pupils could explore scientific phenomena through multisensory experimentation and express their understanding through visual art and storytelling. The instructional design aimed to connect scientific observation with artistic expression, encouraging pupils to explore chemical reactions and develop their ideas through drawing, painting, and storytelling. Chemistry experiments functioned as a starting point for imaginative exploration, collaborative discussion, and artistic interpretation, connecting scientific observation with aesthetic experience and meaning-making.

The teaching experiment lasted approximately two months and was structured in three phases. 1) Pupils were introduced to key concepts through teacher-led demonstrations. 2) They worked collaboratively in small groups, conducting multisensory experiments and observing chemical reactions through colour and material change. 3) They created artworks and short visual narratives based on their interpretations. The process moved from guided introduction



Image 5. A sensory journey of interdisciplinary experimentation. Photograph: Xiaowei Zhang, 2024.

to experimentation and finally to artistic re-creation and reflection. These three phases were used as action cycles, with reflection and pedagogical adjustment informing each subsequent phase. Data included my observation diary, pupils' artworks, oral reflections, and documentary photographs capturing both process and outcomes. The oral reflections were collected during the activities and at the end as short responses. The analysis focused on pupils' engagement with scientific concepts through creative expression, inquiry-based reasoning, and emotional involvement. Visual, verbal, and observational materials were coded inductively, with attention to creative expression, inquisitive thinking, and emotional engagement. Artworks were examined in relation to pupils' reflections and classroom observations to trace meaning-making through experimentation and material engagement.

The analysis and reflection undertaken during this cycle also shaped the direction of the subsequent research. The integration of chemical experimentation, visual art, and storytelling led me to examine material engagement more closely in the following cycles. Based on this reflection, I extended the research to different materials, environments, and educational contexts.

4.2 Cycle Two: Art–Science Education in Northern Finland

The first case, presented in *The Bilberry Experiment for Arctic STEAM Education*, marked a shift in my research from an interdisciplinary school project in China to a primary school in Rovaniemi, Finland. This cycle, conducted with 22 first-grade pupils aged 6–7, deepened



Image 6. A view of wild bilberries in Northern Finland. Photograph: Xiaowei Zhang, 2024.

my interest in how art and science connect through material, sensory, and place-responsive pedagogies. This cycle explored how a locally meaningful natural resource, bilberries, could function as both a scientific material and an artistic medium in Arctic education. Bilberries were selected because of their ecological, cultural, and pedagogical significance in Northern Finland (Image 6). The instructional design aimed to introduce pupils to the chemical properties of natural pigments while encouraging artistic experimentation and creative interpretation of colour transformations.

In the experiment, bilberry soup was used as a natural pigment in chemistry-based activities, where its anthocyanins reacted visibly to acidic and alkaline substances. Pupils observed colour transformations and subsequently used the same material for painting and outdoor artmaking (Image 7). The activities connected classroom experimentation with local materials, seasonal conditions, and outdoor environments.

The cycle took place over six weeks and combined indoor and outdoor activities. The early part of the process involved preparation, collaboration with teachers, and the cultural framing of bilberries as part of local everyday life. This was followed by classroom-based experiments in which pupils tested how bilberry pigments changed colour under different pH conditions and then used the same material in visual expression. As winter conditions developed, the activities expanded into the schoolyard and nearby snowy landscape, where pupils created temporary artworks with bilberries and snow. The research process moved from classroom-based experimentation to artistic activities in outdoor environments.

The data reflected this pedagogical process. In addition to pupils' individual paintings and collaborative snow artworks, I collected observation notes, video recordings, and informal pupil discussions during the activities and interviewed classroom teachers and several parents. My analysis focused on sensory, emotional, artistic, and ecological dimensions of pupils' engagement. I examined the visual characteristics of pupils' artworks (Image 8), coded verbal and observational materials inductively, and analysed teacher and parent interviews thematically.



Image 7. Classroom demonstration: key moments leading to experimental exploration. Photograph: Härkönen Seija, 2024.

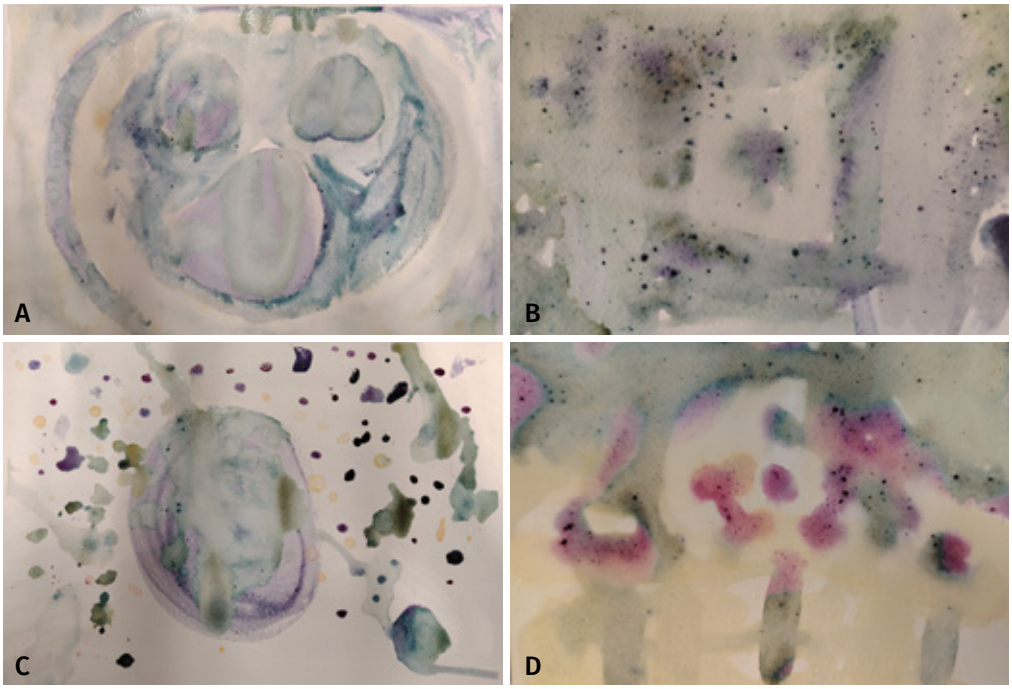


Image 8. A collage of artworks. A: *Colour Experiments with Smiley Pumpkins.* B: *Guardians of the Arctic: Huskies.* C: *Keeping and Surrounding: My Planetary Home.* D: *The Forces of Nature.* Photographs: Xiaowei Zhang, 2024.



Image 9. Colour transformation in an art–science experiment. Photograph: Xiaowei Zhang, 2025.

Reflection on the outcomes of this cycle guided the direction of the subsequent research. The use of bilberries introduced a locally meaningful natural material and extended the research into an Arctic educational setting. This experience led me to examine material engagement, place, and ecocultural contexts more closely in the following cycles. Natural materials, environmental contexts, and sustainability became increasingly important in the later development of research.

The second case, presented in *Integrating Art into Chemistry Class: Exploring pH Reactions through Creative Expression*, extended the research from primary education to a lower secondary chemistry classroom in Finnish Lapland, introducing a more structured and subject-specific approach to art–science integration. The case involved eighth-grade pupils and a chemistry teacher. Compared with the earlier educational settings, it examined how artistic practice could be integrated into a subject-specific chemistry classroom. The teaching activities focused on the visual and material qualities of acid–base reactions. Pupils worked with natural dyes and everyday substances, including cabbage, beetroot, lemon, and vinegar. The materials functioned as chemical agents and artistic media, providing opportunities to observe colour transformations, manipulate reactions, and use chemical processes as starting points for visual expression.

Classroom conditions shaped the development of the activities (Image 9). Scientific instruments, laboratory materials, plant-based substances, paper, and artistic tools formed a working environment that combined chemical experimentation with visual artmaking. Pupils adjusted concentrations, controlled the flow of liquids, experimented with diffusion patterns, and used the resulting transformations in their visual compositions. Discussions during the activities also introduced questions concerning natural dyes, synthetic substances, and environmental issues, extending the teaching process to considerations of material use and sustainability. Data included pupils' artworks, classroom observations, pupils' reflections, and documentation of the experimental and artistic processes. The analysis focused on the relationships among scientific reasoning, material experimentation, visual expression, and ecological perspectives. Particular attention was given to the ways pupils moved between observing chemical reactions, experimenting with materials, and developing visual interpretations. This case marked a further development of the research by examining art–science integration within the more formalised subject context of chemistry education. The experience informed the development of the subsequent stages of the research, with greater attention given to materials and environmental perspectives in the design of later cases.

4.3 Cycle Three: Recycled Paper and Ecological Understanding

This cycle, presented in *Trees, Forests, and Recycled Paper: Art–Science Approaches to Ecological Understanding in Northern Finland*, marked a further development in my research towards ecological and more-than-human perspectives in interdisciplinary education. During a "Nature and Science" summer camp in Northern Finland, the research focus expanded beyond chemistry-based classroom experimentation to include forest environments, recycled materials, and ecological processes in interdisciplinary exploration. It involved 34 pupils aged 7–9 and a small group of teachers, in collaboration with LUMA Centre Lapland, Science Centre Pilke, the Ujunnu Project team, and pre-service teachers from the University of Lapland. Within my



Image 10. Sensing the forest through the body. Photograph: Xiaowei Zhang, 2025.



Image 11. Exploring material transformation through recycled papermaking. Photograph: Xiaowei Zhang, 2025.

broader Art-Based Action Research, this cycle extended the inquiry to pupils' engagement with environmental relations through embodied, material, and collaborative participation. The instructional design aimed to help pupils explore the relationships among trees, paper, and ecological processes through forest-based sensory activities, recycled papermaking, and artistic expression.

This cycle examined pupils' engagement with ecological relations in forest environments. The camp took place in a region where forests are deeply embedded in everyday life while also being shaped by contemporary discussions concerning resource extraction, biodiversity, and sustainability (Image 10). This context provided a pedagogical and conceptual frame for the project. The activities invited pupils to engage with trees, fibres, water, paper, and forest spaces through making, sensing, observation, and discussion. These activities provided the pedagogical basis for examining ecological relations through material and environmental engagement.

The structure of the camp reflected this orientation. Across its three phases, pupils moved between forest-based sensory activities, recycled papermaking, and interdisciplinary exploration at Science Centre Pilke (Image 11). In the forest, they were encouraged to slow down, touch bark, listen to sounds, and attend to the textures and atmospheres of the environment. In the papermaking workshops, they transformed discarded paper into new handmade sheets, working directly with fibres, pulp, water, and pressure. This activity connected materials-based artmaking with chemistry learning through materials-based artmaking. The process involves learning about what paper is made of, particularly cellulose, a natural polymer. In this kind of process, students can compare different types of paper and consider how their composition affects their properties. Thus, handmade recycled paper can provide a meaningful context for chemistry learning, but the chemistry is strongest when the activity goes beyond simply making paper. The educational integration becomes particularly convincing when students investigate why the pulp behaves as it does and how its chemical composition and material structure influence the final paper. At Science Centre Pilke, these activities were connected with questions concerning wood, water, ecosystems, and forestry practices. Earlier encounters with trees were connected with later work with recycled paper, linking forest-based activities with material transformation and ecological themes.

The material generated in this cycle included pupils' drawings, field notes, photographs, reflective observations, and teacher interviews. Drawing on Art-Based Action Research and Barad's notion of intra-action, the analysis examined pupils' visual, verbal, and embodied expressions of ecological understanding, with particular attention to their engagement with forests, trees, and recycled materials through touching, pressing, drawing, making, and discussion.

5 | Summary of the Articles



Image 12. Materialising findings: art-science in practice. Photograph: Xiaowei Zhang, 2025.

5.1 Publication I

Integrating Art and Science in Education: Cultivating Creative Expression and Inquisitive Thinking

This article explores how combining art and science can support young pupils' learning by fostering creative expression, inquisitive thinking, and emotional engagement (Zhang et al., 2026). This article builds on the first cycle of my art-based action research. I conducted this cycle with 20 first-grade pupils in China in an interdisciplinary course integrating science experiments and visual arts activities. The findings show that artistic practice functioned as an integral part of science teaching. It created a space in which pupils could interpret scientific phenomena through multisensory exploration, visual metaphor, and collaborative reflection. Through painting, storytelling, and experimentation, the students transformed chemical observation into imaginative and symbolic expression, while also developing curiosity through repeated testing, discussion, and adjustment.

I identified differences in how confidently students approached open-ended inquiry. While some students engaged actively in experimentation and creative interpretation, others needed more support from teachers or peers to participate fully. This suggested that interdisciplinary environments can open rich possibilities for inquiry, but they also require careful pedagogical guidance to accommodate different learners. The article examines how art–science integration in elementary education can deepen scientific understanding as students explore phenomena using sensory, imaginative, and reflective approaches. Artistic activity can shape scientific inquiry by helping pupils connect observation, emotion, and interpretation. We further suggest that art-based action research provides a pedagogical and methodological framework for understanding interdisciplinary engagement as a creative, embodied, and relational process.

I designed and implemented the study, and developed the research framework, planned and facilitated the teaching activities, and collected and analysed the empirical data. I took the lead in analysing the findings and drafting the manuscript. Mirja Hiltunen and Maria Huhmarniemi contributed to shaping methodological and theoretical framing of this research. They also provided continuous feedback throughout the writing process and helped revise and refine the manuscript.

5.2 Publication II

The Bilberry Experiment for Arctic STEAM Education

I examine the Bilberry Experiment as one cycle of my art-based action research in Arctic primary education. This cycle took place in a Finnish elementary school and explored how bilberries, as a locally meaningful ecological and cultural resource, can connect chemistry, visual arts, and ecocultural education. By observing the colour changes of bilberry anthocyanins, painting with bilberry-based pigments, and continuing the work outdoors in snow, the pupils participated in a process where scientific inquiry and artistic expression developed.

The research identified three closely connected dimensions of engagement. Sensory and emotional engagement played an important role in supporting pupils' early conceptual understanding. Feelings such as surprise and curiosity encouraged close observation and helped pupils begin to recognise acid–based reactions and the function of bilberries as a natural indicator. The pupils further transformed their observations into artistic narratives. Colour changes were reinterpreted through visual forms such as aurora borealis, animals, planets, and other seasonal or environmental imagery, showing how scientific phenomena could be expressed through creative interpretation. Engagement also extended beyond the classroom through ecocultural connections. The experiment was linked with berry-picking traditions, outdoor snow art, and family conversations at home.

A central contribution of the article lies in showing that bilberries functioned as more than classroom material, mediating between scientific concepts, artistic interpretation, and local cultural meanings. The pupils related chemical reactions to familiar northern landscapes, seasonal practices, and everyday experiences, situating scientific understanding within lived and place-based contexts. Art-based action research also helps examine how understanding develops through material engagement and creative practice (Jokela & Huhmarniemi, 2025). In this context, pupils' artworks, observations, and dialogues served as research data, revealing how understanding emerged over time through sensory experience, experimentation, and collaborative reflection (Zhang & Huhmarniemi, 2026a).

My role encompassed the design and execution of the study, including the development of the research framework, the coordination of teaching activities, and the collection and analysis of empirical data. I was primarily responsible for writing the manuscript. Mirja Hiltunen and Maria Huhmarniemi contributed to shaping the methodological and theoretical framing. They also helped revise the manuscript throughout the revision process. Maria Huhmarniemi also contributed her expertise in berry picking culture and Arctic art–science collaborations, which informed the contextual and conceptual development of the study (Huhmarniemi, 2024).

5.3 Publication III

Trees, Forests, and Recycled Paper: Art–Science Approaches to Ecological Understanding in Northern Finland

I examine a Nature and Science summer camp as one action cycle of my art-based action research in Arctic primary education. This cycle was conducted in Northern Finland and explored how forests, recycled paper, and scientific inquiry can be integrated through interdisciplinary art–science education. The summer camp combined forest exploration, recycled papermaking,

artistic creation, and science-center investigations, enabling children to engage with ecological processes through embodied, material, and imaginative experiences.

The research identified three interconnected dimensions of ecological understanding. Sensory and affective engagement with natural materials supported children's early ecological awareness. Through forest games, tree hugging, and careful observation, pupils developed emotional and sensory relationships with forest environments while reflecting on trees as living beings. These embodied encounters encouraged close attention to texture, sound, and seasonal change. Ecological understanding further developed through the creative transformation of recycled materials. By making recycled paper and producing artworks, pupils explored material cycles while expressing ideas of continuity, renewal, coexistence, and environmental care. Their artistic narratives connected recycled materials with broader ecological relationships. Ecological understanding continued to develop during interdisciplinary exploration at the science center. Pupils linked their earlier artistic experiences with scientific investigations of forests, water, wood, and sustainability, allowing ecological concepts to develop across different learning contexts and activities.

A central contribution of the article lies in showing how ecological understanding developed through sustained engagement with materials, places, and interdisciplinary experiences. Forests and recycled paper functioned as mediating materials that connected sensory experience, artistic interpretation, ecological thinking, and everyday environmental relationships. The findings demonstrate that art–science integration can support sustainability-oriented environmental education by encouraging children to interpret ecological processes through embodied participation, creative practice, and repeated engagement across multiple learning environments. In my research, children's artworks, observations, interviews, and documentation of classroom activities served as research data, revealing how ecological understanding developed over time through sensory experience, creative practice, and interdisciplinary exploration.

My role encompassed the design and implementation of the study, including the development of the research framework, the coordination of the interdisciplinary summer camp, and the collection and analysis of empirical data. I was primarily responsible for writing the manuscript. Maria Huhmarniemi contributed to the methodological and theoretical development of the study and provided supervision throughout the research process (Zhang & Huhmarniemi, 2026b).

