EUROPEAN SCIENCE EDUCATION RESEARCH ASSOCIATION ESERA

ESERA 2026 DOCTORAL SCHOOL

Book of Synopses

University of Luxembourg, Campus Belval

29 June - 3 July 2026

European Science Education Research Association (ESERA) Doctoral School 2026, Esch-Belval, Luxembourg 29 June - 3 July

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EUROPEAN SCIENCE EDUCATION RESEARCH ASSOCIATION ESERA

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Welcoming words

A warm welcome to all the participants in the 2026 ESERA Doctoral Summer School!

The Summer School is an annual event which brings together PhD students and mentors with the aim of nurturing an environment for sharing knowledge, expertise, and perspectives on research innovations and recent developments in our field. We are grateful for the opportunity to host the Summer School, which has been structured to create extensive openings for participants to be immersed in dialogue around science education research while developing their networks within the ESERA community.

This Book of Synopses includes the work of the early career researchers that were accepted to participate in this week-long event. 49 students were selected from 78 applications, representing institutions from 23 countries in Europe and beyond.

The abstracts that follow introduce wide ranging topics related to science education across teaching and learning context. This collection showcases foci that highlight current research shaping the future of our field. Our goal is to create a dynamic environment focused on engaging in dialogue to exchange ideas, broaden perspectives, and develop new networks. We hope to inspire new collaborations and directions for research as well as friendships that will extend beyond our week together.

We would like to express our gratitude to all the students and mentors participating in the Summer School, for sharing their experiences and exchanges on current topics that impact science education internationally and giving their time and energy to this exciting event.

We are thankful for the SciTeach Center Team and the Department of Education and Social Work's Administrators for all their collaborative efforts to organize and facilitate the Summer School. We look forward to coming together and learning with you.

With gratitude and enthusiasm,

ESERA Summer School 2026 Local Organizing Committee

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Fostering pedagogical change and teacher self-efficacy through collaborative steam professional development

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Keywords: STEAM; Teacher professional development; Teacher self-efficacy; Science education; Primary education; Arts Integration

Focus of the Study

In contemporary science education, STEAM (Science, Technology, Engineering, Arts and Mathematics) is increasingly positioned as an approach to broaden learning goals beyond disciplinary knowledge, supporting creativity, problem-solving, and participation in authentic inquiry (Khine & Areepattamannil, 2019). However, in primary schooling, STEAM enactment is often constrained by generalist teachers' who struggle with limited preparation to teach the arts and to integrate arts-based processes with science learning. In Portugal, arts education in primary school is typically taught by generalist teachers and includes visual arts, drama/theatre, dance, and music. International research suggests that many generalist teachers report low confidence for teaching the arts, particularly music, alongside limited opportunities for sustained, practice-focused professional learning (e.g., Garvis & Pendergast, 2010; Hallam et al., 2009).

This doctoral study investigates how a collaborative teacher professional development (TPD) programme for primary teachers designed around arts-integrated STEAM can support teachers' self-efficacy for teaching the arts in interdisciplinary ways, and how changes in self-efficacy relate to shifts in pedagogical practices. This study aims to gather empirical evidence about (a) what aspects of collaborative, arts-integrated STEAM TPD are associated with changes in teachers' self-efficacy (b) how those changes are connected to teachers' planning and classroom enactment over time, and (c) which competencies are mobilised by teachers in this process.

Theoretical Framework

Teacher self-efficacy, grounded in social cognitive theory, refers to teachers' beliefs in their capability to organize and execute actions needed to achieve desired teaching outcomes (Bandura, 1997). In arts education, generalist primary teachers often report low confidence for integrating the arts in interdisciplinary ways. This is typically linked to limited initial preparation, few arts-focused in-service opportunities, and lack of support, which may contribute to a perception of insufficient artistic and pedagogical expertise for teaching the arts (Garvis & Pendergast, 2010; Hallam et al., 2009; Russell-Bowie, 2009). Within this project, self-efficacy is considered as a key mechanism influencing teachers' willingness to try unfamiliar practices and persist through iterative design and inquiry cycles. Likewise, STEAM is conceived as an interdisciplinary approach where the arts contribute not only as "products" but also as processes that shape inquiry, representation, and iterative design (Khine & Areepattamannil, 2019; Perignat & Katz-Buonincontro, 2019), usually called arts integration. This conceptualisation aligns with international guidance that emphasises transversal competences, interdisciplinarity, and education for global citizenship and sustainable development (Council of Europe, 2018; OECD, 2016).

The study links self-efficacy to professional learning through research on effective teacher professional development and collaborative learning. TPD is more likely to influence practice when it is sustained, content-focused, context-coherent, and provides active learning and collective participation (Darling-Hammond et al. 2017; Desimone 2009). Collaborative structures (e.g., professional learning communities/communities of practice) can enable shared language, co-construction of resources, and iterative refinement using classroom artefacts (Vescio et al., 2008). In STEAM approach, collaborative training supports cross-disciplinary planning and sustained implementation, with benefits for teacher collaboration and self-efficacy (Boice et al., 2021). The study also follows recommendations to make explicit how training programme features connect to teacher learning and classroom practice in its evaluation, using theories of teacher change and instruction (Wayne et al. 2008), alongside positioning collaboration as a key competency. While this research does not primarily adopt a humanizing methodology, the approach was informed by principles of relational ethics and shared agency between researchers and practitioners, conceived as an ecological and emergent phenomenon (Biesta & Tedder, 2007).

Research Questions

RQ1. To what extent does participation in a collaborative arts-integrated STEAM professional development programme relate to changes in primary teachers' self-efficacy for teaching the arts in interdisciplinary, STEAM-oriented ways?

RQ2. How do participating teachers experience and make sense of the programme, and how do these experiences shape their pedagogical decisions and classroom enactment of arts-integrated STEAM?

RQ3. What changes (if any) are evidenced in teachers' planning and classroom practices regarding (a) integration of arts processes with science learning goals and (b) student participation in inquiry, design, and creative processes?

RQ4. How are changes in self-efficacy associated with engagement in collaborative design, enactment, and reflection activities across the programme?

Research Design and Methods

Research design

The research employed a mixed-methods action-research design, combining data to explore the program's impact through (a) pre-post quantitative questionnaire examining change in teacher self-efficacy and (b) qualitative components examining teachers' learning trajectories and enactment of STEAM projects. Integration occurs through joint displays that relate self-efficacy change patterns to qualitative evidence of pedagogical change.

Participants and context

The study involved three interventions of a blended TPD programme (50 hours: 25 hours face-to-face and 25 hours autonomous work) with in-service generalist primary teachers (grades 1-4) in Portugal. Intervention 1: a public-school cluster in the Sintra region (November 2024-May 2025; n =18). Intervention 2: a private school in Lisbon (July-December 2025; n =10). Intervention 3 is being implemented as a micro-credential with in-service teachers in partnership with a Portuguese public higher education institution, concluding in January 2026.

Intervention design

The intervention is designed as a sustained programme organised around iterative cycles: (1) exploration of arts processes relevant to inquiry and STEAM projects models (e.g., observation, improvisation, visualisation, embodied modelling), (2) collaborative co-design of an integrated STEAM project with explicit science and arts learning intentions, (3) classroom enactment, and (4) structured reflection using evidence from student work and classroom interactions, all supported by an online community of practice. The design follows evidence-informed principles for effective TPD (Darling-Hammond et al., 2017; Desimone, 2009), seeking to support teachers in translating ideas into classroom practice. In each intervention, teachers collaborate in small teams to co-design at least one arts-integrated STEAM project (PBL), implement it in their classrooms, share artefacts and reflections, and receive/give feedback.

Data sources

Quantitative data include a questionnaire adapted for the arts-integrated focus of the programme based on a STEAM self-efficacy instrument developed within the ProSTEAM ERASMUS+ project (Stepanović Ilić et al., 2025). It was administered pre, middle and post-intervention, with an optional follow-up. Additional items capture prior experiences with arts teaching and perceived support. Qualitative data include: (a) teacher reflective portfolios (plans, rationales, reflections, and classroom materials), (b) focus group and individual/group interviews at key programme moments, (c) observations or video/audio recordings of selected TPD sessions and classroom enactments, (d) teachers' written reflections, and (e) samples of student work where available.

Analysis

Quantitative analysis includes descriptive statistics, correlational analysis and non-parametric tests for assessing changes in teacher self-efficacy in 11 categories related to STEAM teaching. Qualitative analysis follows a systematic inductive coding process to identify (1) perceived constraints/enablers for arts-integrated STEAM, (2) teachers' accounts of learning experiences and support, and (3) evidence of change in planning and enactment (e.g., how arts processes are used to support inquiry and modelling, and how students are positioned as creative and epistemic agents). Mixed-methods integration will connect self-efficacy change profiles with qualitative trajectories to develop explanatory propositions about how and why teachers change.