5.4 Publication IV

Integrating Art into Chemistry Class: Exploring pH Reactions through Creative Expression

In this visual essay, I present the "Colours of Chemical Reactions" project in lower secondary chemistry education. The research explores how natural dyes can be used in a chemistry classroom to engage pupils with pH reactions while opening space for creative expression and reflection on ecological sustainability. Working with natural dyes, pupils explored colour changes by manipulating acid–base solutions and translating these transformations into visual compositions. Their actions moved between experimentation and creation, as they tested materials, adjusted methods, and reflected on the visual and ecological qualities of their work. The classroom became a space where scientific observation, artistic decision-making,

and discussions on sustainability were intertwined. Pupils responded to colour changes with curiosity and surprise, which encouraged repeated experimentation and close observation. Some connected their work with broader themes such as ecological balance and environmental responsibility, for example through artworks that visualised sustainability or contrasted pollution with natural systems. Differences in participation also became visible, indicating that open-ended interdisciplinary learning requires careful pedagogical support.

This visual essay highlights how artistic exploration can reshape the experience of chemistry education. Working with natural dyes enabled pupils to explore scientific concepts through sensory experience, material exploration, and visual interpretation, while also encouraging reflection on sustainability and responsible material use. In this context, natural materials can be understood as mediators that connect scientific knowledge, artistic expression, and ecological awareness. The visual essay contributes to broader research by illustrating how art-based action research can transform classroom practices, where meaning emerges through experimentation, reflection, and engagement with materials (Zhang & Hiltunen, 2025).

I developed and implemented the study's visual and pedagogical framework, designing and facilitating activities and collecting and interpreting empirical and visual materials. I was primarily responsible for shaping the manuscript. Mirja Hiltunen contributed to the development of the article's structure and visual composition, supporting the organisation of the visual narrative. She also engaged in critical dialogue and provided feedback during the writing and revision process.



6 | Synthesis of Findings

Image 13. Traces of transformation in art-science. Photograph: Xiaowei Zhang, 2024.

6.1 Creative Expression, Inquisitive Thinking, and Emotional Engagement

The first research question asked: **How does integrating art and chemistry promote students' creative expression, inquisitive thinking, and emotional engagement?** The findings from Publication I show that combining chemical experimentation with artistic practice encouraged pupils to explore chemical phenomena through observation, material experimentation, and visual expression. Pupils observed colour changes and other material transformations during the experiments and subsequently incorporated these observations into their artworks. Artistic practice became part of their exploration of the chemical phenomena, allowing them to develop ideas from what they had observed and experienced during experimentation.

Creative expression was visible in the ways pupils transformed scientific observations into imaginative and symbolic forms. Test tubes, colour changes, and experimental traces appeared in the artworks as trees, musical rhythms, and other visual representations. Pupils experimented with colour, composition, layering, and repetition to represent transformation and movement. Their artworks showed how observations from the experiments could be reorganised through imagination and visual interpretation. Some pupils developed highly imaginative representations, while a small number remained closer to literal depictions of the experiments, revealing differences in how pupils responded to the possibilities offered by artistic expression.

Inquisitive thinking emerged particularly during material experimentation. Pupils adjusted mixtures, compared colour responses, changed proportions and sequences, and repeated experiments when they wanted to explore different results. Their comments about trying to *"find the right colour"* and wanting to *"see what happens if I change this"* showed how changes in materials and colours prompted further questions. Pupils moved repeatedly between observing, testing, comparing, and modifying their ideas. Small-group work also contributed to this exploration as pupils compared experimental results, discussed possible outcomes, and responded to ideas suggested by their peers. Some pupils independently initiated further experiments, whereas others relied more strongly on guidance from teachers or classmates.

Emotional engagement was closely connected with these processes. Colour changes, gradients, textures, and unexpected material transformations generated curiosity, excitement, and anticipation. Pupils often continued experimenting because they wanted to discover a particular colour or see what another combination might produce. Unexpected results therefore became a source of further exploration. Emotional engagement was also visible in pupils' interactions with their peers as they observed one another's experiments and artworks, exchanged reactions, and developed new ideas from what they saw.

Publication I shows that creative expression, inquisitive thinking, and emotional engagement developed in relation to one another during the art–chemistry activities. Artistic practice enabled pupils to transform chemical observations into imaginative visual forms, while material experimentation encouraged questioning, comparison, and repeated testing. Curiosity and emotional involvement helped maintain pupils' attention and willingness to continue exploring. The integration of art and chemistry created opportunities for pupils to observe chemical phenomena, experiment with materials, develop visual interpretations, and pursue questions generated through the process.

6.2 Scientific Understanding through Artistic and Scientific Practices

The second research question asked: **What role do artistic modes of expression play in pupils' meaning-making of scientific phenomena when using bilberries as natural pigments?** The findings from Publication II show that artistic expression provided pupils with ways to interpret and give visual form to the chemical changes they observed during the bilberry experiments. After observing how bilberry anthocyanins changed colour under acidic and alkaline conditions, pupils used painting to translate these transformations into colours, forms, symbols, and narratives. The artworks became part of the pupils' interpretation of the scientific phenomena, connecting direct observation with imagination and personal experience. This process was visible in the ways pupils transformed colour changes into familiar images and cultural references. One pupil explained: *"I painted the aurora borealis because the colour changes made me think of the aurora dancing in the sky."* The pupil connected the greens and purples produced through material experimentation with the aurora, a phenomenon familiar within the local environment. Other artworks similarly transformed chemical observations into pumpkins, animals, planets, and environmental imagery.

The visual expressions allowed pupils to move from observing a chemical change towards constructing symbolic and narrative meanings around what they had experienced. Artistic modes of expression also enabled pupils to represent aspects of chemical phenomena that were dynamic and difficult to communicate verbally. Pupils used dots to depict bubbles, mixed colours to represent moments of colour transition, and used lines to show the spreading movement of a reaction. One pupil described *watching the colour become lighter and then using dots to represent the bubbles*, while another explained *using purple and green to depict the moment when the colour changed*. The visual process provided pupils with different ways of selecting, reorganising, and representing their observations.

The findings also reveal variation among pupils. Sixteen of the twenty-two artworks reflected positive and engaged experiences, while six indicated uncertainty or difficulty, particularly in controlling colour mixtures or achieving intended visual effects. Some pupils needed additional support to move from direct observation towards more developed artistic interpretation. Artistic expression opened possibilities for meaning-making, although pupils engaged with these possibilities in different ways. Publication II shows that artistic modes of expression supported meaning-making by enabling pupils to translate observed chemical transformations into visual, symbolic, and narrative forms. Painting did more than document the experiment: it provided a means through which pupils interpreted scientific phenomena and connected them with imagination, personal experience, and familiar environmental imagery.

6.3 Emerging Scientific Inquiry

The third research question asked: **In what ways does the integration of chemistry and visual arts through bilberry-based experiments foster emerging science during classroom-based inquiry?** Publication II shows that emerging science developed through progression from sensory observation to questioning, experimentation, explanation, and further inquiry. Pupils encountered chemical phenomena through visible and material changes in bilberry pigments. They observed that the pigment turned red under acidic conditions and green under alkaline conditions and gradually began to connect these changes with the concepts of acids, bases, and indicators. During group reflection, pupils described the colour changes as "the bilberry showing the acid" and "turning green because of the base," demonstrating an emerging ability to connect visible changes with underlying chemical conditions.

Sensory and emotional responses played an important role in initiating this inquiry. The unexpected transformations generated surprise and curiosity. Pupils responded with comments including "It's changing!" and "It's doing something inside!" Their initial explanations were sometimes imaginative or scientifically incomplete, particularly when they described bubbles as "air." Teacher prompts encouraged them to reconsider these observations and connect the bubbles with carbon dioxide produced during the acid–based reaction. Emerging science involved movement from initial sensory interpretations towards more differentiated scientific explanations through observation, dialogue, and pedagogical guidance. This development was particularly clear in pupils' reflections. One pupil explained:

> "When we mixed the bilberry soup, I didn't think the colour would change so much. It was surprising to see it turn red and then green. It made me want to look closer and find out why it was happening."

The movement from noticing an unexpected transformation to wanting to investigate its cause illustrates how curiosity generated further inquiry. Another pupil carefully described how bubbles increased in number and size before bursting or becoming smaller, showing close attention to change over time. These observations demonstrate early forms of scientific thinking grounded in direct sensory experience. The inquiry also extended beyond immediate classroom activity. Parents reported that pupils continued asking questions about colour changes at home and wondered whether other materials, including vegetable juices, might behave similarly. One parent observed that their child wanted to conduct additional tests, while another reported increased attention to colours and transformations in everyday surroundings. The findings suggest that pupils began applying processes of observation, questioning, comparison, and experimentation to new situations.

The findings show that the integration of chemistry and visual arts fostered emerging science by creating opportunities for pupils to observe material transformations, express curiosity, formulate tentative explanations, test ideas, discuss observations, and connect their experiences with scientific concepts. Artistic exploration helped sustain attention to colour, texture, movement, and transformation, while teacher guidance supported the development of more precise scientific interpretations. Emerging science developed gradually through pupils' participation in inquiry and their attempts to make sense of phenomena encountered through the bilberry experiments.

6.4 Ecological Understanding through Embodied Engagement

The fourth research question asked: **How did children articulate ecological understanding and their own roles in relation to forest environments through embodied, material, and imaginative engagement in art–science activities?** The findings from Publication III show that children articulated ecological understanding through interconnected sensory, material, and imaginative experiences. Their understanding developed across forest exploration, recycled papermaking, artistic creation, and science-center activities. Through these experiences, children connected trees, fibres, water, paper, animals, and human activities with broader ideas of ecological continuity, renewal, vulnerability, care, and coexistence.

Embodied encounters with the forest provided an important starting point. Touching tree bark, attending to light and sound, standing quietly among trees, and participating in activities such as tree hugging encouraged children to describe trees as living and responsive beings. One pupil described a tree as feeling warm and *"breathing slowly,"* while teachers observed that sensory attention encouraged pupils to imagine what it meant to live among trees. Through bodily contact and focused observation, children began to articulate relationships with forests through feelings of belonging, attentiveness, and care. Material engagement extended this understanding by connecting forest environments with processes of transformation and renewal. During recycled papermaking, children transformed discarded paper through tearing, soaking, blending, and pressing while discussing the relationships between trees, fibres, paper, and recycling. Their comments moved from simple statements such as *"paper comes from trees"* towards ideas concerning material origins, reuse, and ecological continuity. These connections reappeared during later activities, when pupils commented that *"the paper was trees before"* and that *"everything changes and comes back."* Repeated encounters with wood, water, fibres, and paper enabled children to connect individual materials with broader ecological cycles.

Imaginative and artistic expression provided another means through which children articulated ecological relationships and their own positions within them. Their drawings and narratives represented forests, lakes, animals, seasonal change, and human activity as interconnected. Some pupils emphasised continuity and renewal, while others expressed ideas of coexistence, vulnerability, and environmental responsibility. For example, one pupil imagined children and animals sharing a safe space in nature, while another created a superhero protecting trees because they could not escape from danger. A further drawing depicted a child attempting to extinguish a burning tree. Through such visual and narrative expressions, ecological care became connected with children's imagined possibilities for human action. During these activities, children positioned themselves in three recurring ways: as participants, protectors, and co-inhabitants of forest environments. As participants, they explored forests and ecological processes through sensory and material activity. As protectors, they expressed responsibility and concern for vulnerable trees and environments. As co-inhabitants, they imagined humans, animals, and forests sharing spaces and ecological relations. These positions indicate that ecological understanding included both awareness of environmental processes and ways of locating oneself within ecological systems.

Publication III demonstrates that children articulated ecological understanding by connecting direct sensory experience, material transformation, artistic imagination, and interdisciplinary exploration. Their responses moved across different forms of ecological meaning-making,

from noticing trees as living beings and recognising material cycles to expressing care, vulnerability, coexistence, and responsibility. The findings show ecological understanding as a situated and interpretive process in which children developed different ways of understanding environmental relations and their own roles within them.

6.5 Synthesis of the Findings

The main research question asked: **How do pupils' creativity, scientific understanding, inquisitive thinking, and ecological understanding develop through engagement with materials and natural phenomena in interdisciplinary art–science education?** Across the three action cycles, materials and natural phenomena formed a shared focus for artistic and scientific activity. Art and chemistry were integrated through processes in which pupils experimented with chemical reactions and material transformations, observed changes in colour and material properties, and developed these observations through drawing, painting, making, and visual interpretation. Materials such as natural pigments, paper fibers, and other environmental resources therefore became both subjects of scientific inquiry and media for artistic expression. Attention to these phenomena generated questions and interpretations that were developed through both artistic and scientific practices.

Artistic practice gave visual and material form to pupils' observations. Colour, painting, drawing, visualisation, and storytelling were used to interpret changes that pupils encountered during experimentation and environmental activities. Chemical transformations appeared in artworks as colours, rhythms, symbols, and imagined forms, while forest experiences were represented through images and narratives concerning trees, animals, material cycles, care, and coexistence. Scientific inquiry centred on observation, comparison, experimentation, questioning, and explanation. Pupils tested materials, compared changes, repeated procedures, and discussed possible explanations for what they observed. Artistic and scientific practices were connected through attention to the same materials and phenomena, although they offered different ways of exploring and interpreting them.

Creativity was evident in pupils' transformation of observations into visual and imaginative forms and in their exploration of alternative possibilities. Inquisitive thinking appeared in questioning, repeated experimentation, comparison, and responses to unexpected results. Scientific understanding was expressed when pupils began to relate observable changes to explanations of chemical and material processes. Ecological understanding became visible in connections made among trees, fibres, paper, recycling, environmental processes, and human activity. In the forest-based study, pupils also articulated their positions in relation to the environment as participants, protectors, and co-inhabitants. The four dimensions were therefore closely related in the empirical material, although their emphasis varied between the studies and educational contexts. In the two cycles conducted in Northern Finland, these processes were also shaped by the Arctic context in which the activities took place. Seasonal conditions and locally available materials influenced what pupils could observe, handle, and explore. Bilberries connected chemical experimentation with a familiar northern natural resource, while forests, snow, and changing environmental conditions extended art–science activities into pupils' surrounding environment. The Arctic significance of these activities emerged from how materials, seasonal conditions, local environments, and pedagogical practices came together in the specific context of Northern Finland.

The findings also drew attention to pedagogical conditions. Open-ended experimentation did not lead to the same forms of engagement for every pupil. Some pupils readily followed unexpected results and developed new questions or visual ideas, whereas others needed support from teachers or peers. Teacher guidance was particularly relevant when pupils moved from observation towards explanation or encountered uncertainty during experimentation. Pedagogical design supported art–chemistry integration by creating opportunities for pupils to investigate chemical reactions and material transformations through experimentation and to develop their observations through artistic interpretation and visual expression. Figure 5 summarises

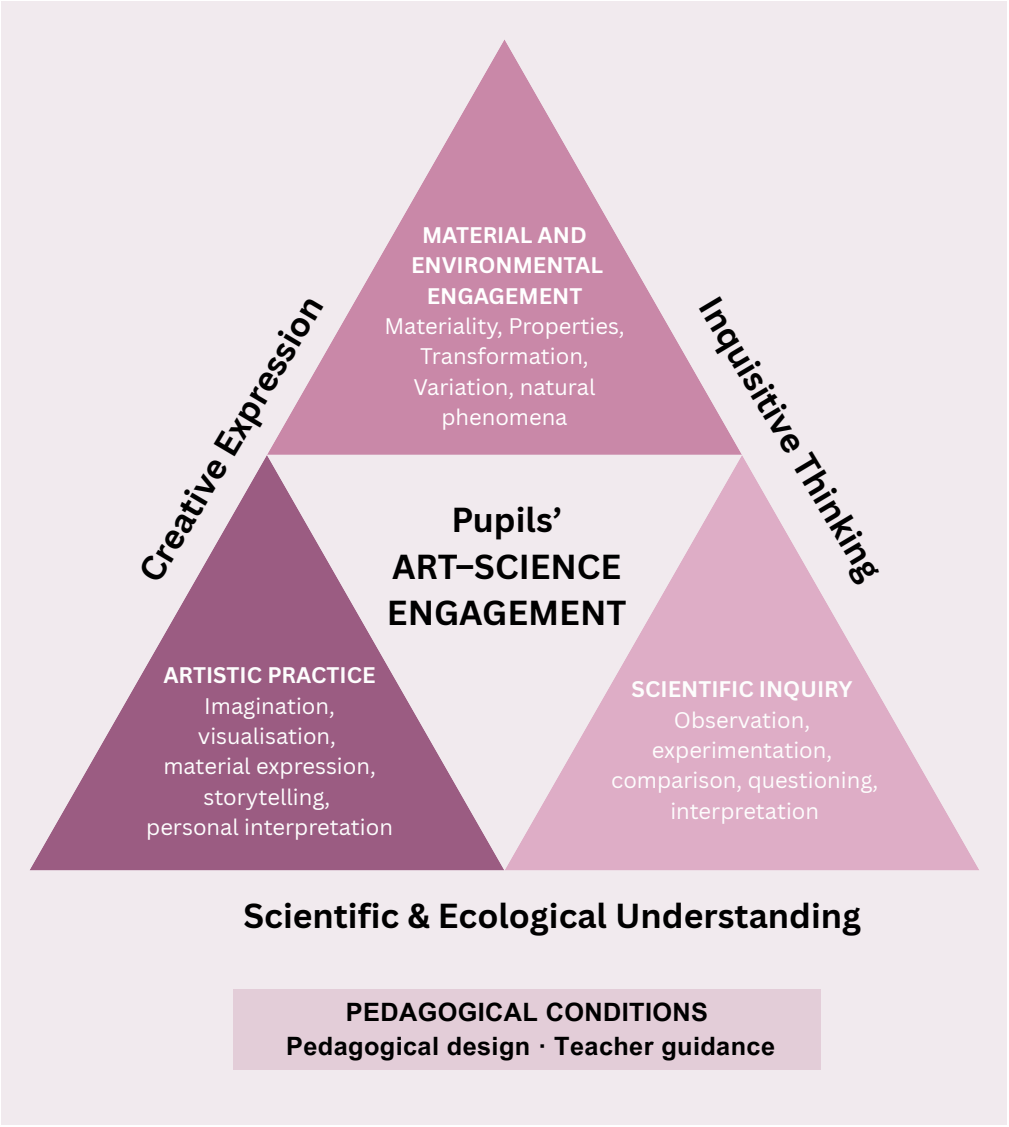


Figure 5. Synthesis of the dissertation findings on pupils' interdisciplinary art–science engagement in the Art-Based Action Research cycles. Xiaowei Zhang, 2026.

these findings from the perspective of pupils' engagement in the three ABAR cycles. It reflects the educational contexts examined in this dissertation and brings together the key forms of engagement and outcomes identified across the studies. Material and environmental engagement, artistic practice, and scientific inquiry represent the three areas through which pupils engaged with the activities. Creative expression, inquisitive thinking, and scientific and ecological understanding summarise the main outcomes identified across the studies. Pedagogical design and teacher guidance are presented as conditions shaping the opportunities for these forms of engagement.



7 | Discussion

Image 14. Material Encounters in the Forest. Photograph: Xiaowei Zhang, 2025.

7.1 The Emergence of Learning through Materials and Environments

The four publications conceptualise engagement as a relational and generative process that develops through situated material engagement, environments, and social relations (Dewey, 1934; Vygotsky, 1978). In the first article, the research was informed by constructivist and STEAM-oriented perspectives, in which meaning-making was understood as socially mediated and the integration of art and science was approached as a connection between disciplinary domains (Land, 2013; Liao, 2016). As the research progressed, this framing was reconsidered through engagement with intra-action theory. Drawing on Barad, the analysis shifted towards understanding processes as emerging through entangled relations in which disciplinary boundaries become less stable (Barad, 2007). In the later articles, this perspective informed an interpretation of art–science integration that paid greater attention to the relationships among artistic practice, scientific inquiry, materials, and pedagogical situations.

In Arctic art–science education, this relational perspective becomes visible through situated involvement in practice, where perception, action, and interpretation develop in relation to changing material, environmental, and pedagogical conditions (Hiltunen, 2023; Jokela & Huhmarniemi, 2022; Rosiek et al., 2024). Material properties and spatial arrangements influence possibilities for participation, while environmental factors such as light, temperature, and seasonal variation affect bodily engagement. Materials further guide action through their responsiveness, resistance, and temporal qualities (Bennett, 2010). Pedagogical discourse contributes by directing attention, supporting reflection, and facilitating shared interpretation. These conditions shape how pupils engage with materials and phenomena in different educational situations.

The concept of material–discursive practice provides an analytical lens for examining how meaning takes shape in these situations (Barad, 2007). Understanding emerges through the interplay of material engagement, embodied activity, and discursive engagement. Material variation introduces uncertainty and prompts adjustment, while dialogue and reflection support the organisation of experience into shared forms of understanding. In this process, participation can be understood through intra-action, where learners, materials, and environments are continuously reconfigured through engagement (Barad, 2007). Agency is distributed across these relations and becomes visible through action, response, and interpretation. Creativity develops through engagement with changing conditions. When materials behave in unexpected ways, learners adjust their actions, shift attention, and explore alternative possibilities. These moments contribute to the formation of new understandings and expressive forms. Creativity is embedded in practice and linked to material engagement, embodied engagement, and environmental responsiveness (Rosiek et al., 2024).

A more-than-human perspective extends this relational understanding to ecological relations, particularly in the outdoor and material-based experiments reported in the articles (Zhang & Huhmarniemi, 2026a; Zhang & Huhmarniemi, 2026b). In the Arctic cases, seasonal rhythms and environmental processes influenced pupils' observation, movement, and artistic expression, connecting material experience with ecological awareness (Copeland, 2023). Similar relational processes appeared in primary school, secondary school, and summer camp settings, although their forms varied according to materials, environments, participants, and pedagogical arrangements (Zhang & Hiltunen, 2025; Zhang et al., 2026; Zhang & Huhmarniemi, 2026a; Zhang & Huhmarniemi, 2026b). This variation highlights the situated character of the findings and provides a basis for examining experimentality in the following section.

7.2 Experimentality as a Pedagogical Logic in Art–Science Education

Experimentation played a central role in the art–science practices examined in this research. Colour change, diffusion, melting, and chemistry-based transformations provided observable phenomena through which pupils explored material properties and change. Experimentation involved observation, manipulation, comparison, and adjustment, connecting scientific attention with direct material experience (Bennett, 2010; Tang, 2022; Zhang & Huhmarniemi, 2026a).

One of the less expected findings concerned the role of chemistry in creating uncertainty that sustained both scientific inquiry and artistic exploration. Chemical reactions produced colour changes and material transformations that were not always predictable to pupils. These unexpected outcomes encouraged some pupils to observe more closely, repeat experiments, compare results, and explore alternative possibilities through artistic interpretation. This finding supports an understanding of experimentation as a process shaped by material response, adjustment, and continued engagement with changing conditions (Bennett, 2010; Tang, 2022; Wilmes & Siry, 2024). From a relational perspective, these moments illustrate how inquiry develops through changing relations among pupils, materials, and pedagogical situations. The role of uncertainty was closely connected to the conditions provided for experimentation. Time for observation, discussion, and repeated experimentation allowed pupils to examine unexpected changes and develop their interpretations, while teacher guidance helped direct attention towards relevant material phenomena (Dewey, 1934; Vygotsky, 1978).

Uncertainty became productive when pupils had sufficient time and opportunities to revisit unexpected outcomes, discuss them, and explore them further through the pedagogical activities. Uncertainty did not support inquiry equally for all pupils. While unexpected material outcomes encouraged some pupils to experiment further, others required more structured guidance from teachers or peers when working with open-ended activities. This finding complicates the assumption that openness and material unpredictability automatically promote creativity or inquiry. The educational value of uncertainty depended on pedagogical support, sufficient time, and pupils' readiness to work with unfamiliar situations.

Environmental conditions also influenced experimentation. Light, temperature, humidity, and seasonal variation affected material behaviour and the possibilities available for observation and action (Fenwick & Edwards, 2013). The same activity could develop differently according to its material and environmental context. This variability was particularly relevant to the

Arctic cases, where artistic expression, scientific observation, and ecological attention often developed through the same material processes (Macdonald et al., 2022).

The configuration of materials, environmental conditions, and pedagogical arrangements helps to clarify how art–science integration operated in the activities examined in this research. In the Finnish basic education context, school subjects involve disciplinary content as well as particular practices and ways of exploring and interpreting the world. Art–science integration can be understood through connections between disciplinary knowledge and different modes of inquiry. Scientific inquiry directed pupils' attention towards observation, comparison, experimentation, and material transformation, while artistic practice opened these observations to imagination, visualisation, material interpretation, and expression. The findings show that these different modes of engagement could interact through shared attention to materials and phenomena (Zhang & Hiltunen, 2025; Zhang & Huhmarniemi, 2026a; Zhang et al., 2026). Experimentality provided opportunities for pupils to move between observation, adjustment, interpretation, and expression while retaining the distinctive contributions of artistic and scientific practices.

7.3 Emergent Art–Science in New Genre Arctic Art Education

In northern environments, artistic practice is closely linked to ecological conditions, community contexts, and place-responsive educational approaches (Jokela, 2019). Existing research has emphasised values such as sustainability, participation, and cultural engagement, while also recognising the role of environmental conditions and local materials in shaping artistic processes (Inwood, 2010; Jokela & Huhmarniemi, 2022). The present research contributes to this field by examining how these principles operate within concrete pedagogical practices that integrate art and science in school education. The teaching experiments show that integrating chemistry into artistic practice introduces a distinctive form of experimentation in Arctic art education. Chemistry brings material transformations governed by chemical processes into the creative process, allowing colour shifts, reactions, diffusion, and changes in material properties to shape the direction of artistic exploration. These transformations generate questions for scientific inquiry while simultaneously opening new visual and material possibilities for artistic expression. In this integration, material transformation becomes both an object of scientific inquiry and a generative force within the artistic process. Engagement with natural phenomena, such as colour transformation, thermal variation, and material change, introduces forms of observation that connect artistic exploration with scientific attention (Sochacka et al., 2016). These practices support situations of understanding in which perception, experimentation, and expression are closely linked (Dewey, 1934; Ingold, 2013). Art extended scientific observation through sensory experience, imagination, material exploration, and personal meaning-making (Barone & Eisner, 2012; Dewey, 1934).

Material conditions were particularly significant in Arctic activities. Art–chemistry integration introduced a form of material engagement in which pupils worked with snow, water, pigments, fibres, and organic substances through their capacity to transform. Chemical processes made change itself central to the artistic process: colour developed through reactions, materials dissolved or diffused, and physical properties shifted over time. Pupils therefore had to observe emerging conditions, interpret material responses, and adjust their artistic decisions

as the processes developed. In this way, chemistry reshaped artistic experimentation by making material transformation a generative condition for inquiry and creation. This responsiveness connected environmental conditions with pedagogical practice (Stöckell & Jokela, 2024). Participation within AAE can include engagement with teachers, peers, materials, environmental processes, and ecological systems (Jokela & Huhmarniemi, 2022; Vygotsky, 1978). The findings show how this broader understanding of participation can be examined through classroom and workshop practices in which ecological relations become visible in concrete situations (Zhang & Hiltunen, 2025; Zhang & Huhmarniemi, 2026a). In my research, art-chemistry practices added another dimension by connecting observation and experimentation with visual interpretation, material exploration, and creative expression. Pupils could move between artistic and scientific ways of engaging with the same phenomena (Henriksen, 2017; Østergaard et al., 2008).

The research also contributes to discussions on sustainability within Arctic art education. Engagement with natural materials and ecological processes supports attention to resource use, environmental change, and human–environment relations. Activities create situations in which ecological themes become part of experience, discussion, and expression. This supports forms of understanding that are grounded in specific contexts and shaped through participation in practice. These findings extend AAE by demonstrating how its principles can be articulated through art–science pedagogical practices. The research provides a practice-based account of how material conditions, environmental processes, and interdisciplinary approaches shape educational processes in Arctic contexts (Zhang & Huhmarniemi, 2026a). This extension situates art–science education as a meaningful direction within the development of Arctic art education, connecting ecological awareness, material engagement, and interdisciplinary learning in concrete educational settings.

Creativity was an important dimension of pupils' artistic engagement, particularly through visual interpretation, imagination, material experimentation, and the transformation of scientific observations into artistic forms. This emphasis reveals a tension within the artistic orientation of the research. While AAE emphasises place-responsive, socially engaged, and ecoculturally situated artistic practices (Jokela & Huhmarniemi, 2022; Jokela & Hiltunen, 2024), some activities in this research also drew on expressive approaches to art education through their emphasis on colour, imagination, personal interpretation, and open-ended visual expression. Such practices can be associated with traditions in which artistic experience and individual expression occupy a central position (Dewey, 1934; Eisner, 2002). The findings show that the artistic dimension of art–science education in this study draws on more than one orientation to art.

Pupils' artistic practices extended beyond individual expression. Their visual and material interpretations developed through encounters with bilberries, snow, recycled paper, and other materials whose properties and transformations influenced the artistic process. From a relational perspective, artistic meaning was produced through relations among pupils, materials, environments, and pedagogical situations (Barad, 2007; Ingold, 2013). This is particularly relevant to AAE, where artistic practice is connected with place, ecological relations, participation, and environmental conditions (Jokela & Huhmarniemi, 2022; Huhmarniemi & Jokela, 2025). Therefore, art served two related functions in the present research: it provided space for imagination and personal interpretation, while also functioning as a mode of inquiry through which

pupils explored material transformations, natural phenomena, and their relationships with local environments. This combination helps explain how expressive practices can coexist with the relational and place-responsive orientation of AAE.

7.4 Methodological Contribution and Reflexivity

Art-Based Action Research functions as a methodological approach that enables the investigation of understanding as a situated, material, and process-oriented phenomenon. The cyclical structure of planning, action, observation, and reflection provides a flexible framework for examining how pedagogical practices evolve. Each cycle contributes to the refinement of teaching design, material selection, and forms of participation, allowing the research process to remain closely connected to practice (Jokela, 2019; Jokela & Huhmarniemi, 2025). The research extends the methodological application of ABAR by foregrounding artistic processes as central sites of school pupils' knowledge production. Educational processes are examined through activities involving making, observation, and active participation. Pupils' artworks, material transformations, and classroom activities are approached as research material that reveals how understanding develops in practice. This perspective supports an analysis that attends to visual, embodied, and processual dimensions, which are often difficult to capture through conventional research approaches (Barone & Eisner, 2012; Leavy, 2017).

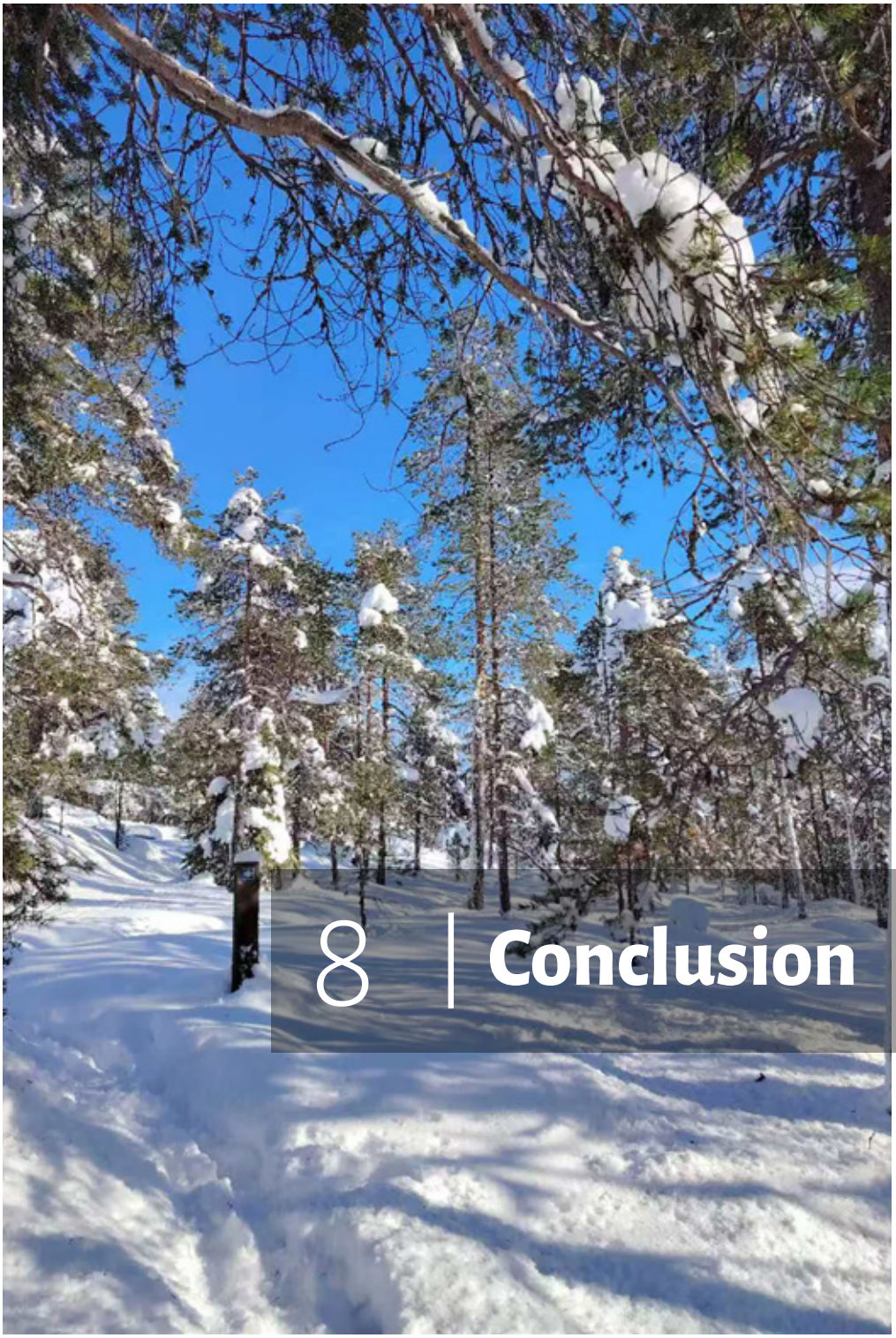
The use of multimodal data further strengthens this methodological orientation. Visual materials are analysed alongside verbal expressions and observational records. This combination allows research to trace how meaning develops across different forms of expression. Processes of knowing become visible through multiple modes, including material engagement, dialogue, and artistic representation. The cyclical nature of ABAR supports responsiveness to changing conditions in Arctic educational contexts. Variations in materials, environmental factors, and participant engagement require continuous adjustment of pedagogical strategies. The research design accommodates these variations by allowing each cycle to inform subsequent actions. This flexibility makes it possible to examine how understanding emerges in relation to specific contexts, where material behaviour and environmental conditions play an active role.