Preliminary Findings

At the time of application, the project comprises three blended programme interventions, enabling comparison across contrasting school contexts. Intervention 1 has already generated a multi-source dataset including baseline self-efficacy questionnaires, documentation from collaborative design sessions (draft unit plans, rationales, and design notes), teacher reflective portfolios with lesson materials and artefacts from early enactment, focus groups and interviews.

Some preliminary findings from intervention 1 shows some exploration results. For qualitative data, a previous content analysis was carried out, to identify the codes and main themes. Within the interviews and written reflection, the peer collaboration was highlighted by the participants, and other codes like STEAM integration, Arts Integration and Interdisciplinary approaches were identified.

For quantitative data, the Friedman non-parametric test for teacher self-efficacy surveys (7-point scale) indicated statistically significant changes across time points in several dimensions (9 of the 11 dimensions). Post hoc Wilcoxon test with Holm correction (to adjust p-values in multiple comparisons) confirmed specific improvements between phases for four dimensions (CHEMISTRY, PHYSICS, ARTS, and INTEGRATION), between time points. The variable INTEGRATION (among contents and STEAM areas) stands out for showing significant differences across the time points.

For intervention 2 the dataset is being prepared following the same analytic logic as Intervention 1 and was extended to include: (a) a questionnaire about teaching practices and levels of collaboration, and (b) a quasi-experimental study with the students (grades 1-4; n=320) considering the effects of the programme on their motivation, through assessing their basic psychological needs using the Basic Psychological Needs for Classroom Scale (BPN-CS) before and after the intervention. For intervention 3, there will be (a) teaching practices questionnaire, (b) portfolio (plans, project enactment) and (c) individual interviews.

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The impact of I-STEM and design thinking on student learning, creativity, and analytical skills

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Focus of the Study

The rapid technological and scientific advancements of recent decades have intensified the need to rethink and reform school curricula in order to ensure that students develop the competencies required to navigate an increasingly complex and technology-driven world. In this context, STEM education (Science, Technology, Engineering, and Mathematics), characterised by its interdisciplinary nature, emphasis on real-world problem solving, and application of knowledge, has been widely recognised as a promising path to revitalise teaching practices and foster essential 21st-century skills (Bybee, 2013). Previous research has shown that STEM education can contribute to improved academic achievement, increased student interest and motivation, and enhanced problem-solving skills, particularly when learning experiences are designed to actively engage students in meaningful tasks (Develaki, 2020; Lei, 2024).

Although science and technology play a central role in contemporary economic and social development, research on STEM education should not be limited to preparing students for technological labour markets. Increasing attention has been drawn to the potential of STEM education to promote broader competencies, including critical thinking, creativity, collaboration, and analytical reasoning, which are fundamental for informed citizenship and lifelong learning (Develaki, 2020; Ortiz-Revilla et al., 2022). Despite this recognised potential, existing research on STEM education has largely focused on non-formal learning environments, such as short-term workshops (e.g., Schnittka et al. (2016)). Furthermore, many of these studies primarily examine outcomes related to students' motivation, engagement, or interest in pursuing STEM-related careers.

Addressing this gap, this doctoral research focuses on examining students' science learning resulting from engagement in Integrated STEM (I-STEM) learning sequences implemented in formal educational contexts. These experiences are framed and guided by Design Thinking (DT), which provides a structured process for interdisciplinary integration, enabling students to actively mobilise scientific knowledge and technological tools to design and implement functional solutions while developing creative and analytical skills.

Consequently, the central objective of this thesis is to examine how I-STEM learning experiences grounded in DT influence conceptual understanding of science and the development of creative and analytical skills.

Theoretical Framework

STEM education emerged as a response to the need to promote scientific and technological innovation, as well as to strengthen economic competitiveness in an increasingly knowledge-driven global context (Bybee, 1997). However, the initial implementation of STEM approaches revealed significant limitations, namely students' lack of interest and the perception of high complexity and fragmentation of disciplinary content (Wang, 2013). These challenges led to the evolution towards more integrated approaches, giving rise to the concept of I-STEM (Integrated STEM).

In contrast to teaching models based on isolated disciplines, I-STEM emphasises the articulation between different areas of knowledge, promoting the integrated application of concepts and practices to solve authentic real-world problems (McComas & Burgin, 2020; Ortiz-Revilla et al., 2022).

To operationalise I-STEM effectively in formal classroom contexts, several interrelated pedagogical approaches have been identified in the literature (Moore et al., 2014; Roehrig et al., 2021; Thibaut et al., 2018). According to Thibaut et al. (2018), effective I-STEM implementation is grounded in a set of core instructional principles, namely: (i) the integration of disciplinary content, in which two or more STEM disciplines are meaningfully combined to create coherent and authentic learning experiences; (ii) problem-based learning, which places students at the centre of the learning process by engaging them in the resolution of complex, real-world problems; (iii) inquiry-based learning, through which students actively explore phenomena, collect and analyse data, and develop scientific investigation practices; and (iv) design-based learning often operationalised through Design Thinking (DT).

The present study emphasises the DT process as the central instructional approach for I-STEM education. DT functions as a methodological framework that facilitates the integration of engineering practices into science curricula and promotes an interdisciplinary understanding of phenomena (English, 2019). Conceptualised as a simultaneously analytical, creative, and human-centred process to problem solving, DT aligns closely with I-STEM principles by integrating scientific inquiry, engineering design, technological reasoning, and mathematical thinking (Li et al., 2019; Razzouk & Shute, 2012). Its iterative and flexible nature enables learners to engage with complex problems in ways that reflect authentic scientific and engineering practices.

This process is typically operationalised through a set of interconnected stages, such as problem identification and understanding, idea development (brainstorming), prototyping, and the testing and evaluation of solutions (English & King, 2015). These stages do not follow a rigid linear sequence but rather cycles of reformulation and continuous improvement (Yu et al., 2024). This structure creates conditions for the systematic mobilisation of creativity throughout the entire process, allowing students to explore multiple possibilities, evaluate alternatives, and progressively refine their solutions (Alashwal, 2020).

As such, DT constitutes a process capable of leveraging key 21st-century competencies, including creativity, analytical reasoning, collaboration and reflective decision-making.

Research Questions

The main question guiding the investigation is: How does the implementation of I-STEM learning sequences, grounded in Design Thinking, influence students' science learning outcomes, specifically concerning conceptual understanding and the development of creative and analytical skills?

Research Design and Methods

This doctoral research adopts a qualitative methodology focused on the design, implementation, and evaluation of three I-STEM learning sequences developed within a formal educational context. Two of these sequences have already been implemented at the 8th, 10th, and 12th grade levels, within the subjects of Physics, Chemistry, and Geology. The third sequence, specifically designed for Primary Education, constitutes the final phase of the fieldwork.

Intervention Design

All three learning sequences are grounded in the DT process and aligned with the formal curriculum of each educational level. Furthermore, all learning sequences underwent a validation process involving peer researchers, practising teachers, and education specialists.

Completed Interventions: Students engaged with real-world environmental challenges through indoor air quality monitoring and the construction, training, and validation of predictive Machine Learning models used to assess classroom environmental conditions. Throughout these interventions, students worked collaboratively in teams, integrating scientific knowledge with technological and engineering practices. This interdisciplinary work fostered the development of creativity, critical thinking, data analysis skills, and problem-solving competencies, which are central I-STEM education.

In the first sequence, students worked collaboratively to design prototypes for monitoring indoor air quality (measuring CO_2 levels) using Micro:bit and sensors, addressing real-world environmental problems. In the second learning sequence, students explored Machine Learning models by actively participating in the construction and validation of predictive models used to determine whether indoor environments, particularly classrooms, met appropriate environmental conditions. Variables such as temperature, ventilation, and CO_2 concentration were analysed, allowing students to develop an integrated understanding of environmental comfort and well-being in educational spaces.

Upcoming Intervention: The final sequence focuses on investigating soil properties. In this context, younger students will use Micro:bit controllers to collect data, adapting the I-STEM approach to their developmental level and specific curricular goals.

Data Collection

For the completed sequences, multiple sources of qualitative data were collected, including written records, prototypes, photographs, video recordings, and field notes. A similar data collection protocol is planned for the upcoming sequence, ensuring methodological consistency across the doctoral study.

Data Analysis

For the data already collected, a qualitative content analysis was conducted.

Creativity Assessment: A dedicated assessment rubric was developed and validated specifically for this study. This rubric evaluated Creativity across two dimensions: Cognitive (divergent/convergent thinking) and Functional (prototyping and refinement).

Scientific & Analytical Skills: Learning outcomes regarding scientific concepts and Machine Learning engagement were analysed using categories derived from the literature and formal curricular goals. This analysis focused on conceptual understanding, data interpretation, and evidence-based justification

Preliminary Findings

Data collected so far consist of qualitative evidence derived from students' teamwork across educational levels ranging from 8th to 12th grade. The analysis focused on the implementation of the first two I-STEM learning sequences. Coding and categorization were undertaken using the specifically developed creativity rubric and the literature-based framework for Machine Learning engagement. The analysis of the collected data reveals significant patterns in students' learning and skill development:

Creativity and Iteration: Preliminary results indicate that iteration is central to the creative process. Teams that engaged in multiple iterative cycles produced more original ideas, demonstrated greater resilience in problem-solving, and developed superior functional prototypes. The analysis distinguishes between cognitive creativity, which was most evident during ideation and evaluation phases, and functional creativity, which emerged as students translated abstract ideas into tangible solutions.