My dual position as both educator and researcher contributes to the methodological approach by enabling close engagement with teaching practice. This positioning allows direct observation of how learners interact with materials, respond to changes, and participate in activities. At the same time, it requires continuous ethical awareness, including protecting participants' privacy and addressing power relations in educational settings (TENK, 2019). Reflective documentation, including teaching logs and analytical notes, supports the examination of pedagogical decisions and their effects on learning processes. Through this approach, the research demonstrates how ABAR can be used to investigate interdisciplinary education in contexts where material engagement, environmental conditions, and artistic practice are closely intertwined. The methodology provides a way to examine how understanding develops through adjustment and participation in practice. It offers a framework for research that remains sensitive to process, context, and relational complexity, contributing to the development of methodological approaches in art–science education and Arctic art education.

The interpretation of these findings is closely connected with the educational context in which the action cycles were implemented. Materials such as snow, berries, and materials

from forests are embedded in the ecological conditions, seasonal processes, and place-responsive pedagogical traditions of Northern Finland. These contextual conditions shaped the selection of teaching materials, the organisation of learning activities, and pupils' interpretations of natural phenomena throughout the research. The findings show that the contribution of this dissertation extends beyond the materials themselves. They illustrate how ecological conditions, locally meaningful materials, and educational practices worked together to support interdisciplinary inquiry and learning. In this way, the Arctic functioned as an active pedagogical context that shaped educational experiences, interdisciplinary inquiry, and pupils' engagement with natural phenomena across the action cycles.

The significance of locality and materiality raises questions about equity and regional equality in art–science education. The Arctic cases in this research benefited from access to snow, berries, seasonal environmental changes, and educational settings that supported outdoor and material-based activities. Comparable opportunities may not be equally available in all schools or regions. Geographical location, school resources, teacher expertise, available time, and access to outdoor or informal learning environments may influence how place-responsive art–science education can be implemented. Therefore, locality should not be understood as dependence on particular Arctic materials or environments. Its pedagogical significance lies in attending to materials, phenomena, and environments that are accessible and meaningful within each educational context.



8 | Conclusion

Image 15. Beyond the study: art-science in contect. Photograph: Xiaowei Zhang, 2026.

In my dissertation, I use an art-based action research approach to examine and develop art–science teaching practices, with particular attention to the integration of art and chemistry. I understand this integration as a relational and material process, where materials, bodies, environments, and pedagogical practices shape the development of understanding and creativity. The findings collectively address the research questions by demonstrating how art–science teaching in Arctic contexts supports pupils' creativity, emerging scientific understanding, and inquisitive thinking through engagement with materials, ecological processes, and experimental practice. I show that integration takes shape through participation in shared practices where observation, experimentation, interpretation, and expression become interconnected. Through the research, I contribute new knowledge by demonstrating how material engagement and embodied experience support learning in art–science education.

One key contribution of this dissertation lies in showing how art–science integration can connect different disciplinary ways of exploring and interpreting the world through shared engagement with materials and phenomena. The findings show how art–chemistry integration creates material-engaged and process-oriented pedagogical situations in which artistic and scientific modes of inquiry interact. When pupils encounter material transformations and uncertainty, they develop understanding and expressive capacities through ongoing experimentation, adjustment, and reflection. Therefore, creativity can be understood as responsive engagement with material behaviour, experimentation, and changing conditions.

In the activities, I show that pupils' understanding of natural phenomena develops gradually through repeated acts of manipulation, observation, and expression. Experimental and materially embedded pedagogical structures support sustained attention to change and variation. Embodied experience and material feedback supported pupils' developing scientific understanding, while artistic expression and scientific observation form a continuous and dynamic relationship within practice. In this way, the findings demonstrate that art–science integration is shaped through pedagogical processes that connect disciplinary aims with material, experimental, and expressive practices. Natural and ecological materials function as teaching resources and active participants in shaping cognitive, affective, and ecological understanding.

This dissertation also demonstrates that teaching practice and research can evolve as a single interconnected process. Through multiple cycles of pedagogical design, enactment, documentation, and reflection, I show how teaching, data generation, analysis, and redesign co-produce knowledge. I argue that Art-Based Action Research provides a methodological framework that allows me to trace how educational practices develop over time in response to materials and environments. By adopting a more-than-human perspective and analysing

material participation, I extend AAE by showing how relational and material processes are enacted in concrete educational situations.

The findings also have implications for educational practice. In Finnish education and Arctic STEAM contexts, material-based and open-ended activities can provide opportunities for pupils to move between scientific observation, experimentation, artistic interpretation, and reflection. The findings highlight the importance of pedagogical planning in creating connections between artistic and scientific practices. Teachers need sufficient time and flexibility to organise materials, structure opportunities for experimentation, and support pupils in moving between observation, inquiry, and artistic interpretation. The implementation of these approaches needs to remain responsive to pupils' age, available resources, local environments, and the aims of the subjects involved.

Future educational development in Arctic contexts should recognise local ecological materials and environments as active pedagogical resources. I see strong potential in developing long-term school–research partnerships that allow teachers and pupils to engage in sustained cycles of experimentation and reflection. These kinds of longitudinal approaches would deepen understanding of how relational and material processes evolve over time. This pedagogical orientation could be further explored and adapted across different cultural, geographical, age-related, and teacher education contexts. There is also potential to explore how technology can participate in art–science practices as an active relational element, alongside materials and environmental processes. Future research could also examine teacher collaboration more directly, including how art and science teachers negotiate disciplinary aims, share pedagogical planning, and develop interdisciplinary activities.

These directions suggest that the implications of this dissertation extend beyond the specific empirical contexts in which the research was conducted. My dissertation develops art–science education through art–chemistry integration and material engagement, with attention to pupils' creativity, scientific understanding, and inquisitive thinking through encounters with materials and natural phenomena. This perspective connects material engagement, relational processes, and experimentation with structured educational aims and open-ended exploration. The findings also show that these practices are shaped by particular materials, environments, participants, and pedagogical conditions. Their application in other educational contexts requires attention to local resources, disciplinary aims, and the conditions available for teaching and learning.

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Article I

Zhang, X., Huhmarniemi, M., & Hiltunen, M. (2026). Integrating art and science in education: Cultivating creative expression and inquisitive thinking. *International Journal of Education and the Arts,27* (29). http://doi.org/10.59236/ijea27n29

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International Journal of Education & the Arts

https://journals.psu.edu/ijea ISSN: 1529-8094

Volume 27 Number 29 August 31, 2026

Integrating Art and Science in Education: Cultivating Creative Expression and Inquisitive Thinking

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Citation: Zhang, X., Huhmarniemi, M., & Hiltunen, M. (2026). Integrating art and science in education: Cultivating creative expression and inquisitive thinking. *International Journal of Education & the Arts*, *26*(29). http://doi.org/10.59236/ijea27n29

Abstract

STEAM education has gained increasing attention as an interdisciplinary approach that integrates the arts to enrich science learning and foster creative thinking. This study examines how combining artistic creation with scientific experimentation promotes students' creative expression, inquisitive thinking, and emotional engagement. The study utilized an art-based action research methodology, conducted over two months, with 20 first-grade students in China. Data were collected through the researcher's observation diary, students' artworks, oral reflections, and photographic documentation of the instructional process. Data analysis involved reflective observation and interpretation to examine how students engaged with scientific concepts through creativity. The findings suggest that integrating art and science through multisensory activities promotes creative expression, fosters inquisitive thinking, and enhances emotional engagement, engaging with scientific phenomena in exploratory ways.

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Introduction

STEAM education (science, technology, engineering, arts, and math) has gained increasing attention as an interdisciplinary teaching and learning model (Perignat & Katz-Buonincontro, 2019), with the arts acknowledged as a crucial element for improving interdisciplinary education worldwide (Henriksen et al., 2018). STEAM education differs from STEM education by integrating arts, thereby eliminating disciplinary borders and offering students a more comprehensive learning experience (Bequette & Bequette, 2012; Ghanbari, 2015; Repko & Szostak, 2020). Art goes beyond mere creative expression; it serves as a means of comprehending the intricacies of the world (Ljokkoi & Slotte Dufva, 2020). By integrating art and science, students can engage with and analyze scientific phenomena through a multi-sensory approach, facilitating enhanced cognition and reflection (Henriksen, 2014) and the examination of complex reality (Hiltunen, 2025). The interdisciplinary model demonstrates significant results in cultivating creativity and helps students cope with complex global challenges (Liao, 2016).

The relevance of STEAM education extends beyond improving students' academic achievement and problem-solving abilities. It fosters authentic learning experiences, critical thinking, and creative problem-solving skills (Chung & Li, 2021; Henriksen, 2014; Sederholm, 2015). Students construct knowledge through active exploration and reflection (Piaget, 1954). Artistic processes enable them to approach scientific issues from diverse perspectives and to build new cognitive relationships between art and science. Through artistic processes, learners approach scientific issues from multiple perspectives, forming new cognitive connections between artistic and scientific ways of understanding.

Recent advances in educational technology have broadened the scope of STEAM instruction globally. Cloud-based platforms, computer simulations, and augmented reality technologies are increasingly being incorporated into interdisciplinary educational settings, providing dynamic and multimodal methods for students to interact with scientific material (Papadakis et al., 2023a, 2023b). Artificial intelligence and educational robotics have been investigated as instruments to facilitate personalized, interdisciplinary learning (Lampropoulos & Papadakis, 2025; Lavidas et al., 2024). Despite ongoing improvements in STEAM education, there is an urgent need to investigate how embodied, material-based, and art-centered methodologies might enhance these digital developments, especially in early childhood education, where sensory engagement is vital.

Ruccius (1994) contended that the objective of arts education extends beyond merely supplementing other courses. Through its distinctive methodology, visual arts education has demonstrated to educators the essence of authentic constructivist, contextualized, supporting, and collaborative teaching and learning (Efland, 2002; Räsänen, 2008, 2012). It provides

students with a multidimensional learning platform that utilizes bodily knowledge, contextual knowledge, and practical experience to help them construct knowledge and reflect deeply on real-life situations (Brown et al., 1989; Van Dijk & Frens, 2011). STEAM education enhances this potential by providing students with the opportunity to explore new realms through creative and collaborative interactions that merge art and science (McGarry, 2018). In China, STEAM education has received growing scholarly attention. Researchers have examined teachers' perceptions and attitudes toward STEAM disciplines (Li & Chiang, 2019). Furthermore, Luo and Cong (2024) indicated that creativity plays a significant role in fostering interdisciplinary integration and regional equity.

In recent years, the need to foster creativity, cognitive development, and interdisciplinary thinking in basic education has gained increasing attention. Art-integrated learning environments enhance children's observational skills, conceptual reasoning, and scientific thinking by engaging multiple sensory modalities and symbolic systems (Eisner, 2002; Winner et al., 2013). Responding to this need, the researchers employed an art-based action research (ABAR) method to create a learning environment that facilitates the intersection between scientific exploration and artistic expression. Specifically, the research focused on the design and implementation of an interdisciplinary course that combined basic chemistry experiments with visual arts activities for students, aiming to strengthen their sensory engagement, conceptual understanding, and imaginative thinking as part of broader cognitive growth.

The study is based on a two-month interdisciplinary curriculum involving first-grade students (N = 20) from a university-affiliated elementary school in China. The curriculum integrated chemical experiments with art education to create an interdisciplinary framework. Through this approach, students explored scientific topics through multisensory experiences and articulated their understanding using artistic expression. The following research question: How does integrating art and chemistry promote students' creative expression, inquisitive thinking, and emotional engagement? The article is a result of first cycle of action research continued in Finland (Zhang & Hiltunen, 2025; Zhang & Huhmarniemi, in press).

Theoretical Framework

Learning is increasingly recognized as a socially and culturally mediated process where meaning is formed through interaction, conversation, and shared experience (Danielson, 2022). In this context, art offers a symbolic and real place for learners to explore, express, and evaluate their experiences (Cappello et al., 2024). Art serves as an integrative inquiry method that connects perceptual experience with conceptual understanding, allowing students to convert observation into reflection and creative interpretation (Hetland et al., 2023). Through these processes, learners comprehend abstract concepts, perceive scientific phenomena, and

convey emotional and cultural significances related to their education (Filipe et al., 2024).

Wijnen-Meijer et al. (2022) and Filipe et al. (2024) reported that artistic reinterpretation of hands-on experimentation transformed scientific inquiry into creative meaning-making within STEAM education informed by constructivist and experiential learning traditions. The integration of art and science promotes epistemic engagement and reflective inquiry (Burnard & Colucci-Gray, 2020). It positions STEAM as a field where creative and scientific knowledge are developed collaboratively. Scholars Boice et al. (2021) emphasized the educational aspect of this integration, illustrating how collaborative teacher training fosters imaginative and inquiry-based learning environments. Meanwhile, Liston et al. (2022) illustrated how technological innovation and data-driven creativity broaden the fields of modern STEAM education.

In arts-based science education, emphasis is placed on how visual and performative techniques facilitate learners' exploration of scientific phenomena through multiple sensory and semiotic modalities (Henriksen et al., 2018; McGarry, 2018). McGarry (2019) further describes this process as multitextual literacy, where learners draw meaning from visual, linguistic, and performative modes of communication. Therefore, art provides an open and flexible arena for exploration and meaning-making through multimodal experience, allowing students to express personal responses to scientific ideas through creative processes (Paatela-Nieminen, 2021).

Constructivist approaches highlight meaning-making through experience, while arts-based pedagogies enhance this process by incorporating embodied, emotive, and aesthetic aspects of learning. Eisner (2002) contended that the arts cultivate specific cognitive modalities based on sensory perception and imagination. They enable learners to identify complex distinctions, use metaphorical reasoning, and articulate concepts that exceed verbal or numerical confines. Räsänen (2008, 2015) considered contemporary art education as a platform for ethical, aesthetic, and interdisciplinary exploration, allowing students to investigate ecological and scientific problems from cultural, symbolic, and personal perspectives. Students integrate intuitive play, material exploration, and reflective dialogue to build knowledge (McGarry, 2018).

Creativity is important to these processes, which involve curiosity, introspection, and the ability to manage uncertainty and complexity. According to Craft (2005), possibility thinking represents the imaginative aspect of creativity that allows learners to transition from "what is" to "what could be". It emphasizes the ability to cope with uncertainty through inquiry, imagination, and reflective judgment. Creativity involves the generation of innovative ideas, as well as critical and inquisitive participation (Lukaka, 2023). Recent research in the field of

art education has advanced an ecological relational perspective on creativity. This perspective emphasizes that creative processes emerge through material, social, and cultural interactions. Researchers have highlighted that interdisciplinary and reflexive practices facilitate creative thinking and the integration of artistic and scientific knowledge (Samaniego, 2024). Creativity is increasingly conceptualized as transferable and situated, shaped by learners' motivation, environment, and cultural background (Gormley, 2025; Kadyirov et al., 2024; Lukaka, 2023). This suggests that creativity in art-based STEAM education is understood as a dynamic, socially situated, and ecologically embedded process of meaning-making. Creative learning is shaped by learners' relationships with their surroundings, including the cultural and spatial contexts in which they live and learn (McGarry, 2024).

Combining artistic methods with scientific investigation enhances learning through multimodal, embodied, and contextualized experiences (Eisner, 2002; Henriksen et al., 2018). In STEAM classrooms, creativity emerges as a practice-based and embodied experience, shaped by learners' engagement with materials, experimentation, and reflection (Samaniego, 2024). STEAM education is widely recognized as fostering creativity, critical thinking, and problem-solving abilities essential for resolving complex ecological and social issues (Kristanto & Mariana, 2023; Perignat & Katz-Buonincontro, 2019). Vervoort et al. (2024) emphasized the socio-emotional and ethical aspects of creativity, associating artistic processes with empathy, collaboration, and environmental responsibility. Similarly, Sternfeld et al. (2024) argued that integrating the arts with social-emotional learning fosters creative learning environments where emotional engagement and imagination enhance students' holistic development and creative potential.

Many studies on STEAM education have focused on curricular frameworks and educators' perspectives, often overlooking children's experiential engagement with art–science integration, particularly in relation to material exploration and embodied creation. As a result, representational outcomes are frequently prioritized over the processes of creative inquiry. The study was designed to examine how children engage with scientific concepts through multisensory and art-based experiences, and how creative expression facilitates meaning-making in interdisciplinary learning environments.

ABAR Methodology and Data Collection

An extended art-based action research (ABAR) study that integrates repetitive cycles of educational intervention, reflection, and analysis with the expressive potential of art. ABAR integrates the reflective processes of action research with creative practices to examine educational phenomena (Jokela et al., 2015, 2019; Jokela & Huhmarniemi, 2025). It involves cycles of planning, intervention, and reflection. The artworks produced by stakeholders frequently function as research data, as demonstrated in this study.

The study was carried out at a university-affiliated elementary school located in southern China. The interdisciplinary curriculum was developed by Zhang in collaboration with two teachers from the fields of science and art at the school. It was implemented as a component of the school's extracurricular program over a period of two months in spring 2024. The sample included 20 first-grade students (ages 6–7) who had also engaged in the program during the previous fall semester. In the spring sessions (Figure 1), the first author directed the implementation in collaboration with the school's instructional team. Students collaborated in small groups of three to four to conduct scientific experiments and engage in artistic activities.



Figure 1. A Sensory Journey of Interdisciplinary Experimentation, 2024. © Photograph by Xiaowei Zhang.

The teaching experiment consisted of three unique phases: (1) concept presentation via lectures and teacher-led scientific demonstrations, (2) collaborative experimentation using multisensory activities, (3) artistic creation and storytelling creation based on the students' interpretations of scientific phenomena. Sessions were held once or twice a week, depending on the phase. The objective was to enhance students' creative thinking and comprehension of science. The sequence of planning, implementation, data collection, and analysis clarifies the cyclical structure of the study design and the correspondence between educational interventions and research activities (see Figure 2).



Figure 2. The Cyclical Process of Art-Based Action Research (ABAR) in Interdisciplinary Education.