Analytical Skills and AI: Engagement with Machine Learning models significantly supported analytical reasoning. Students demonstrated the ability to recognise patterns, select relevant variables, and progressively justify decisions based on evidence. Notably, nearly half of the teams achieved an "advanced profile", successfully integrating data interpretation with critical reflection. A key finding is that students learned to treat ML models as tools for interrogation rather than definitive answers. Many teams were able to identify model limitations, thereby developing a clearer understanding of the relationship between algorithmic predictions and scientific explanations.

Overall, these preliminary findings suggest that Design Thinking is an effective framework for I-STEM learning, fostering a dual development of creativity and analytical reasoning in formal science education.

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Promoting students' systems thinking using computer modelling in biology lessons

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Keywords: systems thinking, computer modelling, biology lessons, secondary education

Focus of the Study

Understanding complex systems, such as climate change, has become increasingly prominent in our daily lives, providing a challenge for science teaching. Addressing this challenge, systems thinking plays a critical role in equipping individuals to navigate complex issues. The urgency of developing systems thinking has been incorporated into the formal curriculum. For instance, the Next Generation Science Standards (NGSS) include system and systems thinking as crosscut-ting concepts which focus on systems thinking and systems modelling (NRC, 2012). It is also recognized in the Dutch science curriculum (CvTE, 2016). Although an expanded curriculum indicates awareness of systems thinking, it remains unclear whether the curriculum really leads to students to become systems thinkers. Therefore, my PhD project aims to promote students' systems thinking using computer modelling in biology lessons at secondary school level. The project will comprise of four partial studies (Figure 1).

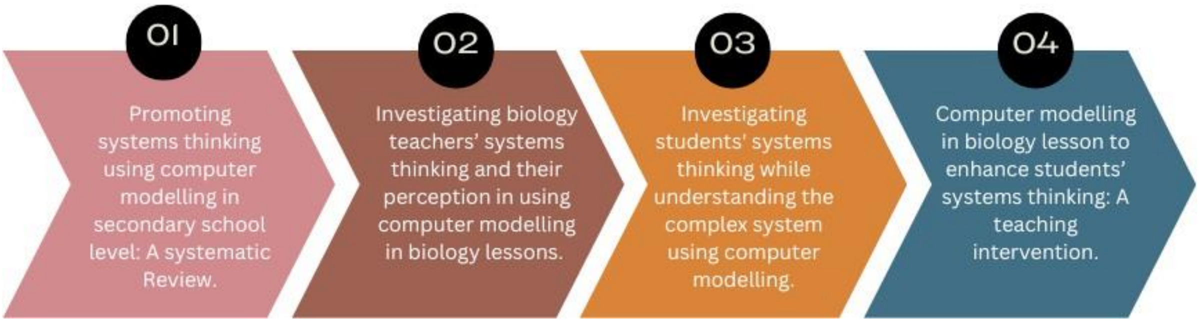

Figure 1. Four Partial Studies

As an initial step prior to efforts to improve students' systems thinking, this study investigates teachers' systems thinking. The investigation focuses on teachers' systems thinking and their perspectives on teaching it through computer modelling. Subsequently, based on the finding of this study, instructional design will then be developed to enhance students' systems thinking (ST) through computer modelling (study 3 and 4).

Review of Literature

In the first study we conducted a Systematic Literature Review (SLR) on how ST can be fostered with the help of computer modelling in science education. We conducted a literature search on three databases: Scopus, Web of Science, and ERIC. From the extensive screening of the 5411 articles, 60 articles were included in the final corpus. We summarize the main findings below.

Systems Thinking

Some frameworks have been established to understand how complex systems works and how to identify ST skills in teaching and learning practice, such as such as Systems Thinking Hierarchical (Ben-Zvi Assaraf & Orion, 2005), Structure-Behavior-Function (Hmelo-Silver & Pfeffer, 2004), and Component-Mechanism-Phenomenon (Hmelo-Silver et al., 2017). Each framework has its own focus on one or more of the system concepts in systems theories, such as General System Theory, cybernetics, and Dynamical System Theory. Gilissen and colleagues (2020) built on follow-up work by Verhoeff et al., (2018) that integrated these three system theories to arrive at eight characteristics, boundaries, components, hierarchy, input-output, interactions, feedback, dynamics, and emergence. The resulting framework serves as a starting point for our studies.

Computer Modelling

Two types of computer modelling approach are commonly used in science education: agent-based modelling (ABM) and system dynamics (SD). ABM approach is a bottom-up approach that the aggerate behaviour of the systems emerge from the interaction between individual agent-level (Wilensky & Rand, 2015), while SD modelling approach is based on aggregate reasoning in which interaction between systems components are considered as stock and flow (Sweeney & Sterman, 2000). ABM tools such as are NetLogo and StarLogo Nova were the most frequently used tools with 34 articles. 10 articles used SD modelling tools such as SageModeler and STELLA, 13 articles used other computers modelling tools such as PhET and SiMSAM, and 4 articles used the integration of ABM with other representations.

Teaching ST using Computer Modelling

The SLR showed that learning complex systems using computer modelling can be designed using model and modelling-based teaching approaches with various forms of scaffolding. Model-based teaching emphasizes learning to use and revise models, where students explore the given model and perhaps modify it (Saba et al., 2023). In modelling-based teaching, it emphasizes how students construct their own model (Miller & Yoon, 2023).

Research Questions

The study is currently at the second stage of the research which aims to investigate teachers' ST and their perspectives on teaching ST through computer modelling. The aims will be achieved through three research questions:

1. To what extent do teachers demonstrate ST in terms of understanding system characteristics in a particular biological system?
2. To what extent do teachers demonstrate ST in terms of understanding system characteristics while interacting with computer modelling?
3. What are teachers' perspectives on using computer modelling in teaching biological systems?

Research Design and Methods

A qualitative research approach was adopted for this study. Data were obtained through task-based interviews. 33 biology teachers from various secondary schools in Special Region of Yogyakarta, Indonesia were interviewed. Prior to the data collection, we developed interview protocols and conducted a pilot study with three biology teachers to refine and revise the interview protocol. Based on the pilot study, we decided to focus on two biological system (ecosystem and blood glucose regulation), from which teachers were allowed to choose one. Teachers then participated in a three-phase one-on-one task-based interview lasting 60-90 minutes. It involved 1) activities to construct a concept map of the chosen biological example to externalize their understanding of system characteristics, 2) interact with computer model in ABM tool (NetLogo), and 3) revise the concept map.

The interview sessions were recorded, including teachers' processes in constructing the concept maps and their interaction with NetLogo. Teachers' concept maps were collected for analysis. All recordings were transcribed verbatim. Currently, we are conducting initial data analysis by applying deductive coding (Bingham, 2023) based on the conceptual framework (eight system characteristics: boundaries, components, hierarchy, interactions, input-output, feedback, dynamics, and emergence). Data analysis will be finished in March 2026.

Preliminary Findings

Among the 33 participating biology teachers, 22 teachers selected ecosystems, whereas the remaining 11 chose blood glucose regulation as the topic of discussion. Using deductive coding, we identified distinct patterns in teachers understanding of system characteristics on the topic addressed.

Topic 1: Ecosystems

In the context of ecosystems, without any prompts, teachers explained system components and interactions. For instance, Elda (pseudonym) referred to her initial concept map to explain these characteristics (Figure 2), "*(...) As an example of an ecosystem, this national park con-sists of biotic and abiotic components (...) For instance, food web starts from producers like grass or plants that eaten by herbivore (...) For deer, banteng, and buffalo are then eaten by dholes as their predator.*"

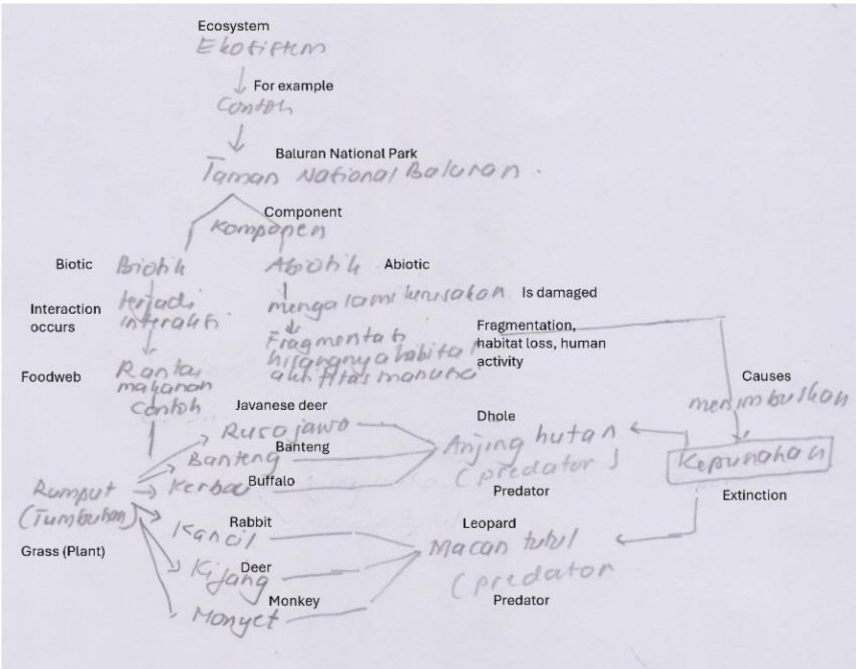

Figure 2. Teacher's initial concept map

After giving prompts and interacting with the computer model, some teachers explained other system characteristics such as boundaries, hierarchy, input-output, feedback, dynamic and emergence. The current results showed that while interacting with NetLogo, teachers could recognize the dynamic of the ecosystem and were able to explain the aggregate behaviour of the system that emerge from the interaction between predator and prey in the ecosystem.

Topic 2: Blood glucose regulations

For blood glucose regulation, without any prompts, some teachers were able to explain the feedback mechanism in the blood glucose regulation in how hormones such as insulin and glucagon maintain the blood glucose level. Some teachers also already explained the overarching characteristic, emergence, by explaining the homeostasis as the result of the interaction between glucose, insulin and glucagon. For instance, Leo said *"(...) The human body maintains internal stability through a process known as homeostasis. When blood glucose levels rise above the normal range, the body responds by stimulating the secretion of insulin, a hormone produced by the pancreatic beta cells. The role of insulin is to convert excess glucose into glycogen, which is stored in the muscles, thereby allowing blood glucose levels to return to the normal range."*

The current results showed that NetLogo could help teachers to recognize system characteristics, particularly the feedback mechanism, dynamics, and emergence. For example, Gita explained what occurred in the model (Figure 3) *"When blood glucose levels rise after eating, insulin levels also increase. This response is closely linked to the glucose concentration in the body. As glucose begins to decrease, insulin initially continues to normalize blood glucose levels. However, when blood glucose falls below normal, the role of insulin is replaced by glucagon, which acts to restore glucose levels. Glucagon stimulates processes that increase blood glucose, maintaining homeostasis in response to the drop."*

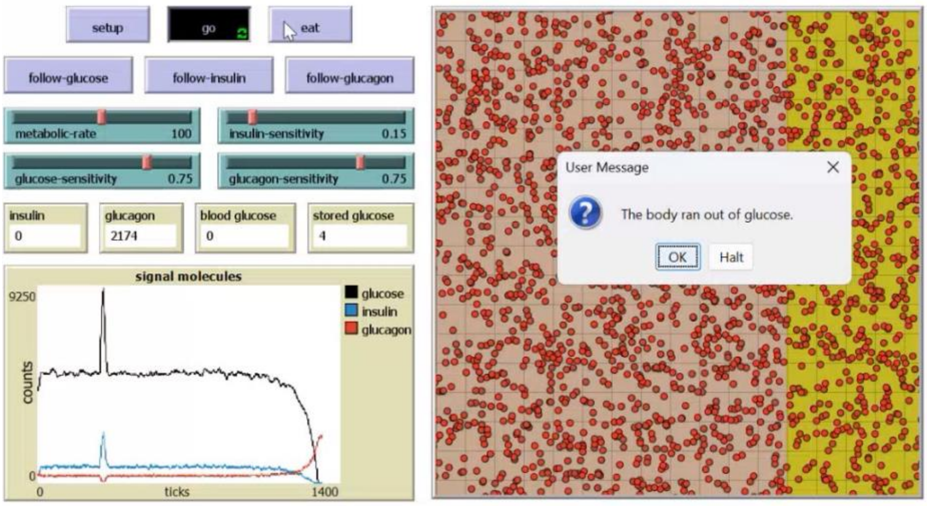

Figure 2. Teacher's initial concept map

Teachers' perspective on using computer modelling

Current findings indicated that teachers have positive response toward the use of ABM tools, NetLogo, because it could simulate how the interaction of the individual component of the system can cause the aggregate level behaviour, which could not be adequately represented using static models. Some teachers also found this tool helpful to explain the system characteristics particularly interaction, feedback, dynamics, and emergence. However, some other teachers also experienced difficulties in understanding system characteristics through the model due to their lack of prior experience with the tool.

To conclude, preliminary findings indicated that teachers could explain system characteristics when provided with the activities to externalize their thinking through concept mapping. The results also indicated that engaging with ABM tool, NetLogo supported teachers understanding system characteristics particularly in interaction, feedback, dynamic, and emergence in the ecosystem topic. However, in the blood glucose regulation topic, ABM tool was less helpful due to the model representation at the molecular level.

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Killing them slowly: The significance of the transition from kindergarten to school and encounters in science education have for children's experience of and relationship with nature

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Keywords: Science Education, Primary Education, Nature Connectedness, Sustainability Education

Focus of the Study

Over the past decades, several studies have shown that nature connectedness, motivation for science, and time spent in nature decline when children transition from kindergarten to school and in the years that follow in Denmark (Børne- og undervisningsministeriet, 2024; Graf & Debrabant, 2023; Kjeldsen et al., 2024; Legarth et al., 2024). Increasingly, research has highlighted how relationships with nature influence both personal health and well-being, as well as behaviors that support a more sustainable future (Barragan-Jason et al., 2022; Martin et al., 2020).

The transition from kindergarten to school introduces children to new environments, institutional structures, and forms of engagement with nature. In school, nature is frequently encountered through structured science education, which contrasts with the more play-based, embodied, and exploratory engagements often found in kindergarten. These differences may influence how children experience and relate to nature.

Nature connectedness is shaped by factors such as time spent in nature, access to natural environments, forms of interaction, and parental relationships with nature (Fränkel et al., 2019; Giusti et al., 2018; Giusti, Mäkelä, et al., 2025; Lumber et al., 2017; Passmore et al., 2021; Rosa et al., 2018; Wu et al., 2023). However, less attention has been paid to how institutional transitions and educational practices shape these dynamics (Giusti, Mäkelä, et al., 2025).

This study investigates how the transition from kindergarten to school, and children's subsequent encounters with science education, influence their experience of and relationship with nature. It particularly focuses on how these processes may contribute to the observed decline in nature connectedness among children aged 5–12 years.

Theoretical Framework

The study is informed by two complementary frameworks: *naturbildung* (Hartmeyer & Præstholm, 2021) and the *BeNature!* framework (Giusti, Shorthose, et al., 2025).

The concept of naturbildung builds on Ives et al. (2018), identifying five dimensions of nature connectedness: material, experiential, cognitive, emotional, and philosophical. These dimensions highlight the multiple ways in which humans can relate to nature and provide a lens for analysing educational practices.

The BeNature! framework identifies characteristics of nature experiences that are particularly meaningful in developing human–nature relationships, emphasising embodied, emotional, and socially situated engagement with nature. Compared to naturbildung, the BeNature! framework provides a more fine-grained analytical tool for examining specific qualities of nature encounters.

While naturbildung conceptualises the dimensions as equally important, research suggests that direct contact and emotional–aesthetic experiences may have stronger effects on fostering nature connectedness than more abstract or knowledge-based approaches (Barragan-Jason et al., 2022; Lumber et al., 2017; Price et al., 2022).

In this study, the two frameworks are brought into dialogue. The BeNature! framework is translated and adapted to a Danish educational context and used as an analytical tool to examine how educational practices in kindergarten and school afford or constrain opportunities for meaningful nature experiences.

Research Questions

In a Danish context, what significance does the transition from kindergarten to school and children's subsequent encounters with science education have on their relationship with and experience of nature?

This study is designed as a multi-stranded qualitative inquiry combining theoretical development and empirical investigation. It consists of three interconnected components:

1. Translation and development of an analytical framework (BeNature!)
2. Ethnographic fieldwork across educational contexts
3. Exploration of children's perspectives through photo elicitation

Together, these components create an iterative research design in which theoretical and empirical work inform each other.

Research Context and Participants

The study takes place in a rural Danish context involving: One kindergarten group and one class from 1st, 3rd and 5th grade.

A subset of 3–6 children from each class participates in photo elicitation exploring children's perspectives on nature experiences in school.

Additionally, observations may include visits to a nature school to capture variation in nature-related educational practices.

Methods

1. *Translation and Development of the BeNature! framework*

The study begins with the translation and adaptation of the BeNature! framework into Danish. This is approached not as a purely linguistic process, but as a conceptual and analytical transformation aimed at making the framework meaningful in a specific educational context.