The data were collected by Zhang and included the researcher's observation diary, students' artworks, oral reflections, and documentary photographs of the teaching process. These sources were triangulated to examine how the integration of art and chemistry contributed to students' creative, cognitive, and emotional engagement. Each artwork was accompanied by a brief oral description from the students, which Zhang recorded and transcribed. The observational data captured verbal and non-verbal expressions, group collaboration, and spontaneous comments during the experimental activities. In addition to the students' final artworks, sequential photographs documented the work-in-progress stages, illustrating the students' evolving ideas and techniques. Students' oral descriptions were collected at two points: as spontaneous in-situ comments during the creative process and as reflective responses at the end of the activities.

All ethical procedures adhered to the national guidelines of the Finnish National Board on Research Integrity (TENK, 2023). The school principal and classroom teachers gave their approval for the study. Informed consent was obtained from parents after they were fully informed about the purpose and use of the research materials, and the children agreed to participate. All materials were anonymized as appropriate. All images containing identifiable facial characteristics were systematically obscured in accordance with privacy and data protection regulations.

Data Analysis

The analysis followed theoretical frameworks that conceptualize learning in art-based STEAM education as an embodied, imaginative, and reflective process (Eisner, 2002; Craft, 2005; Räsänen, 2015). It concentrated on how students engaged with materials and artistic processes to understand scientific concepts, experiencing creativity as an integral aspect of their education. Creativity was defined in this study as an emergent, social process of meaning-making, guiding the examination of how creative and scientific thinking were integrated in students' learning processes.

Inductive content analysis was used within an art-based methodology (Barone & Eisner, 2012), employing visual methodologies to investigate the aesthetic and narrative aspects of students' learning (Leavy, 2009). Visual, verbal, and observational materials were analyzed iteratively, concentrating on instances where creative and scientific thinking converged through exploration, debate, and reflection. The analysis was conducted in two steps. During the initial phase, visual and verbal resources, comprising artworks, transcribed oral reflections, and field notes, were analyzed. The data were subsequently coded inductively to identify emergent trends. During the second phase, preliminary codes were developed and classified into three interpretive dimensions: creative expression, inquiry-based reasoning, and emotional engagement. The analysis was focused on how students developed their understanding through sensory experiences and material exploration, demonstrating the transformative power of interdisciplinary learning. The students' artworks were examined using inductive visual coding to enhance the interpretive process, concentrating on repeating elements. Visual elements were analyzed in connection with students' oral reflections, reflective notebooks, and group presentations.

To ensure analytical reliability, 25% of the dataset was independently coded by another researcher, a specialist in natural sciences, providing an inter-coder agreement rate of 88%. The reliability and validity of the findings were enhanced through triangulation of visual, verbal, and observational data sources (Denzin, 2017; Patton, 2002) and informal member confirmation. Reflexivity was ensured during the study through reflective diary and regular peer discussions. This process allowed the researcher to critically reflect on their positionality, interpretive decisions, and underlying assumptions. To enhance transparency, selected students' artworks are included to exemplify the analytical reasoning and interpretation presented in this study.

Findings

Creative Expression: Transforming Scientific Observation into Symbolic Meaning

Students were able to interpret scientific facts using visual and symbolic language when art

was incorporated into chemistry experiments. Most students created imaginative compositions that connected scientific processes with natural, emotional, and narrative components, rather than literally portraying reactions. They used symbolic and metaphorical images to reinterpret the chemical experiments in the artworks (Figure 3). Some students represented the reactions as rhythmic compositions that resembled musical notes, while others saw test tubes as tree trunks that were bursting with vibrant colors. These creative imaginings show how students viewed scientific methods as dynamic, connected, and expressive systems, as opposed to fixed results. Through aesthetic reasoning, students organized sensory impressions into conceptual understanding and translated observation into visual metaphors of growth and rhythm. Artistic practice functioned as a mediating process through which scientific observation was reconfigured into relational and process-oriented understanding, enabling students to grasp chemical change as a dynamic phenomenon unfolding over time. In their creative process, they further experimented with composition, layering, and rhythmic repetition to express transformation, balance, and continuity, perceiving color change as a continuous and dynamic phenomenon.



Figure 3. Students' Artworks, 2024. © Photograph by Xiaowei Zhang.

In order to make sense of chemical change, students used art to create a reflective environment in which they could visualize abstract concepts and integrate their imagination and senses. As a result, the artwork served as beautiful symbols of cognitive knowledge, allowing students to express their thoughts visually rather than verbally. However, a few students produced paintings that mainly illustrated the experiment itself, showing limited imaginative transformation, influenced by group dynamics and individual confidence. These creative activities show how art helps students reflect on materials and turn scientific observation into expressive knowledge, highlighting learning as a meaning-making process where imagination and material engagement work together to develop understanding through aesthetic reflection. This emphasizes how art acts as a cognitive process that transforms sensory perception into conceptual knowledge.

Inquisitive Thinking: Experimentation, Dialogue, and Reflection

The way students interacted with the experiment demonstrated their curiosity. They tested theories, tracked outcomes, and improved their methods because of their curiosity and perseverance. To comprehend color responses, students actively changed mixes, compared results, and spoke about adjustments to proportions and sequencing. Many students spoke of going through the same steps repeatedly in an attempt to "find the right color" or "see what happens if I change this." These actions demonstrate a readiness to deal with ambiguity and to acquire knowledge via experimentation, observation, and modification. The artistic framing of the activity shaped how inquiry developed by foregrounding visual variation, material choice, and open-ended manipulation. Working with color and composition encouraged students to attend to subtle changes, compare emerging outcomes, and explore alternative possibilities through repeated trials. Artistic experimentation thus supported inquisitive thinking by transforming uncertainty into an exploratory space, where questioning, testing, and revising ideas were guided by visual and material feedback. Another characteristic that distinguished students' curious thinking was collaborative discussion. They collaborated in small groups, observed each other's tests, shared ideas, and considered potential explanations for variations in results. Teachers saw students express their ideas aloud, ask questions, make predictions, and react to suggestions from their peers. Students were able to link action and reflection through this type of interaction, which demonstrated how thinking evolved through both discussion and embodied experimentation.

Students started to connect conceptual understanding with hands-on experimentation. Their investigation encompassed observation, interpretation, and group meaning-making, in addition to material manipulation. Interaction patterns showed that students gradually moved from simple observation to more intentional explanation as they learned through involvement and group discussions. In scientific learning, artistic experimentation can foster both cognitive flexibility and creative reasoning, as demonstrated by the iterative cycles of testing, reflection, and modification. There were additional differences between the groups. While some students enthusiastically embarked on new experiments, others paused and awaited advice from teachers or classmates. These differences imply that differentiated support is beneficial for inquiry-based learning, especially when it comes to assisting learners who lack the confidence to effectively navigate uncertainty.

The findings indicated that inquisitive thinking in this situation integrated reflection, teamwork, and curiosity. Instead of viewing the experiment as a set task, students viewed it as an open-ended investigation. By putting theories to the test, tracking results, and collaborating, they turned curiosity into knowledge and showed how scientific research can be advanced through artistic and social interaction. This illustrates a relational approach to learning, which is prominent in modern art and design education, and which holds that

knowledge grows through group investigation and mutual reflection.

Emotional Engagement: Experiencing Science Aesthetically

Students' emotional engagement with scientific phenomena emerged through their aesthetic and sensory involvement in the experimental process. Students experienced experimentation as an open-ended, visually and affectively engaging activity. The artistic framing of the task positioned scientific inquiry as something to explore, notice, and feel, inviting students to attend closely to color, texture, rhythm, and subtle visual changes. This sensory attentiveness fostered curiosity and sustained interest, creating an affective entry point into scientific exploration.

The integration of artistic practice transformed experimentation into a perceptual and emotional inquiry. As students worked with color, they became absorbed in observing tonal shifts, gradients, and unexpected transitions, often expressing excitement or anticipation about what might emerge next. This aesthetic engagement encouraged repeated testing and adjustment, as students sought to "find the right color" or to explore how slight changes in proportion or sequence would alter the visual outcome. In this process, uncertainty was experienced not as a source of frustration but as an invitation to continue experimenting. Emotional engagement thus supported a willingness to dwell in trial-and-error, extending both the temporal and cognitive space of inquiry.



Figure 4. Elemental Harmony: Science Meets Nature, 2024. © Photograph by Xiaowei Zhang.

Collaborative dialogue was similarly shaped by aesthetic engagement. As students observed one another's artworks and experimental traces, their interactions moved beyond checking procedural accuracy toward sharing impressions, reactions, and interpretations. Visual artifacts functioned as emotionally resonant reference points that stimulated discussion, comparison, and mutual suggestion. Students responded to peers' ideas by modifying their own experimental actions and artistic compositions, demonstrating how shared aesthetic experiences supported collective meaning-making. Through these exchanges, emotional involvement sustained attention and encouraged responsiveness to others' perspectives.

Through aesthetic and emotional engagement, students' inquiry gradually shifted from immediate observation toward more intentional explanation. Visual outcomes prompted questioning, hypothesizing, and re-testing, while emotional investment helped maintain motivation and openness throughout the exploratory process. The findings indicate that emotional engagement, fostered through artistic practice, played a critical role in supporting participation and perseverance by encouraging sustained attention to sensory change.

Discussion

The findings emerged from a specific classroom context; they address questions that are central to broader discussions in STEAM education. The analysis demonstrates how artistic practices can shape scientific inquiry by supporting meaning-making, exploratory experimentation, and sustained engagement, rather than functioning only as a supplementary or motivational component. By articulating the roles of creative expression, inquisitive thinking, and emotional engagement, insights were gained into how art–science integration can inform the design of inquiry-oriented learning environments across diverse STEAM contexts.

The results highlight how art-based, interdisciplinary learning enhances students' engagement with science by including aesthetic, cognitive, and emotional aspects of comprehension. The integration of scientific investigation and artistic creation transforms learning into an immersive process rooted in perception, imagination, and reflection. Learning functions as a relational and participatory process in which meaning is constructed through collaborative effort and reflection (Danielson, 2022; Hetland et al., 2023). In this educational framework, art serves as a symbolic and tangible language that allows learners to link sensory observation with conceptual interpretation, converting factual knowledge into reflective comprehension (Eisner, 2002; Filipe et al., 2024).

Students' artworks illustrated the transformation of perceptual experience into aesthetic representation. They articulated their understanding of chemical events through visual metaphors, including trees, rhythms, and natural cycles. These visual representations suggest

that aesthetic cognition and possibility thinking might foster interpretive and imaginative engagement with scientific knowledge (Craft, 2005; Eisner, 2002). Their playful application of color, composition, and rhythm clarified the construction of meaning through imagination and material interaction, demonstrating that creativity in STEAM education arises from the interplay between perception and conceptual reasoning (McGarry, 2018; Räsänen, 2015).

The students' inquiry processes demonstrated that learning in interdisciplinary situations evolves through cycles of exploration, interpretation, and reflection. As students experimented with mixtures, shared observations, and honed their concepts, they showed the iterative process of knowledge building described in constructivist and sociocultural theories (Burnard & Colucci-Gray, 2020). Their conversations illustrated that thinking was both embodied and social: comprehension developed through material manipulation and peer discourse. This finding suggests that inquiry in STEAM education becomes most effective when learners engage with uncertainty as a productive condition for meaning-making and deepen their understanding through collaborative reflection (Wijnen-Meijer et al., 2022). In this study, students engaged in open-ended exploration in which inquiry was framed as an interpretive process that encouraged imaginative reasoning and reflection.

Emotional and sensory involvement contributed significantly to meaning-making. Their feelings of joy, curiosity, and wonder suggested that emotional resonance affected both their motivation and their aesthetic choices. Their use of color, balance, and rhythm reflected feelings of tranquility or exhilaration, demonstrating the effects of directed attention and prolonged involvement. These experiences demonstrate that emotion is fundamental to cognition, influencing how learners perceive and assimilate complex facts (Vervoort et al., 2024). The interaction between emotion, perception, and thought can foster ecological and embodied awareness by connecting learners' inner experiences with the natural environment (Räsänen, 2015).

International discussions on STEAM education may be informed by evidence showing how children engaged creatively and emotionally with scientific phenomena through art-based processes. Whereas previous research has primarily focused on curricular design and teacher perspectives (Henriksen et al., 2018), this work turns attention to students' experiences and the cognitive value of aesthetic expression. Building on the ecological view of creativity proposed by McGarry (2024) and Filipe et al. (2024), it shows that creativity develops through interactions between learners, materials, and the environment. When perceptual, emotional, and cognitive forms of knowing intersect, interdisciplinary learning enables students to approach science as a dynamic and interpretive practice, rather than as a fixed body of knowledge.

Teachers can enhance interdisciplinary learning by fostering open and reflective classroom environments that facilitate the mutual influence between art and science. Facilitating time for observation, debate, and innovative reinterpretation fosters curiosity and empathy, enhancing children's comprehension of natural processes (Bequette & Bequette, 2012; Räsänen, 2015). Scientific research becomes a personal and imaginative endeavor, demonstrating how art-based methodologies can enhance cognitive growth and creative confidence in elementary school.

This research is a component of Zhang's extensive STEAM education initiative conducted in Finland and China, encompassing various schools and educational levels. The study uses art-based action research to provide contextual knowledge of the integration of aesthetic and scientific thinking through interdisciplinary practices in elementary education. By emphasizing students' creative processes and perspectives, the study enhances the global discourse on the integration of art, science, and ecology in education. It provides practical and methodological insights into the use of ABAR as an instructional strategy and mode of inquiry. Future studies will enhance this cross-cultural perspective to investigate the enduring effects of art and science integration on students' creativity, ecological consciousness, and scientific involvement.

Conclusion

Students' artworks and interviews with participating students from a STEAM project conducted at an elementary school were analyzed. The project constituted the first cycle of ABAR. The study was designed integrate art and chemistry teaching, allowing students to perceive natural occurrences through chemical experiments and express their reflections through visual storytelling. STEAM education promotes creative discovery and multisensory learning, helping students improve their comprehension of scientific concepts and engage in active cognitive development.

Students collaboratively presented distinctive visual representations of chemical processes, utilizing components such as colorful test tubes, natural objects, and auditory aspects. These activities enhanced creative expression through visual storytelling and interpretation, while educators promoted thorough observation and experimentation. Students exhibited imagination, inquiry-based reasoning, and affective involvement. Creativity was demonstrated through the use of original materials and metaphorical representation. Inquisitive thinking was demonstrated through questioning, prediction, and causal reasoning. Emotional engagement was evident through expressions of curiosity, persistence, and excitement during collaborative tasks.

The value of multisensory learning in STEAM education was demonstrated through evidence

showing how visual art extended beyond representation to deepen understanding and inform interdisciplinary instructional design. Future iterations of this study could benefit from the use of validated assessment tools to strengthen the empirical foundation of core concepts such as creativity, inquisitive thinking, and emotional engagement. The next cycles of ABAR will extend this inquiry to new contexts and materials. The research will investigate how interdisciplinary art and science initiatives enhance students' creativity, emotional engagement, ecological awareness, and scientific comprehension in elementary education. This initiative seeks to enhance theoretical and practical frameworks for integrating visual art education into science instruction. It explores the use of natural resources and culturally significant materials, addressing issues of sustainability, local relevance, and challenges in early childhood education.

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Article III

Zhang, X., & Huhmarniemi, M. (2026b). Trees, forests, and recycled paper: art–science approaches to ecological understanding in Northern Finland. *Environmental Education Research*, 1–19. https://doi.org/10.1080/13504622.2026.2693945

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Environmental Education Research

ISSN: 1350-4622 (Print) 1469-5871 (Online) Journal homepage: www.tandfonline.com/journals/ceer20

Trees, forests, and recycled paper: art–science approaches to ecological understanding in Northern Finland

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To cite this article: Xiaowei Zhang & Maria Huhmarniemi (25 Jun 2026): Trees, forests, and recycled paper: art–science approaches to ecological understanding in Northern Finland, Environmental Education Research, DOI: 10.1080/13504622.2026.2693945

To link to this article: https://doi.org/10.1080/13504622.2026.2693945

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Published online: 25 Jun 2026.

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ENVIRONMENTAL EDUCATION RESEARCH
https://doi.org/10.1080/13504622.2026.2693945

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Trees, forests, and recycled paper: art–science approaches to ecological understanding in Northern Finland

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ABSTRACT

The escalating environmental concerns highlight the need for educational approaches that engage children with ecological relations in everyday environments. The integration of art and science can connect learners with natural processes through experiential and multimodal practices. This study examines how children articulated ecological understanding through embodied, material, and imaginative engagement in art–science integrated activities during a 'Nature and Science' summer camp in Northern Finland. The camp was situated in a forest-rich region where forests are integral to everyday life and debates on sustainability and resource use. The study draws on art-based action research, in which artistic activity functions as both pedagogy and research data. The analysis approaches learning situations as embodied, material, and collaborative processes in which artworks and interpretations developed through activity. The camp included recycled papermaking, sensory forest activities, and exploration at a science center. Data included observations, children's artworks, field notes, photographs, and teacher interviews. The analysis identified three recurring forms of articulation: (1) sensory encounters with forest environments, (2) the transformation of recycled paper through collaborative making, (3) connections described across activities during interdisciplinary exploration. Ecological understanding developed through engagement with materials, places, and activities, as pupils connected experiences across forest exploration, recycled papermaking, artistic creation, and science-center investigations. The children's artworks and reflections referred to continuity, renewal, vulnerability, and care, while positioning themselves as participants, protectors, and co-inhabitants in relation to forest environments. The findings show how art–science activities can support children's ecological meaning-making through material engagement, imagination, and interdisciplinary exploration.