The process includes:

- Translation of key concepts from English into Danish
- Iterative refinement through empirical testing
- Application of the framework in coding observational data
- Revision based on analytical challenges and insights

The translation process is informed by qualitative research on translation as an interpretive and context-dependent practice (Abfalter et al., 2021; Yunus et al., 2022)

2. Ethnographic fieldwork

The empirical component is based on ethnographic fieldwork conducted through participant observation (DeWalt & DeWalt, 2011) in each setting for approximately 2–3 weeks.

Observations are structured in two phases, conducting both *Unstructured observations*, following daily practices across subjects and breaks to gain familiarity and identify relevant patterns and *more focused observations*, examining specific practices related to nature encounters and science education.

Participant observation allows access to situated practices, norms, and tacit knowledge that are not easily articulated by participants (DeWalt & DeWalt, 2011; Mogensen & Dalsgård, 2018).

The observations aim to identify differences in how nature is encountered across contexts, examine how science education mediates these encounters and explore how institutional educational practices change across the transition.

Data are documented through field notes.

3. Children's perspectives through photo elicitation

To access children's lived experiences, the participants will have the opportunity to do a photo elicitation (Ali-Khan & Siry, 2014; C. D. Clark, 1999; Epstein et al., 2006). The children will take photos and inspired by the mosaic approach (A. Clark & Moss, 2017) conduct into a interview using visual methods to elaborate on the situations encountered in education.

These methods support expression beyond verbal language and allow children to highlight what they perceive as meaningful or significant (Hoppe & Holmegaard, 2022)d, 2024).

Participation is voluntary, and tasks are adapted to age and abilities.

Data Material and analysis

The study draws on multiple qualitative data sources:

- Field notes from observations
- Photographs produced by children and researchers
- Audio recordings of interviews

Data will be analysed through an iterative and abductive approach combining inductive coding and theory-informed analysis.

Preliminary Findings

Data will be collected during spring 2026 so there might be preliminary findings to present at the Summer School and discuss how to analyse them in an appropriate way to answer my research question.

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Ethico-critical popular education praxis in natural sciences

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Keywords: Concrete reality; Dialogue; Cultural synthesis; Thematic Investigation; Transformative science education

Focus of the Study

The scientific and technological development we experience within a system of "perverse globalization" (Santos, 2008) does not address issues such as hunger, poverty, and the environmental crisis. At the same time, school practices in the field of Natural Sciences often display a decontextualized, content-driven, and rigid bias, disconnecting scientific knowledge from students' concrete lives (Morales-Doyle, 2024). Against this background, my doctoral project aims to value educational practices that are collectively and interdisciplinarily constructed, in order to recover forms of knowledge (both scientific and popular) that can contribute to the transformation of reality in a humanizing direction (Freire, 2019; Silva, 2004).

In this sense, I draw inspiration from Thematic Investigation (Freire, 2019) and from an ethico-critical popular education perspective (Silva, 2004), towards fostering educative praxis that create the conditions for scientific knowledge to engage in the transformation of unjust realities experienced by communities of victims (Dussel, 2012). Based on these premises, I established three criteria that make it possible to bring educational praxis closer to an ethico-critical popular perspective: (1) reality as a concrete totality, (2) dialogue, and (3) cultural synthesis.

The doctoral studies consist of three papers, each focusing on a different aspect of the research. The first paper addresses the epistemological analysis of the criteria for an ethico-critical popular education praxis. The second paper focuses on the analysis of two empirical projects previously developed with Prosa (Center for Research in Ethico-Critical Education and Technology), of which I am a member, at the Federal University of Santa Catarina (UFSC, Brazil). In 2024, one project involved teachers, teaching interns (from UFSC graduate programs), and undergraduate students from Rural Education programs. Its goal was the collective and interdisciplinary planning and implementation of activities in schools located in peripheral, fishing, and/or agricultural contexts, addressing knowledge from the fields of Natural Sciences and Mathematics based on the specificities of the communities. The second project took place in 2025 and was connected to popular preparatory courses in Florianópolis, within a movement focused on the education of popular educators, involving collective lesson-planning processes across different areas of knowledge. Both initiatives are inspired by Thematic Investigation (Freire, 2019). The third paper concerns group discussions between Prosa and individuals working with popular education in diverse contexts, aiming to draw inspiration from educational praxis being developed internationally. This part of the research will begin in February 2026 during a doctoral period at the University of Groningen, in the Netherlands.

Theoretical Framework

Silva (2004) argues that the scientific knowledge addressed in educational praxis should be selected according to its relationship with the lived contradictions, considering its relevance for empowering the community toward transforming its reality. The author refers to this conception of education as ethico-critical (Dussel, 2012). It is based on the assumption that the transformation of realities is only possible through the recognition of subjects as “oppressed” or as “communities of victims”.

In this sense, Latin American popular education is understood to be aligned with what an ethico-critical perspective of education proposes (Dussel, 2012; Silva, 2004). By taking an explicit ethical stance in favor of communities of victims within the prevailing system, this perspective commits itself to transforming realities of injustice through authentic educational praxis. Within this framework, Thematic Investigation (Freire, 2019) is adopted as a methodological perspective that grounds educational praxis in the communities’ reality and its contradictions. Assuming reality as a concrete totality is grounded in understanding the relationship between educational processes and the subjects’ concrete reality primarily from the community’s own perceptions, and especially by addressing contradictions (Freire, 2019). Ethico-critical educative praxis are invariably dialogical, insofar as they aim to transform reality based on the perceptions and knowledge of different groups. In addition to reality as a concrete totality and dialogue, I suggest the realization of a cultural synthesis as a third criterion for ethico-critical educative praxis. Those involved in a cultural synthesis, “even if they come from ‘another world,’ come to know it with the people and not to ‘teach,’ transmit, or deliver anything to the people” (Freire, 2019, p. 247). In other words, there is no hierarchization among people or ways of knowing, scientific knowledge is understood as one possible tool among others for understanding and transforming the situations of injustice experienced by the community.

Research Questions

This doctoral project is guided by the following overarching question, which unfolds into three analytical sub-questions: **How does Natural Science contribute towards a humanizing education?**

- What aspects can be related to an ethico-critical educational praxis in Science Education committed to the transformation of reality towards humanizing?
- In what ways does collective planning influence educational praxis from a popular education perspective?
- What tensions and possibilities emerge in the dialogue between scientific and local knowledge within popular education practices?

Research Design and Methods

There is an in-depth descriptive and analytical process concerning the practices developed in the work contexts, which characterizes the research as qualitative (Lüdke & André, 1986). Moreover, in light of the assumptions of the ethico-critical perspective, participatory research (Brandão & Borges, 2007) appears to be a coherent path to follow, especially considering its proximity to popular struggles. Participatory research, as explained by Brandão and Borges

(2007), assumes the political character of scientific development, mobilizing their knowledge dialogically with the communities with whom they engage.

The research aims to materialize a process guided by Thematic Investigation (Freire, 2019) that articulates knowledge from the Natural Sciences with popular education. One empirical component of the research was carried out in Brazil, through the accompaniment of activities developed by undergraduate students in Rural Education programs and by educators involved in popular preparatory courses. In each school community, cycles of Thematic Investigation were conducted and documented in reports collectively produced by the project participants, as well as in reflective journals on the experiences. These materials constitute the objects of analysis of the doctoral thesis. In addition to this analysis, a process of group conversations is beginning between Prosa and individuals engaged with popular education in different parts of the world. The discussions will be prepared based on a guiding set of questions, while allowing flexibility in the conduct of the conversations according to other lines of inquiry that may emerge. The invited participants will be educators committed to social justice and who embody this principle in their educational praxis.

The analysis of the educational praxis developed in the Brazilian projects and of the group discussions with popular educators will be inspired by discursive textual analysis (Moraes & Galiazzi, 2006). According to Moraes and Galiazzi (2006), discursive textual analysis enables an understanding of the process of scientific knowledge production, as well as the reconstruction of meanings related to the research object.

Preliminary Findings

The theoretical results achieved thus far make it possible to identify that, among the three criteria explored in this study that bring educational praxis closer to an ethico-critical popular education perspective, assuming reality as a concrete totality requires placing dehumanization at the core of educational praxis. This centrality generates tensions between educators' and learners' perceptions of reality. Despite this, it is indispensable that the community's perceptions and knowledge be taken into account in educative praxis, as presupposed by dialogue, the second criterion defended in this study. Finally, in defense of cultural synthesis, scientific knowledge must be constructed based on a principle of commitment to the community, in the pursuit of overcoming experienced injustices, a principle that is far from trivial within the traditional, banking educational practices to which we are accustomed.

In the analysis of the projects developed in Brazil, the aim is to identify the contributions of the Natural Sciences to the development of popular education practices engaged with communities that are victims of systems of oppression. One difficulty already observed, however, relates to the deepening of scientific knowledge in relation to reality, given that such forms of engaged science remain incipient. On the other hand, greater student engagement with the content has been observed, along with more direct interactions between schools and communities. The school thus ceases to be an institution isolated from society and instead becomes a socially committed organism with direct involvement in its context, as highlighted by Silva (2004). Another analytical focus concerns the relevance of collectivity in planning processes. This analysis further strengthens the dialogue with the concept of self-organized communities (Torres-Olave & González, 2021), as these planning groups organize themselves around a collective commitment to transforming education and struggling for social justice.

What becomes evident, however, are the challenges involved in engaging with the criteria of an ethico-critical popular educational praxis, which is far from straightforward. Participation in the Summer School is therefore understood as a key opportunity to critically examine these challenges and to explore methodological possibilities for strengthening educational praxis genuinely engaged with communities. Furthermore, the analysis of the group discussions with popular educators from different contexts will benefit from dialogue with other science educators, contributing to the understanding of the limits and possibilities of articulating popular and scientific knowledge in educational praxis. The intention is to join an existing collective of educators in this field – or to create such a collective, following the model of the self-organized communities described by Torres-Olave and González (2021) – in order to establish dialogue among these educators and to foster the development of educational praxis in different contexts.

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Scientific knowledge in comics: An analysis of authors' didactic choices and their impact on audiences

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Keywords: Physic, Out of School Education, Comics, Didactic Transposition, Semiotics

Focus of the Study

Scientific popularization comics have become a privileged medium for examining the circulation and shaping of scientific knowledge within the public sphere. Through their distinctive articulation of sequential storytelling, graphic visualization, and pedagogical intent, they pro-vide a fertile ground for investigating the dynamics of knowledge transmission and reformulation. As such, scientific comics stand at the intersection of art, science, and education.

This doctoral research focuses on the ways in which scientific knowledge—particularly knowledge from physics—is transformed when it is communicated through the medium of comics. More specifically, it examines the didactic choices made by authors and artists, the strategies they mobilize to mediate scientific content, and the effects these choices may have on audiences' reception and understanding of science.

While previous studies have emphasized the educational potential of visual narration, the explicit viewpoints of creators and readers remain largely underexplored. This study addresses this gap by investigating both the intentions and practices of authors of scientific comics and, in a later stage, the responses of readers. The educational context of the study thus lies at the crossroads of science education, informal learning, and public science communication.

Review of Literature / Theoretical Background / Theoretical Framework

This research builds on foundational work in the field of knowledge mediation and scientific popularization (Jurdant, 1969; Roqueplo, 1974; Jacobi, 1986; Bensaude-Vincent, 1997; Cohen-Azria, 2002; Allamel-Raffin, 2009; Triquet, 2011), as well as more recent studies specifically devoted to popular science comics (Girault, 1989; Rouvière, 2017; Farinella, 2018; de Hosson & Bordenave, 2022). These studies highlight the role of images and narrative in supporting active appropriation of knowledge, while rarely addressing creators' strategies or readers' interpretations in detail.

To analyze what Kuhn (1962) describes as a "site of incommensurability" between artistic and scientific logics, the study articulates two complementary theoretical frameworks.

The first framework is drawn from the didactics of physics, through the concept of didactic transposition (Chevallard, 1985), which examines how scholarly knowledge is transformed, adapted, and reconfigured as it circulates toward other institutions, media, or audiences.

The second framework comes from the semiotics of comics (McCloud, 1993; Groensteen, 2007; Cohn, 2013), which provides tools to analyze visual codes, sequentiality, and modes of graphic narration.

Together, these frameworks make it possible to examine how visual and narrative choices actively participate in the transformation of scientific knowledge into popularized knowledge that is socially and culturally redefined.

Research Questions

The study is guided by the following research questions:

- How do authors of scientific comics conceive of science and scientific knowledge, and how do they appropriate scientific content in their creative process?
- What sources of knowledge do they mobilize, and how are these sources transformed through narrative and visual strategies?
- What didactic and popularization strategies are implemented in scientific comics, and how are distinctions between fiction and scientific facts made visible?
- How do authors conceptualize their intended or "model" reader (Eco, 1979)?
- How do editorial, institutional, and production contexts influence both artistic and pedagogical choices?
- How do these choices shape the reception and understanding of scientific knowledge by non-expert audiences?

Research Design and Methods

The study is based on a qualitative research design combining corpus analysis and semi-structured interviews.

The corpus consists of approximately twenty science comics published between 1980 and 2025, covering a range of scientific fields (physics, biology, medicine, astronomy). These works originate from diverse production contexts, including institutional commissions (universities, CNRS, INRAE), independent author initiatives, and commercial publishing houses.

To date, twenty-two semi-structured interviews have been conducted with authors of varied profiles: artists without formal scientific training, researcher-cartoonists, author–scientist pairs, screenwriters, and science communicators. The interviews aim to document authors' representations of science, their motivations, their use of sources, and the strategies they employ to make scientific knowledge accessible.

The qualitative analysis is conducted on full interview transcripts and focuses on several analytical dimensions: authors' relationships to science, sources of knowledge, popularization strategies (anthropomorphism, visual metaphor, humor, schematization, alternation between narrative and explanatory sequences), graphic markers distinguishing fiction from scientific facts, conceptions of the reader, and editorial or institutional constraints.

In a subsequent phase, the study will be extended through an empirical investigation involving targeted groups of readers, in order to analyze reception, comprehension difficulties, misinterpretations, and engagement.

Preliminary Findings

The ongoing analysis highlights scientific comics as a complex space of mediation in which the rigor of scientific content, the constraints of the medium, and the expectations of a non-expert audience are continuously negotiated. Authors emerge as key agents of didactic transposition, comparable to teachers in Chevallard's model: they select, adapt, hierarchize, and stage knowledge according to aesthetic, cognitive, and social logics.

Preliminary findings also point to the strong influence of production contexts on the nature of the didactic transposition at work. Institutional frameworks tend to impose specific expectations regarding scientific accuracy and clarity, while independent productions allow for greater narrative and visual experimentation. These factors significantly shape both the form and the content of scientific knowledge as it is communicated through comics

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A neuroscience-informed framework for analysing representations in physics education

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Focus of the Study

This PhD project focuses on theory-informed research in physics education grounded in selected knowledge from cognitive neuroscience and conceptual change research. Building on the results of the author's bachelor's and master's theses, which explored the application of the Theory of Five Pillars of the Mind in physics education, the project investigates how selected neuroscience-informed theoretical frameworks can enrich theories of physics education. This project explores both possibilities and limitations of using neuroscience-informed frameworks to understand pupils' reasoning, domain-specific networks and conceptual change in physics education.

Theoretical Background

Research on domain-specific networks remains relatively underrepresented in physics education research when compared to the extensive body of work on conceptual change. In response to this gap, this PhD project builds on the Theory of the Five Pillars of the Mind (Tokuhama-Espinosa, 2019), which conceptualises learning as supported by five domain-specific networks: symbols, patterns, order, categories, and relationships. These networks are proposed as foundational for learning across subject domains and are grounded in findings from cognitive neuroscience. There are no known studies other than the authors' that explicitly apply the Theory of the Five Pillars of the Mind within the context of physics education. Nevertheless, elements of this framework can be identified implicitly in several textbooks within the International Baccalaureate (IB) Middle Years Programme (MYP). This project seeks to make such implicit structures explicit and to critically examine the applicability of this neuroscience-informed framework to physics education.

This research builds on prior work conducted during the author's bachelor's and master's studies. The bachelor's thesis focused on an initial application of the Five Pillars framework to the topic of the inclined plane through a qualitative analysis of learning materials, providing an exploratory basis for the present research. Subsequently, in the master's thesis, learning materials on fluid mechanics were designed to support the development of all five domain-specific networks intentionally. These materials were empirically tested on a sample of 58 lower-secondary students (aged 15–16), providing initial evidence of their educational potential. Within this PhD project, the author enlarges the research sample and refines the learning materials based on pilot findings. In parallel, the project investigates the specifics of physics education and how these specifics will influence the application of this theoretical framework. Current findings indicate that physics learning materials predominantly foster the development of symbols and relationships, and several experts in physics education research perceive these domain-specific neural networks as central to learning physics (Červeňová & Demkanin, 2025a). In collaboration with a researcher from the United Kingdom, further analysis of this theory in relation to existing theories of physics education has been conducted, resulting in the identification of their overlaps and several limitations that arise when applying this theory to physics education have been discussed (Červeňová, Demkanin, & Sands, 2025).

The topic of conceptual change is currently highly prominent, with numerous research teams worldwide contributing to its development. The research group at the University of Washington focuses particularly on resources and their identification in physics education (Heron & Snow, 2025; Goodhew et al., 2021). One of the more recent contributions to conceptual change theory is prevalence theory (Potvin, 2017), which is adopted in this project to investigate congruent and incongruent contexts for scientific and alternative conceptions related to fluid mechanics. This part of the research is conducted in collaboration with the Canadian team led by the author of the theory, Patrice Potvin. It is hypothesised that, in incongruent contexts for a given idea, the response time required to answer an item correctly will be longer than in congruent contexts for the same idea.

Research Questions

RQ1: How are domain-specific networks (pillars) represented and supported within physics education?