ARTICLE HISTORY
Received 29 October 2025
Accepted 19 June 2026

KEYWORDS
Environmental education; art-science education; art-based action research; ecological understanding; place-based learning

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1. Introduction

The escalating global environmental crisis has intensified discussions within environmental education research concerning how children come to know and understand forest environments and ecological processes. Environmental education has long sought to foster human–environment relations. However, contemporary childhood is increasingly shaped by urbanized and technologically mediated environments in which sustained and sensory engagement with natural environments is limited. This situation has been described as an 'extinction of experience' (Beery et al. 2023, 473), highlighting a decline in embodied and affective encounters with nature that are central to ecological understanding and care (Whitburn, Abrahamse, and Linklater 2023). When children's understanding of ecological processes is limited or remains disconnected from lived experience, environmental issues may be perceived as abstract concepts. This disconnection can reduce opportunities to develop a sense of responsibility, care, and agency in relation to environmental challenges. For this reason, environmental education increasingly emphasizes learning experiences that support meaningful engagement with local environments and ecological processes.

Forests are places where ecological, social, and cultural meanings intersect. In Northern Finland, they function as everyday landscapes that are closely connected to local livelihoods, biodiversity conservation, and debates concerning sustainability and resource use. The coexistence of these multiple and sometimes conflicting roles makes forests particularly relevant contexts for exploring how children come to understand ecological processes and human–environment relations. Industrial forestry has contributed to biodiversity loss, while debates surrounding forest protection influence how forests are understood and valued by communities, families, and children. These tensions make forests significant sites for exploring how children come to understand ecological processes, environmental responsibility, and human–environment relations. Recent research has increasingly emphasized embodied, experiential, and affect-oriented approaches that support children's engagement with specific environments through direct interaction (Hallam, Gallagher, and Owen 2022; Whitburn, Abrahamse, and Linklater 2023). In this study, affect-oriented approaches refer to the emotional and relational dimensions of children's engagement with environments.

Within environmental art education, artistic processes have long been used to engage with natural environments through sensory, material, and place-based interaction (Jokela, Hiltunen, and Härkönen 2015). These practices emphasize direct encounters with materials and sites, supporting forms of learning that emerge through perception, manipulation, and reflection (van Boeckel 2013). While scientific approaches contribute knowledge about ecological systems and environmental processes, artistic practices offer opportunities for sensory engagement, imagination, and interpretation. Integrating science and art can support ecological understanding by connecting conceptual knowledge with embodied and personal experience, enabling learners to engage with environmental phenomena from multiple perspectives. In the forest, art-based activities invite attention to textures, material transformations, and ecological interdependencies. Forest-based outdoor activities further support embodied engagement by offering open-ended contexts for play, experimentation, and collaboration (Huhmarniemi and Lande 2025; Whitburn, Abrahamse, and Linklater 2023). In this

study, art is approached as a material and interpretive practice through which children engage with trees, fibers, soil, and water in situated learning activities. Drawing on perspectives from environmental art education and arts-based learning (Eisner 2002; Inwood 2008), interpretive practice in this study refers to the ways children make meaning from environmental experiences through observation, material engagement, artistic creation, and reflection.

This article examines how children articulated ecological understanding through embodied, material, and imaginative engagement in forest-based art–science practices. Ecological understanding is approached as a situated process through which children make sense of ecological processes, material cycles, and connections between forest environments and everyday life (Desmarais 2024). Empirical material derives from an art-based action research project conducted during a 'Nature and Science' summer camp in Northern Finland, forming part of an ongoing multi-cycle longitudinal study on interdisciplinary education (Zhang and Hiltunen 2025; Zhang and Huhmarniemi 2026). The research question is: How did children articulate ecological understanding and their own roles in relation to forest environments through embodied, material, and imaginative engagement in art–science activities?

2. Research and the theoretical background

This study is situated at the intersection of environmental education and art–science integrated learning. Environmental education provides the broader context, while art–science integration offers a pedagogical approach that combines scientific inquiry with artistic exploration. Visual art contributes sensory, material, and interpretive dimensions to environmental learning. The following sections outline the perspectives informing the analysis.

2.1. Art–science integration in environmental education

In environmental and sustainability education, visual art practices have increasingly been approached as pedagogical practices that support learners' engagement with ecological issues through sensory, emotional, and participatory forms of learning (Ison and Bramwell-Lalor 2023). Dewey (1934) described aesthetic experience as learning grounded in human–environment interaction, where perception, emotion, and action are integrated through direct engagement with the world. Eisner (2002) extended this idea by emphasizing how artistic processes support perception, interpretation, and meaning-making, which is central to the present study's focus on learning through engagement with environmental phenomena. Research in environmental and art–science education highlights the role of artistic practices such as drawing, creative work with natural materials, and visual reflection in supporting experiential and inquiry-oriented learning. These practices enable learners to engage with materials, observe processes, and develop interpretations through making and reflection (Barone & Eisner, 2012; van Boeckel 2013).

In these fields, interdisciplinary approaches have become increasingly important for connecting artistic, scientific, and environmental ways of knowing (Perignat and Katz-Buonincontro 2019). Art–science approaches combine scientific observation

with artistic exploration and are often associated with interdisciplinary or phenomenon-based learning organized around real-world processes (Sochacka, Guyotte, and Walther 2016). Within these contexts, artistic practices function as ways of investigating and interpreting environmental processes (Glass and Wilson 2016; Marshall 2014), including attention to transformation and material change (Kewalramani and Veresov 2022; Macdonald, Malone, and Firth 2022). Visual art practices introduce interpretive, imaginative, and affective dimensions that enable learners to engage with ecological phenomena in personally meaningful ways. In this sense, art provides opportunities to explore ecological relationships through sensory experience, creative interpretation, and emotional engagement, extending approaches that rely primarily on scientific explanation alone. Research emphasizes that the educational value of art depends on pedagogical framing, task openness, and the degree of agency afforded to learners (Cremin and Chappell 2021; Illeris 2016). In art–science integrated settings, visual arts practices such as drawing support observation, material engagement, and the investigation of environmental processes and transformations (Sochacka, Guyotte, and Walther 2016; van Boeckel 2013). These processes are linked to creativity as a dimension of learning, where artistic practices provide opportunities for situated meaning-making through engagement with materials, environments, and experiences.

In art–science integrated environmental learning, interdisciplinary approaches are further developed through place-based and experiential pedagogies (Inwood 2008; Jokela, Hiltunen, and Härkönen 2015). Visual arts have been closely associated with environmental education that emphasizes place-responsive and materially situated learning (Jokela, Hiltunen, and Härkönen 2015; van Boeckel 2013). Within these place-responsive approaches, artistic practices support situated engagement with materials and experiences. Artistic activities such as drawing and creative work can support observation and interpretation of environmental phenomena. Children's drawings, when emerging from open-ended and exploratory processes, function as visual articulations of environmental experiences and understandings (Hiltunen, Kallio-Tavin, and Sohlman 2021). Previous research has identified challenges within art–science integrated environmental education. Interdisciplinary projects may privilege scientific content, and connecting creative activities with deeper ecological understanding remains a continuing challenge (Perignat and Katz-Buonincontro 2019).

2.2. Embodied and multimodal perspectives on learning

Learning in environmental and art–science contexts is closely connected to embodied and multimodal processes (Anttila 2015). Understanding develops as learners engage with materials, environments, and situations through sensory experience and participation (Thomas Jha and Price 2022). Artistic practices such as drawing, making, and collaborative experimentation open up ways for learners to work across visual, verbal, and bodily modes (Wright 2010). Through this engagement, learning begins to take shape in relation to materials and environments, as perception and action become intertwined in the exploration of phenomena (Ingold 2013). Bodily movement and material manipulation support this process by enabling learners to encounter and make sense of phenomena through direct experience (Wilson 2002).

As learners move within and across these modes, meaning develops through continuous shifts between perception, action, and representation (Kewalramani and Veresov 2022). Multimodal engagement allows learners to revisit and reorganize their experiences, gradually forming more complex understandings through interaction with materials and environments (Dunn and Wright 2014). In art–science integrated contexts, this process extends into inquiry, as learners begin to investigate and interpret phenomena through both artistic exploration and scientific thinking (Sochacka, Guyotte, and Walther 2016). Artistic and material practices support this development by creating opportunities to test ideas, reconsider observations, and explore alternative interpretations (Guyotte et al. 2014). Through this engagement, attention is directed toward processes such as transformation, causality, and material change as they emerge in practice (Hadzigeorgiou, Fokialis, and Kabouropoulou 2012).

As the learning process develops through engagement with materials, experiences, and environmental phenomena, imagination becomes increasingly significant in shaping how learners engage with and interpret phenomena. Through this development, engagement extends beyond immediate perception, as learners explore possibilities and form connections between materials, experiences, and ecological processes (Vecchi 2010). In this process, meaning-making involves the reinterpretation of phenomena through narrative, transformation, and personal experience (Beghetto 2010). Through the interplay of perception, action, and imagination, interpretations emerge that are grounded in experience while remaining open to new possibilities (Thomas Jha, Price, and Motion 2020). Embodied and multimodal perspectives frame learning as a dynamic process shaped by interaction, inquiry, and imaginative engagement in art–science contexts (Anttila 2015). Embodied and multimodal perspectives guide the analysis of how children make sense of ecological phenomena and inform the design of the summer camp activities. Forest exploration, recycled papermaking, drawing, and science-center investigations engaged children through sensory, visual, and verbal modes, encouraging movement between observation, material experimentation, artistic expression, and discussion.

2.3. Developing ecological understanding in place-based art–science learning contexts

Ecological understanding has become an important concern in environmental education as contemporary environmental challenges increasingly require learners to understand relationships between human activities and ecological systems (Stone and Barlow 2005; United Nations 2015; Vesterinen and Ratinen 2024). Recent studies have highlighted the role of situated and experiential engagement in supporting children's ecological understanding (Kiviranta et al. 2024). Place-based perspectives contribute to ecological understanding by connecting learning to specific environments, local experiences, and material encounters. From this experiential and place-based perspective, ecological understanding is examined as developing through engagement with place, materials, and ecological processes (Inwood 2008; Jokela and Coutts 2018). Participation in environmentally situated activities enables direct encounters with seasonal change and material transformation (Huhmarniemi 2023;

Jokela, Hiltunen, and Huhmarniemi 2019). Ecological understanding is also closely connected to broader aims of sustainability education (UNESCO 2017).

Art–science perspectives guide the examination of how children interpret ecological processes through engagement with materials and environments (Perignat and Katz-Buonincontro 2019). Arts-based and material-oriented pedagogies support ecological understanding by fostering sensory and imaginative engagement with ecological phenomena through visual and tactile practices that cultivate attentiveness and care. Ecological learning concerns how learners connect everyday experiences with broader environmental processes through situated activities (Thomashow 1996). In this study, the analytical focus is placed on how such connections are articulated through children's engagement with materials and environments in art–science learning situations. This study examines ecological understanding primarily through an art–science and embodied learning perspective. Place-based and multimodal perspectives provide complementary lenses for understanding how such processes develop in specific educational contexts.

3. Methodology

Art-based Action Research (ABAR) combines the cyclical structure of action research with creative and reflective practices (Jokela, Hiltunen, and Härkönen 2015; Jokela, Hiltunen, and Huhmarniemi 2019). Emerging from Finnish community and environmental art education, it links artistic practice with educational and social development across school and ecological contexts (Jokela, 2019). It has been described as a collaborative process integrating art, participatory action, and place-based learning through iterative cycles of planning, creation, and reflection. In a previous ABAR cycle using bilberry-based pigments (Zhang and Huhmarniemi 2026), pupils explored color changes and expressed them visually, demonstrating the learning potential of natural material experimentation.

In this study, ABAR operated as a mode of knowledge production in which artistic activity generated the research material, guided interpretation, and shaped the progression of the research process. This was realized through artistic practice functioning simultaneously as pedagogy, data production, and an analytical process. Artistic practice shaped the learning activities, generated visual and material data through pupils' creative work, and informed the interpretation of these expressions during analysis. Children's artworks were approached as interpretive material through which ecological understanding became visible, and interpretations developed through attention to visual, material, and interactional processes. Art was conceptualized primarily as children's visual and material making, including drawing and recycled papermaking. The study was conducted in forest environments because forests constitute an important local environment in Northern Finland and provided opportunities to examine ecological understanding through direct engagement with natural materials. The study followed a cyclical process in which pedagogical planning, artistic activity, and reflection informed one another. Zhang worked in a dual role as educator and researcher, allowing pedagogical decisions to be shaped by children's actions, material engagements, and emerging meanings.

3.1. Data collection and analysis methods

Data collection employed arts-based research methods (Leavy 2009, 2017) combined with qualitative inquiry, incorporating visual, verbal, and observational materials. The dataset consisted of 34 children's drawings, photographs, field notes, and reflective records documenting workshop activities, outdoor explorations, and material experimentation. Semi-structured interviews were conducted with four participating teachers to explore pupils' engagement, interdisciplinary collaboration, and the integration of art and science practices. All procedures followed TENK (2019) ethical guidelines. Written informed consent was obtained from 31 guardians, and participant anonymity was ensured throughout the study.

An inductive content analysis was conducted, grounded in an arts-based research framework (Barone & Eisner, 2012) and informed by visual methodologies (Leavy 2017). The analysis focused on how children expressed creative and ecological understanding through artistic and sensory processes. Attention was given to the pupils' use of texture, color, and material transformation in their artworks. Visual data were examined through a process of close looking, adapted from Manarin's (2018) approach to close reading and extended to visual materials. The analysis integrated observational notes, photographic documentation, and the pupils' verbal descriptions. A purposive selection of artworks was analyzed in depth to illustrate representative and diverse examples of learning through the creative process. To ensure credibility and trustworthiness, another researcher specialized in environmental education reviewed a subset of the data. Interpretations were discussed until agreement was reached on key themes. Methodological triangulation across visual, verbal, and observational sources (Denzin 1978; Patton 2002) strengthened the reliability and depth of the analysis. Three overarching analytical dimensions were identified: (1) sensory and affective engagement with natural materials, (2) the creative transformation of recycled resources into artistic expressions, (3) ecological understanding through interdisciplinary experience. Although these dimensions were informed by the organization of the camp activities, they served as analytical categories for examining recurring patterns in pupils' experiences, expressions, and interpretations across different data sources.

3.2. The research context and case study

In Northern Finland, forests play a central role in everyday life and in debates concerning sustainability and resource use. This action research cycle was implemented as a summer camp integrating arts, science, and environmental education. The camp aimed to support children's sensory engagement with forest environments and to explore ecological themes through material-based art–science practices. The first author collaborated with the LUMA Center Lapland, the Pilke Science Center, the Junnu Science Education Center, and pre-service teachers from the University of Lapland. A total of 34 children aged 7–9 and 5 teachers participated.

The camp comprised three phases (see Figure 1): forest-based sensory activities, collaborative papermaking and drawing using recycled materials, and interdisciplinary exploration at the Pilke Science Center. The participants were second- and third-grade pupils from local primary schools. Approximately 60% of the pupils had participated



Figure 1. The phases of the activities with the pupils in the summer camp.

in an earlier action research cycle involving embodied engagement with natural materials, which may have supported their familiarity with material-based exploration. At the beginning of the camp, the first author introduced themes related to trees, forests, and environmental art to establish a shared starting point for the activities.

4. Findings and analysis

The findings show how children articulated ecological understanding through the activities of the summer camp. Pupils expressed relationships with forest environments and positioned themselves through sensory, material, and creative engagement. Teachers supported these processes through open-ended prompts that encouraged observation, reflection, and discussion. The following sections explore how these understandings emerged through sensory engagement, material-based artistic practices, and interdisciplinary exploration.

4.1. Sensory and affective engagement with natural materials

The Nature and Science summer camp began with outdoor activities designed to cultivate children's sensory awareness and emotional connection with the natural environment. In the first phase, the pupils participated in forest games and the collective act of 'tree hugging' (see Figure 2). By touching bark and noticing shifting patterns of light and shadow, the pupils encountered the pine trunk through embodied sensory engagement with texture, leaves, air, and the surrounding forest environment. The teachers encouraged them to describe what they felt, heard, and saw. This approach prompts reflection on how trees and other living materials breathe, grow, and change.

During these activities, the pupils engaged in tactile and sensory exploration that supported the expression of affective and imaginative relationships with the forest environment. Within the encounter, the particular tree they held was articulated as a breathing being through the combined presence of touch, stillness, and shared language. The pupils noted how bark 'holds the warmth of the sun,' describing trees as responsive and meaningful beings. One pupil stated:

> The tree feels warm. It feels as if it is breathing slowly. When I put my arms around the trunk and stood still, I could feel the tree being alive in a quiet way, even though it was not moving like people do. (Pupil A)



Figure 2. Sensing the forest through the body. Photograph by Xiaowei Zhang, 2025.

The sense of the tree as living emerged through bodily contact with the bark, focused attention, and shared talk. These expressions were shaped by teachers' prompts, peer interaction, and moments of stillness that influenced what pupils attended to and expressed. Some pupils extended these encounters into imaginative possibilities, such as living 'with the animals in a tree house.' Forests were understood in multiple ways, including care, play, protection, and imaginative identification. These relations were situational and shaped by materials, tasks, and social interaction. The teachers similarly observed that sensory attentiveness accompanied more elaborated descriptions:

> When the children hugged the trees or stood still to listen, they didn't just describe what they saw. They started imagining how the forest feels and what it means to live among the trees. That sense of belonging made them more attentive and expressive. (Teacher A)

The teacher's observation situates the activity as a guided sensory encounter. Pupils were encouraged to attend to touch, sound, and stillness while working together around the trees. Talk, movement, and shared attention formed the conditions within which different ways of relating to trees were articulated during the activity. As they moved into creative work, many demonstrated greater care in handling materials, sensitivity to form and texture, and a desire to represent their relationship with the forest.