RQ2: What roles do domain-specific networks play in processes of conceptual change in physics education?

Research Design and Methods

This project adopts a mixed-methods research design to investigate the role of domain-specific networks in physics education and their relationship to conceptual change. Several steps of the research have been taken already:

- Design phase: Physics learning materials on fluid mechanics have been developed and iteratively refined based on the Pillars theory.

- Textbook and learning materials analysis: selected physics textbooks and learning materials concerning inclined plane and fluid mechanics have been analysed using a theoretically grounded coding framework aligned with the five pillars (symbols, patterns, order, categories, relationships).

- Empirical classroom study: a pilot study and iterative quasi-experimental design with control and experimental groups have been employed to investigate the effects of the designed learning materials on students' conceptual understanding.

Further on, we plan to continue to analyse textbooks and learning materials concerning different physics topics. We have created a pilot version of an analytical data-driven framework for the identification of pillars in physics learning materials, and we plan to validate this framework in a pilot study with a non-randomly selected sample of 14 pre-service teachers. Based on results of a pilot study, this framework will be updated. We will continue with verification, and we will create a supplement oriented for the implementation of the framework to research (how to analyse data obtained using this framework and how to interpret results). With the analytical framework and its supplement, we aim to develop a tool for the identification of the extent to which a domain-specific network (pillar) is fostered based on the measurable pupils' outcomes. We are collaborating with the author of the theory about pillars, who is working at Harvard, on this part of the research.

In collaboration with a research team at UQAM in Montreal (Université du Québec à Montréal), we are developing an instrument to investigate conceptual change in the context of fluid mechanics. Data collection using this instrument is planned for early 2026. After pilot testing, the instrument will be refined and used to identify congruent and incongruent contexts for both scientific and alternative conceptions in fluid mechanics. These conceptions were identified in previous research conducted with a sample of 150 first-year upper-secondary pupils enrolled in a four-year grammar school programme.

Research Sample and Collected Data

As our research is conducted in a mixed-methods design, we collected data and analysed data from different sources. We are focusing on Physics learning materials and textbooks in a qualitative analysis while aiming to develop a data-driven analytical framework for physics textbooks analysis from pillars perspective. The other part of the research is aimed at upper-secondary pupils (aged 15–16) at grammar school, and so far, we have collected data in various ways:

- Pre-test, post-test, and retention test responses focused on conceptual understanding in fluid mechanics;
- Response accuracy and response time data to examine congruent and incongruent contexts of scientific and alternative conceptions;
- Student-written responses and explanations.

We plan to continue in this design, and based on the results of this stage of our research, we plan to adapt our research to further examine preliminary results.

Preliminary Findings

The outcomes of a pilot analysis of selected physics learning materials provide a basis for the development of the tool for the identification of the extent to which a domain-specific network (pillar) is fostered in the learning materials. The results indicate that physics education has several specifics, and each domain-specific network (pillar), as it is defined by the author of the theory, needs to be further examined in the context of physics education. (Demkanin, Červeňová, Sands, 2025) Preliminary analyses also indicate that physics textbooks predominantly support the development of symbols and relationships, while patterns, order, and categories are less explicitly emphasised. (Červeňová, Demkanin, 2025a) Derived from data obtained in the analysis of several resources of learning materials concerning fluid mechanics, an analytical data-driven framework for the identification of pillars in physics learning materials has been developed and is currently being validated.

Within initial classroom research, we focused on pupils' initial ideas and shifts in their knowledge. We compared the results of the research group with the results of the control group. Our research group consisted of 78 pupils, two groups of 26 pupils in the pilot study and one group of 26 pupils in the quasi-experiment. We had a control group of 27 pupils in a quasi-experiment. Comparisons have shown significant improvements in all research groups towards the normative state in post-test, but also in follow-up test that was assigned to pupils 6 months after intervention. The control group in the quasi-experiment, compared to the research group, obtained higher scores in the pre-test; however, in the post-test and follow-up test, the research group performed significantly better. We have also observed that pupils who had difficulties with physics performed better in the designed tool than in the summative test. We assume that observed phenomena might be connected to providing additional lawyers to traditional learning through the pillars framework, which is essentially through domain-specific networks of neurons. These results suggest that learning materials intentionally designed to address all five domain-specific networks are associated with a shift in students' conceptions toward more normative scientific understanding when compared to traditional materials. (Červeňová, Demkanin, 2025b)

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The role and importance of mathematics in the academic performance in undergraduate chemistry

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Focus of the Study

As higher education in Hungary expands, meeting the needs of an increasingly heterogeneous population of incoming students poses growing challenges. Given the substantial variability in entry-level competences, a proportion of students are unable to meet the academic requirements of their degree programmes. The identification of competence gaps and the systematic assessment of prior knowledge and skills are therefore crucial for supporting students at risk of academic underperformance, highlighting the need for diagnostic instruments with high predictive validity that can reliably forecast subsequent academic achievement.

Each academic year, first-year students at a large Hungarian university complete an entrance competence assessment designed to evaluate their initial competence levels. However, the resulting data are not systematically communicated to lecturers; instead, there is a need for locally adapted interventions and forms of support. This is especially important in university science courses, which have relatively low persistence rates. Among Hungarian students starting STEM undergraduate studies, 62% obtain a STEM degree and 4% a non-STEM degree within three years after the theoretical completion date of their programme (OECD, 2025).

Although student attrition has multiple determinants, the present study focuses on cognitive and affective variables associated with mathematics learning. The aims of this research are (1) to examine how basic mathematical skills, mathematics-related motivation, and additional background variables influence academic achievement, and (2) to identify students' strengths and systematic errors in arithmetic skills to formulate evidence-based recommendations for pedagogical interventions. Within the broader domain of the natural sciences, the study concentrates exclusively on undergraduate chemistry.

Theoretical Background

Research on academic performance and persistence in undergraduate chemistry has increasingly emphasized the early identification of students at academic risk, particularly in gatekeeper courses. Within chemistry education research, prior mathematical knowledge and skills have been widely investigated as predictors of achievement, especially in first-year chemistry courses. While many studies report positive associations between mathematical preparation and chemistry performance, the strength and consistency of these relationships vary across contexts and assessment instruments (Lee et al., 2023). Furthermore, much of the existing empirical evidence is based on U.S. samples, underscoring the need for research conducted in other educational systems.

From a learning-theoretical perspective, the importance of mathematical skills for chemistry learning is grounded in constructivist theories that highlight the role of prior knowledge.

Introductory chemistry places heavy demands on students' quantitative reasoning and procedural fluency, requiring basic arithmetic for stoichiometric calculations, proportional reasoning, laboratory measurements, and interpreting symbolic representations. Weak foundational arithmetic can increase cognitive load and limit students' ability to engage with chemical concepts, even when their conceptual understanding is developing.

Integrated STEM frameworks further support this view by positioning mathematics as a foundational discipline for learning and problem solving in the natural sciences. Consequently, mathematical skills are not just external prerequisites but integral to chemical reasoning and practice. Early diagnostic assessments of mathematical skills in chemistry courses can therefore identify students' readiness for quantitative tasks and reveal potential barriers to learning.

In addition to cognitive factors, affective variables have been shown to play an important role in academic achievement in science. Existing predictive models in chemistry education predominantly incorporate affective constructs directly related to chemistry learning, whereas affective factors associated with mathematics learning have received comparatively little attention (House, 1995). Drawing on motivational theories such as expectancy-value and self-determination perspectives, it can be assumed that students' motivation toward mathematics influences their engagement with the quantitative aspects of chemistry tasks, their persistence when facing challenges, and their willingness to invest effort in problem solving. For this reason, mathematics-related motivation may contribute to chemistry performance beyond the effects of arithmetic skills alone.

As documented in prior research, academic performance in chemistry is influenced by a broad range of demographic, cognitive, and psychological variables (McCarren et al., 2024). When constructing predictive models, the goal is therefore not to exhaustively capture all possible influences, but to include variables that have demonstrated explanatory potential in previous empirical studies. This consideration informs the selection of background variables in the present study and supports a model-building approach that balances theoretical relevance with practical applicability.

Recent work in chemistry education has highlighted a shift toward predictive and diagnostic approaches aimed at the early identification of students at risk of academic difficulties (Williamson et al., 2020). From an educational perspective, such approaches are most valuable when they not only achieve satisfactory predictive performance but also generate actionable insights for instructional design. Building on these theoretical considerations, the present study examines the combined role of basic arithmetic skills, mathematics-related motivation, and selected background variables in undergraduate chemistry performance, while also adopting a diagnostic perspective through the analysis of systematic arithmetic error patterns to inform targeted instructional interventions.

Research Questions

RQ1: How are basic arithmetic skills and mathematics-related motivation related to academic performance in first-semester undergraduate chemistry?

RQ2: How does the inclusion of mathematics-related motivation affect the classification of students at risk of low academic performance in first-semester undergraduate chemistry?

RQ3: What systematic arithmetic error patterns characterize low-performing students, and how can these inform targeted instructional interventions?