4.2. The creative transformation of recycled resources into artistic expressions

At the beginning of the papermaking activity, the teacher briefly introduced the connection between paper and trees. Pupils initially expressed this in simple terms, such as 'paper comes from trees.' The second phase focused on recycled papermaking and art creation (see Figure 3). Pupils collaboratively transformed discarded paper into new sheets through tearing, soaking, blending, and pressing. Through working with pulp, fibers, water, and pigment, they explored material transformation while discussing the relationship between trees, paper, and recycling. Pupils frequently referred to material origins and renewal, suggesting that recycling could support ecological continuity.



Figure 3. Exploring material transformation through recycled papermaking. Photograph by Xiaowei Zhang, 2025.



Figure 4. Cycles of decay and renewal. Photograph by Xiaowei Zhang, 2025.

The artworks produced in this phase reflected shared ecological orientations alongside varied emotional and imaginative responses. Many pupils represented forests, lakes, and animals as interconnected systems, often through references to seasonal change and continuity. One example is a drawing of a tree beside a lake (see Figure 4), which points to themes of endurance and renewal. During the storytelling stage, one pupil described it as:

> The tree looks bare, with only some yellow leaves at the tops, but it is not dead because when there is water and it stays there for a long time, the tree can grow again, even if it looks very quiet right now. (Pupil B)

The visual composition of the artwork and the pupil's explanation reflect a conceptualization of nature as dynamic and continuous. The tree was understood through processes of change. The pupil described seasonal transformation in terms of continuity.

Other pupils expressed ecological belonging and affective attachment through imaginative integration of humans and more-than-human life. In one drawing (Figure 5), a flowering branch rises between sea and land while children and animals coexist



Figure 5. The harmony of land, sea, and life. Photograph by Xiaowei Zhang, 2025.

in play. The composition conveys harmony and interdependence, where nature was described as dynamic within the drawing and storytelling encounter. This interpretation was further supported during the group discussion, when the pupil explained that:

> The branch grows in the middle because everyone can be together there. The animals and children are playing because the place is safe, and nobody is alone in nature, even if they are different. (Pupil C)

This explanation shows how the pupil framed environmental relations through ideas of togetherness, safety, and shared space. While this drawing emphasized togetherness and safety through images of play and shared space, other pupils expressed environmental concern through more action-oriented and dramatic narratives. Another drawing (Figure 6A) depicted a superhero protecting forest tree houses, presenting environmental care as both imaginative action and hopeful responsibility. The pupil who created the drawing explained:

> The superhero is there to help the trees because they cannot run away when something bad happens. The hero has to stay and protect the tree houses all the time because trees need someone to look after them when they are in danger. (Pupil D)

This explanation frames environmental care as an active and protective response to perceived vulnerability in the natural world. Meanwhile, another drawing shows a burning tree and a child attempting to extinguish the flames (Figure 6B), depicting urgency and empathy, showing awareness of ecological fragility and human agency.

The artworks show how pupils explored different meanings associated with forest environments through visual expression. Recurring motifs such as trees, animals, and



Figure 6. (A) Sky Island. (B) Acting to save the forest. Photograph by Xiaowei Zhang, 2025.

acts of care reflected different ways of engaging with ecological themes. Pupils positioned themselves in relation to the forest as participants, protectors, and co-inhabitants, with imagination extending engagement beyond direct perception and supporting narratives of coexistence and care. The transformation of recycled paper into artistic compositions further encouraged ideas of reuse, continuity, and ecological connection, demonstrating how ecological meaning-making developed through both experience and imagination.

4.3. Ecological understanding through interdisciplinary experience

The third phase of the camp took place at Science Center Pilke (see Figure 7), where pupils connected experiences across activities through interdisciplinary engagement with art, science, and environmental themes. When examining river water and discussing forest ecosystems, they linked these observations to earlier papermaking experiences. Wood fibers, water, and paper were understood as part of the same cycle, as pupils revisited prior encounters with fibers, pressing, and water. Comments such as 'The paper was trees before' and 'everything changes and comes back' indicate how cyclical transformation was articulated as a key ecological idea. This understanding extended into collaborative wooden block constructions, where many pupils created structures resembling 'forest villages,' exploring spatial organization and balance. Several pupils noted that the wooden blocks 'used to be trees,' linking construction materials back to the forest. These observations suggest that ecological understanding developed across activities through repeated engagement with materials.

A teacher further observed that moving between papermaking, water testing, and construction supported pupils in recognizing connections across natural processes.



Figure 7. Interdisciplinary exploration at the science center. Photograph by Xiaowei Zhang, 2025.

This phase highlighted how art–science integration enabled pupils to engage with ecological themes through experimentation, construction, and reflection. Pupils expressed their roles as makers, observers, and caretakers, indicating how participation in activities shaped their understanding of ecological processes. These expressions were also shaped by the pedagogical context, including guidance and shared expectations. Following Hackett et al. (2025), they can be interpreted as situated responses emerging through interaction and activity. From this perspective, ecological understanding appears as a process developing through embodied participation, material engagement, and collaborative interpretation.

5. Discussion

The discussion examines how ecological understanding developed through art–science and embodied learning processes in the camp activities. Ecological meaning-making emerged through pupils' sensory encounters with forest environments and their engagement with materials and peers. Touching bark, listening to sounds, and moving within the forest shaped how they noticed and interpreted ecological processes, supporting awareness of environmental relationships (Beery and Jørgensen 2018). As the activities developed, recycled papermaking extended these experiences through material transformation. Pupils connected changing materials with broader ecological ideas of continuity, renewal, vulnerability, and care. These findings suggest that ecological understanding in art–science contexts develops through the interplay of material engagement, sensory experience, and collaborative interpretation. Ecological learning emerged through direct encounters with nature and through opportunities to revisit and reinterpret ecological meanings across different materials and activities (Kewalramani and Veresov 2022; Thomashow 1996). This process deepened pupils' emotional and interpretive connections with environmental phenomena.

Engagement with ecological themes was closely connected to sensory, imaginative, and embodied encounters with the forest environment. Embodied learning research shows that understanding develops through interaction between perception and action (Anttila 2015). When pupils touched tree bark, listened to forest sounds, or described trees as 'breathing,' they expressed interpretations grounded in bodily

sensation and attention *in situ* (Hallam, Gallagher, and Owen 2022). The environment provided as an active setting shaping sensory and imaginative engagement. The forest functioned as an active source of sensory, material, and ecological experiences, allowing ecological meanings to emerge through direct engagement with local surroundings. Pupils moved between living trees and processed materials such as pulp and paper. This movement illustrates how meaning developed through engagement with materials and shifts between experience and representation (Ingold 2013; Kewalramani and Veresov 2022). During the papermaking activity, pupils adjusted their actions in response to the behavior of wet pulp, while their comments connected ideas about trees with material properties. Expressions such as 'the paper was trees before' referred to material origins and cycles. Through collaborative experimentation, prior knowledge was reworked as pupils interpreted transformation by handling fibers and observing change, highlighting the role of material engagement in understanding transformation processes (Barone & Eisner, 2012; Sochacka, Guyotte, and Walther 2016). While previous studies have highlighted the importance of embodied and multimodal engagement in environmental learning (Anttila 2015; Thomas Jha and Price 2022), the present findings provide a more detailed account of how ecological understanding developed through movement across different learning situations and material transformations. The study demonstrates how ecological meanings were revisited and reformulated through successive encounters with trees, fibers, paper, and forest-related systems.

The interdisciplinary activities at the science center extended these processes, as pupils explored connections among wood, water, and paper while engaging with ecological systems. The science-center exhibition introduced perspectives on forestry and sustainability within managed systems, complementing earlier sensory and creative engagements. Experiential and system-oriented perspectives were brought together, as pupils discussed knowledge, feelings, and responsibility, and meaning developed across different forms of representation (Wright 2010). In this context, interdisciplinary learning supported engagement across multiple modes of understanding (Perignat and Katz-Buonincontro 2019), and ecological understanding developed through interconnected experiential dimensions (Stone and Barlow 2005). A distinctive feature of this study was the way ecological understanding emerged across interconnected activities. Pupils revisited ecological ideas through forest exploration, recycled papermaking, artistic creation, and science-center investigations. These findings highlight the value of connecting multiple experiences within interdisciplinary environmental learning.

The study also draws attention to the role of pedagogical framing in shaping ecological understanding. Teacher guidance and task structure directed pupils' attention toward particular ecological themes while still allowing space for their own interpretations (Illeris 2016). Pupils positioned themselves in relation to the forest as participants, protectors, and co-inhabitants, suggesting that ecological understanding developed not only as knowledge of environmental processes but also as a relational way of locating oneself within ecological systems (Vecchi 2010). Although several common themes emerged across the activities, pupils did not approach ecological understanding in identical ways. Some emphasized sensory and affective relationships with trees and forest environments, whereas others focused on protection, coexistence, or material transformation.

The participant, protector, and co-inhabitant positions reflected different ways of relating to forest environments through exploration, responsibility, and coexistence. These positions suggest that ecological understanding involved both knowledge of environmental processes and relational ways of locating oneself within ecological systems. From a pedagogical perspective, this suggests the importance of designing learning environments that allow movement between exploration, making, and interpretation. This also points to challenges in supporting such open-ended and interpretive processes within structured educational settings, especially where curricular goals and assessment frameworks are more prescriptive. This tension points to the need for further research on how art–science approaches can balance guidance and openness while supporting meaningful ecological learning. The findings also invite critical reflection on the pedagogical design itself. The activities encouraged pupils to engage with forests through themes of care, coexistence, and sustainability. Some pupils also recognized that forests involve both care and use, suggesting an emerging awareness of balancing environmental protection with the use of natural resources. Broader issues related to industrial forestry and competing land uses received less attention, highlighting how pedagogical choices shape the ecological meanings available for learners to express.

Ecological understanding developed across interconnected activities. Pupils linked experiences of touching trees, transforming recycled paper, and exploring forest-related exhibits at the science center, indicating that ecological meaning-making emerged through repeated engagement across different contexts. This highlights how interdisciplinary art–science approaches structure the conditions under which ecological understanding develops in situated educational contexts (Perignat and Katz-Buonincontro 2019). One unexpected finding was the extent to which pupils connected experiences across activities and materials. These extend existing work on embodied and multimodal learning by showing how sensory, material, and imaginative engagement become intertwined in practice. This highlights the importance of designing learning environments that support both experiential engagement and interpretive depth. It also points to future research examining how these processes unfold over longer periods in educational contexts.

6. Conclusion

This study shows how ecological understanding and children's roles in relation to forest environments became visible in art–science learning situations. Pupils expressed this through engagement with materials, sensory experiences, and imagination, as well as through movement between different ways of interpreting the forest. These processes show how pupils interpreted ecological relations by connecting direct experience with broader environmental ideas and meanings. The findings further demonstrate how pupils reworked material processes in diverse ways during the activities. Their responses extended beyond repeating given information, taking shape as varied expressions of continuity, care, vulnerability, and coexistence through drawings, narratives, and collaborative interactions. This perspective contributes to environmental education research by examining how ecological understanding develops as a situated and interpretive process within art–science learning contexts.

Interdisciplinary art–science approaches supported connections between experience, interpretation, and ecological understanding. Ecological learning emerged as a situated and interpretive process shaped by engagement with materials, environments, and shared activity. Although grounded in a specific educational context, the findings may inform other art–science and environmental learning settings. They suggest the value of learning environments that support sensory engagement, creative exploration, and interpretation. A limitation of the study is its focus on a short-term educational intervention and specific learning activities. Future research could examine how these processes develop over longer periods and in different educational contexts.

Acknowledgements

We thank the pupils and parents for their participation and collaboration. We are also grateful to our partners at the LUMA Center Lapland, Science Center Pilke, the Junnu Science Education Center, and the pre-service teachers from the Faculty of Education of the University of Lapland. Their support provided an important foundation for developing and implementing interdisciplinary STEAM education in the Arctic region. We also thank anonymous referees for their constructive comments and suggestions.

Author contributions

CRediT: **Xiaowei Zhang**: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Visualization, Writing – original draft, Writing – review & editing; **Maria Huhmarniemi**: Methodology, Supervision, Writing – review & editing.

Disclosure statement

No potential conflict of interest is reported by the authors.

Funding

This work was supported by the EDUFI Fellowship of the Finnish National Agency for Education under grant number TM-24-12158.

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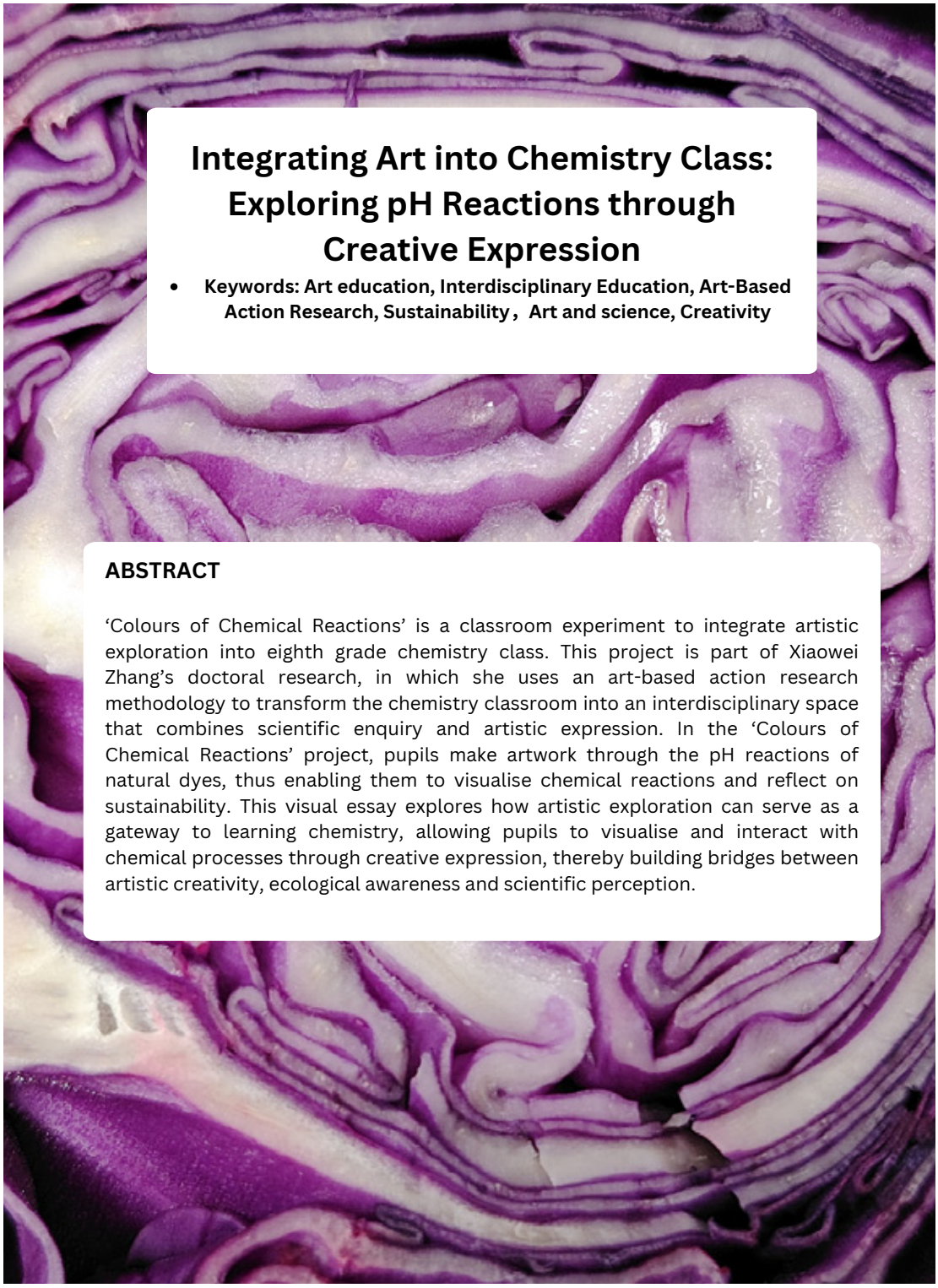
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Article IV

Zhang, X., & Hiltunen, M. (2025). Integrating art into chemistry class: Exploring pH reactions through creative expression. *International Journal of Education through Art,* 21(3), 483–493. https://doi.org/10.1386/eta_00213_3

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Integrating Art into Chemistry Class: Exploring pH Reactions through Creative Expression

- **Keywords: Art education, Interdisciplinary Education, Art-Based Action Research, Sustainability , Art and science, Creativity**

ABSTRACT

‘Colours of Chemical Reactions’ is a classroom experiment to integrate artistic exploration into eighth grade chemistry class. This project is part of Xiaowei Zhang’s doctoral research, in which she uses an art-based action research methodology to transform the chemistry classroom into an interdisciplinary space that combines scientific enquiry and artistic expression. In the ‘Colours of Chemical Reactions’ project, pupils make artwork through the pH reactions of natural dyes, thus enabling them to visualise chemical reactions and reflect on sustainability. This visual essay explores how artistic exploration can serve as a gateway to learning chemistry, allowing pupils to visualise and interact with chemical processes through creative expression, thereby building bridges between artistic creativity, ecological awareness and scientific perception.

INTRODUCTION

Disciplinary boundaries are often seen as an unbridgeable, which affects the development of creativity and the ability to solve complex problems. In recent years, the integration of art and science has promoted a deeper understanding of scientific concepts and enhanced the application of knowledge through artistic expression (Straksiene et al. 2022). However, science education usually focuses on conceptual explanations and experimental validation (Markula & Aksela 2022), whereas arts education is often marginalised as skills training in middle school curricula (Lilliedahl 2022). This can limit the development of pupils' creative thinking.

This project is part of a doctoral research project which uses an art-based action research approach (Jokela et al. 2019) to examine interdisciplinary teaching across four educational levels in Finland, involving 185 participants from primary school to university. This essay focuses on the second cycle of the study, carried out with nine eighth-grade pupils and one chemistry teacher. Located in Finnish Lapland, the project was co-designed with the teacher and supported by the University's Science Education Center, Ujunnu. Over a two-month period, pupils explored acid–base reactions using natural dyes, integrating artistic expression into scientific inquiry. The researcher encouraged pupils to consider sustainability as a theme, which they interpreted through their own artistic approaches. During the process, the pupils had a lively discussion with the teachers. Together, they considered the ecology of materials and the impact of their use on the environment.



Figure 1: Exploring Chemical Reactions with Natural Dyes, 2025. Photograph by Xiaowei Zhang.

In this essay we ask: How can the integration of art and science in chemistry education enhance pupils' understanding of ecological sustainability and scientific concepts through artistic exploration?The study findings reported here indicate ways in which participants reflected on the interplay between colour, ecology, and sustainability while creating their own artworks.

INTERDISCIPLINARY CLASSROOM: FROM CHEMICAL REACTIONS TO ART

Upon entering the classroom, the eight-grade pupils put on lab coats. They were surrounded by scientific instruments and natural materials, including droppers, beakers, lemons, vinegar, cabbage, beetroot, and more.

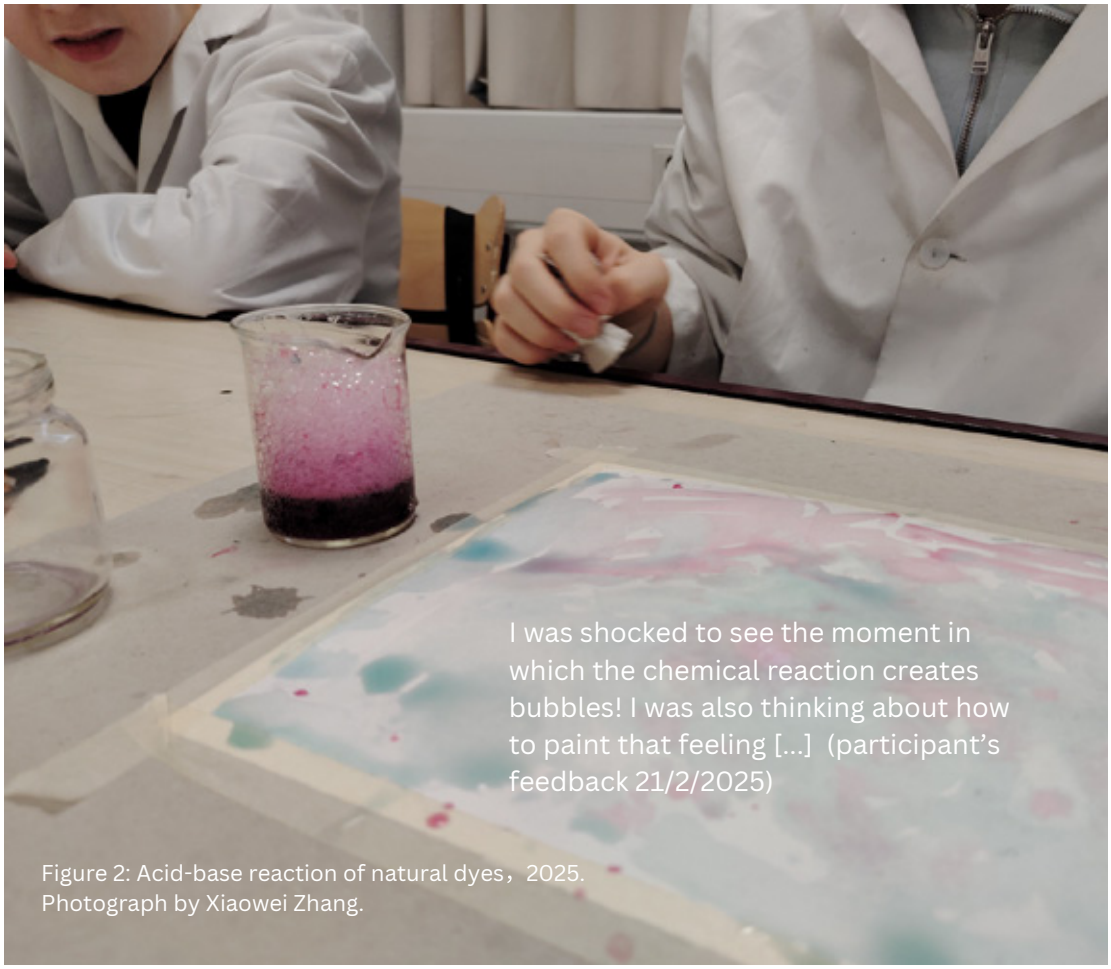


Figure 2: Acid-base reaction of natural dyes，2025.
Photograph by Xiaowei Zhang.

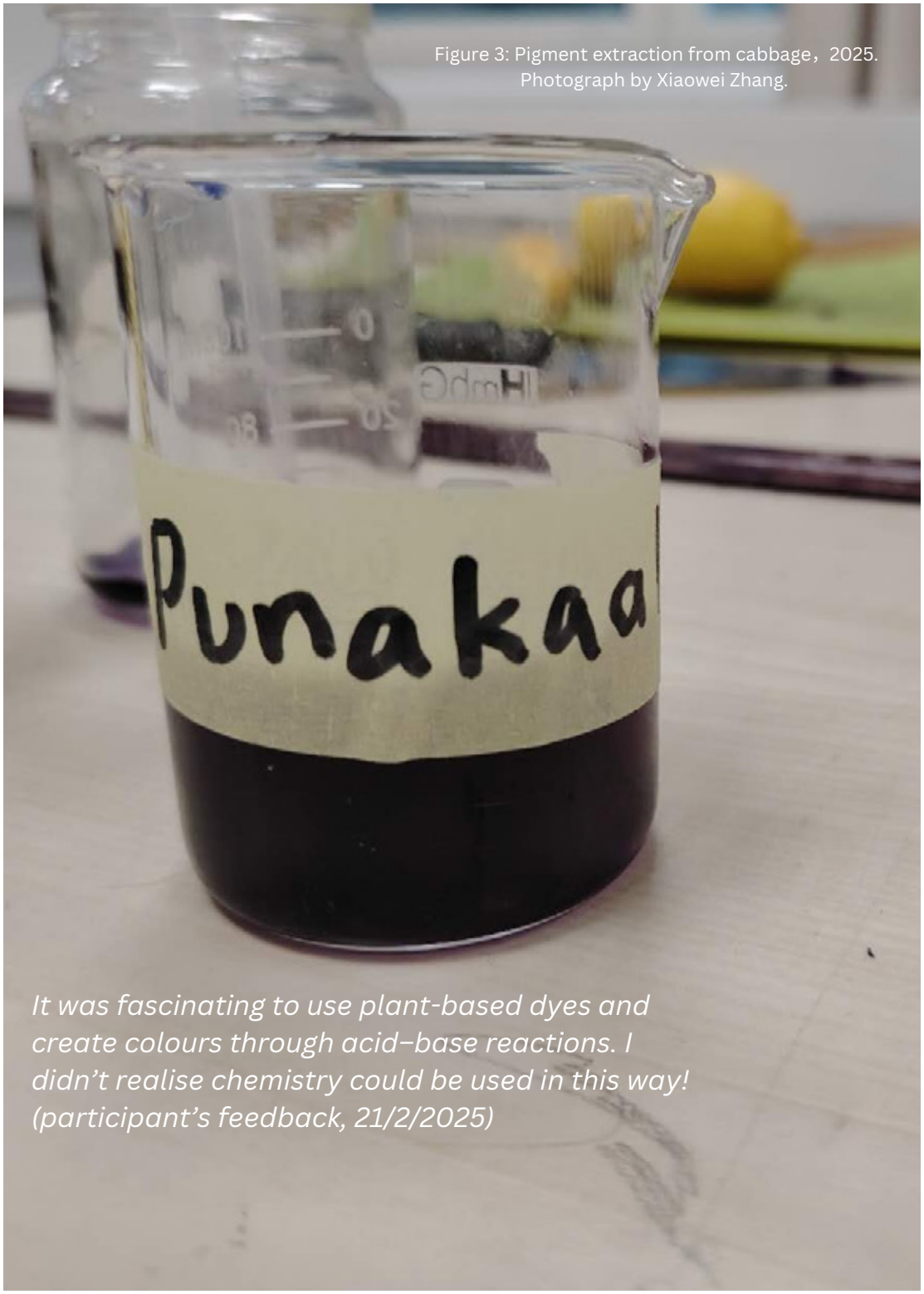


Figure 3: Pigment extraction from cabbage，2025. Photograph by Xiaowei Zhang.

It was fascinating to use plant-based dyes and create colours through acid–base reactions. I didn't realise chemistry could be used in this way! (participant's feedback, 21/2/2025)

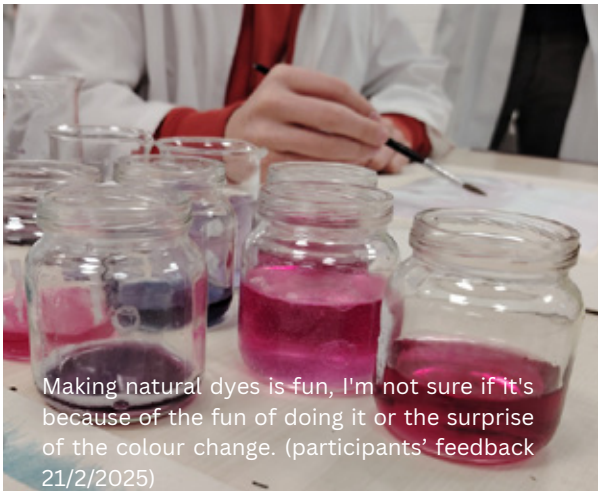


With curiosity, pupils moved from recording observations to creating works of art, using a variety of pH reagents to manipulate colour variations and create visual layers in their compositions. They constantly adjusted their strategies between experimentation and creation, testing the effects of different reagents on the colours, analysing the way the colours spread and trying to create patterns on the paper.

Figure 4–7: Explore different materials, 2025. Photograph by Xiaowei Zhang.



Pupils carefully controlled the concentration of acid and base solutions to experiment with different effects of natural dyes on paper. One pupil tried different ways of dripping liquids so that the colours formed naturally diffused patterns. The formation of these patterns was influenced by chemical factors and physical diffusion principles. Another pupil combined the results of their experiments with personal narratives to create an artwork. One pupil said he drew a map and named it ‘Shape of Sustainability’, symbolising the conflict between pollution and ecological balance through the contrasting colours of acid and base changes.



Making natural dyes is fun, I'm not sure if it's because of the fun of doing it or the surprise of the colour change. (participants’ feedback 21/2/2025)



Figure 8–11:Making Natural Dyes, 2025. Photograph by Xiaowei Zhang.





Figure 12-19: 'Oh, we can do art in this way! ' The process of creating ChemArt, 2025. Photograph by Xiaowei Zhang.

SUMMARY

The interdisciplinary integration of teaching and learning strategies is effective in enhancing pupils' creativity (Bertling & Galbraith 2024). By exploring chemical phenomena through artistic means, pupils created paintings with a thematic focus on ecological sustainability. These artworks visualise the colour response to pH changes and incorporate pupils' reflections on the sustainability of materials and the relationship between humans and nature. In the process, the artwork became an expression of sustainable practice. By working as both scientists and artists, pupils explored how natural pH indicators function and how these materials can be used sustainably in creative processes, linking scientific understanding with environmental responsibility. These findings echo Marqués-Ibáñez's (2023) ideas about the importance of sustainability awareness in education, highlighting the value of interdisciplinary teaching in ecological education.

It's really fun to make art with natural dyes and test tubes, and it offers a more environmentally responsible alternative to conventional chemical paints. (participant's feedback 21/2/2025)









Figure 20-23: Towards the final artworks, 2025. Photograph by Xiaowei Zhang.

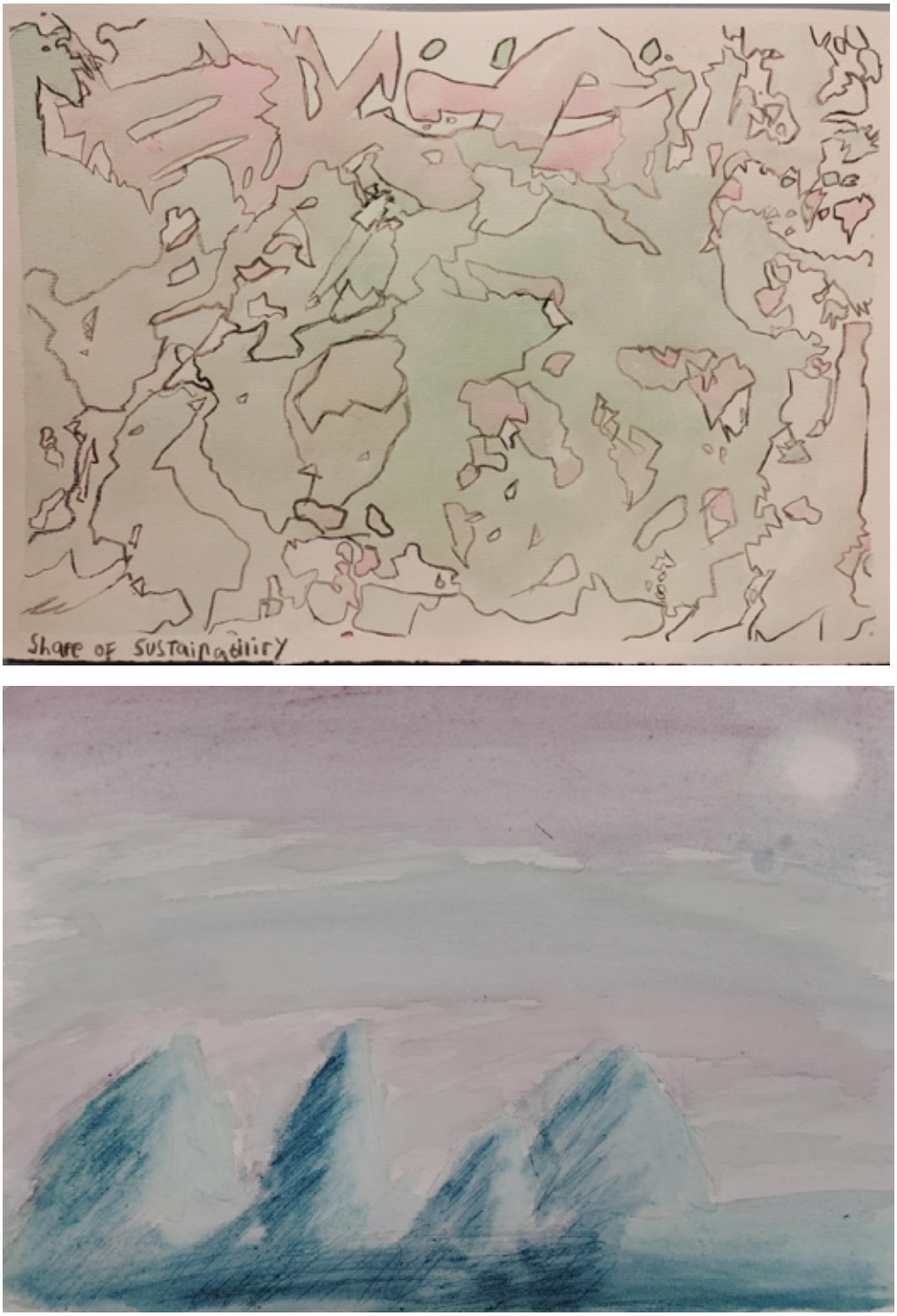


Figure 24-25: ChemArts, 2025. Photograph by Xiaowei Zhang.

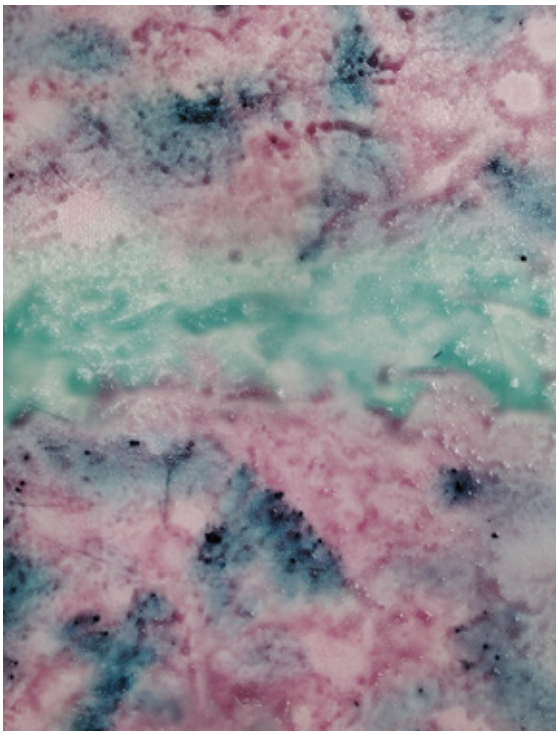




Figure 26-27: ChemArts, 2025. Photograph by Xiaowei Zhang.

ACKNOWLEDGEMENTS

This collaboration involves the University's Science Education Center uJunnu, Luma center Lapland, Rantavitikka school in Rovaniemi, University of Lapland.

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