Research Design and Methods

The study employs a mixed-methods approach within a correlational research design. The target population consists of first-year undergraduate students enrolled in compulsory first-semester general chemistry lecture courses, which are commonly described as gatekeeper courses across multiple degree programmes. These courses provide an appropriate context for examining early predictors of academic performance and identifying students at risk of falling behind.

Data collection occurs in two phases. At the beginning of the fall semester, students complete a paper-based assessment battery consisting of a mathematics skills test and two questionnaires. At the end of the semester, final course grades are obtained from the Dean's Office and used as indicators of academic performance. To achieve an adequate sample size, data are collected across multiple cross-sectional waves, with a target of at least 300 valid cases.

Basic arithmetic skills are assessed using the Math-Up Skills Test (MUST, Albaladejo et al., 2018), which has demonstrated predictive validity in studies of undergraduate chemistry performance. The test consists primarily of open-ended items assessing fundamental topics relevant to chemistry learning, including multiplication, division, fractions, powers, and logarithms. The open-ended format allows both quantitative scoring and qualitative analysis of student responses to identify systematic error patterns.

Mathematics-related motivation is measured using the Mathematics Motivation Questionnaire (MMQ, Fiorella et al., 2021), a multi-dimensional instrument assessing students' motivation toward mathematics learning. In addition, a self-developed questionnaire is used to collect demographic and educational background information based on variables identified in prior research as having potential predictive relevance.

Quantitative analyses examine relationships between arithmetic skills, mathematics-related motivation, background variables, and chemistry performance using descriptive statistics and regression-based and classification models. To complement these analyses, a qualitative error analysis is conducted on student responses to the arithmetic skills test. Since the test items assess diverse mathematical topics and no established coding scheme exists, an inductive coding approach is employed. Item-specific error categories are developed through iterative analysis and applied to conceptually related items. The resulting categorization of error patterns is intended to inform the design of targeted instructional interventions addressing common difficulties in students' mathematical reasoning.

Preliminary Findings

Before data collection, the mathematics skills test and motivation questionnaire were translated and culturally adapted into Hungarian, and the self-developed background questionnaire was iteratively revised. Preliminary analyses show satisfactory internal consistency for both the arithmetic skills test and the motivation questionnaire. Item response theory analyses indicate that the mathematics test discriminates well across proficiency levels, while highlighting the need for additional easier and more difficult items. Confirmatory factor analysis supports the proposed factor structure of the motivation questionnaire.

The mathematics skills test was first administered in September 2024 to students in two first-semester general chemistry lecture courses (n = 138). A second cross-sectional data collection, using the same paper-based procedures, took place in September 2025; analyses are ongoing. Across waves, about 340 valid mathematics test responses and 200 questionnaire responses have been collected. Final course grades for the most recent cohorts are not yet available, so predictive modeling of chemistry performance will begin once these data are obtained, in line with the study's early diagnostic focus. Current analyses emphasize descriptive and diagnostic aspects of the arithmetic skills test.

Using dichotomous scoring (1 = correct, 0 = incorrect or missing), the mean test score in the first wave was 55.9% (SD = 22.8%), indicating substantial variability in entry-level arithmetic skills. Item-level analyses showed large differences in difficulty: only 33% of students correctly gave the square root of a product, whereas 88% correctly calculated a power with an index of zero and balanced a chemical equation. An inductive qualitative analysis of responses identified systematic arithmetic error patterns. Item-specific error categories, developed from recurring response types, were applied to conceptually related item pairs. This analysis offers initial insights into common difficulties in arithmetic reasoning and informs the design of targeted instructional interventions.

Overall, the preliminary findings support the reliability and diagnostic value of the instruments and prepare the way for analyses linking arithmetic skills, mathematics-related motivation, background variables, and academic performance in undergraduate chemistry.

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Socio-scientific argumentation in the chemistry classroom: implementation of Toulmin's argumentation pattern to enhance secondary students' socio-scientific argumentation skills within a chemistry-based socio-scientific issue

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Keywords: Chemistry, Secondary Education, Socio-Scientific Argumentation, Toulmin's Argumentation Pattern

Focus of the Study

The study explores strategies to support secondary students (ISCED 3, age 16-18) in improving socio-scientific argumentation, thereby advancing scientific literacy. An adapted version of Toulmin's argumentation pattern (TAP) (Toulmin, 2003) is implemented step by step in chemistry lessons. Human-induced ocean acidification (HIOA) serves as the socio-scientific issue (SSI), a complex dilemma with social and scientific dimensions (Sadler, 2004). The study ex-amines whether TAP effectively supports socio-scientific argumentation in chemistry education, addressing the lack of subject-specific research at the secondary level (Christodoulou & Grace, 2019).

Theoretical Background

Science education is essential for enhancing scientific literacy, enabling informed decisions based on scientific knowledge and participation in SSI-related discussions (Lederman et al., 2024). Subsequently, students should be able to re-construct existing arguments and construct their own as part of this decision-making process (Christodoulou & Grace, 2019; Osborne, 2002). Building on Osborne and colleagues' (2016) findings, this study adopts one of their major implications, proposing that "[e]xercises that asked students to distinguish claims, warrants and data would provide a foundation for more demanding exercises which asked students to construct their own arguments." (p. 841). As Toulmin (2003) explicitly distinguishes be-tween claims, warrants and data – along with backing of warrants, rebuttals, and modal qualifiers – this study applies TAP to understand and support upper secondary school students' intuitive socio-scientific argumentation. While TAP has been used in science education (Lazarou & Erduran, 2021), studies are required that help to delineate a chemistry-specific approach at the secondary level (Christodoulou & Grace, 2019).

Beyond subject matters, SSIs are excellent vehicles to practise socio-scientific argumentation (Christodoulou & Grace, 2019). Tackling SSIs via argumentation enables students to become responsible citizens capable of facing global and personal challenges (Sadler, 2004). While argumentation – formally linking premises to conclusions – is generalisable, constructing arguments within SSIs requires domain-specific knowledge (Tricot, 2018) and the use of knowledge that goes beyond scientific knowledge. This study focusses on the chemical dimension of HIOA, where understanding processes like coral skeleton calcification involves concepts such as "chemical equilibrium" and the "donor-acceptor concept" (Barke et al., 2018), making HIOA an excellent SSI to foster socio-scientific argumentation. Socially, it is highly relevant when discussing climate change (IPCC, 2023).

Research Questions

The main and sub-research question addressed by this study are as follows:

In what way is TAP beneficial for enhancing students' socio-scientific argumentation skills by supporting them in (re-)constructing scientifically adequate arguments within a chemistry-based socio-scientific issue?

> *Q1: What design principles are applied in the development of materials used to implement TAP in the chemistry classroom to support socio-scientific argumentation?*
>
> *Q2: How do students use TAP, after its implementation in the classroom, to (re-)con-struct socio-scientific arguments?*
>
> *Q3: In what way can applying TAP in chemistry education support students to improve the quality of the structural aspects and content of their socio-scientific arguments?*

Research Design and Methods

This project implements an adapted TAP within the SSI of HIOA to support students' socio-scientific argumentation in an intervention study. The framework includes *data, claim and reasoning* – integrating *warrants* and their *backing* (McNeill et al., 2006) – plus *modal qualifier* and *rebuttal*.

A pilot study (n = 29) investigated how Austrian high school students (ISCED 3, age 16-18) with prior relevant declarative knowledge constructed socio-scientific arguments on HIOA. Attention was on students' use of TAP-based scaffolds and their impact on argument quality. Scaffolds were introduced implicitly, without defining elements, to encourage intuitive use. Students responded to a fictional newspaper headline, "Calcification of coral skeletons is im-paired", writing arguments before and after scaffold introduction. Arguments were analysed for structural and content quality, with intercoder reliability assessed. Structural quality was examined through structured qualitative content analysis with deductive category assignment; con-tent quality through summarising qualitative content analysis based on inductive categories (Mayring, 2022).

Based on pilot study findings and relevant literature (Osborne et al., 2016; McNeill et al., 2006), teaching materials for the main intervention study are developed through Design-Based Re-search (DBR) (Bakker, 2018). An initial draft was refined through discussions with chemistry education colleagues and pre-service teachers. Current evaluation involves students (n ~ 10-15) working in pairs employing the think aloud-method (Sandmann, 2014), followed by individual semi-structured interviews (Flick, 2014). Likewise, small teacher groups (n ≈ 10) assess the materials using the same approach. All statements are transcribed and analysed through summarising qualitative content analysis (Mayring, 2022), with inductive categories. Findings guide iterative refinement across up to three design cycles.

The main intervention includes two interrelated teaching units with four upper secondary chemistry classes (~ 100 students) in Austrian high schools. TAP is introduced step by step, starting with implicit integration through scaffolds – introducing elements without naming or defining them so students engage intuitively – followed by their explicit introduction. Unit 1 focusses structurally on a simplified TAP (*data, claim, reasoning*) and content-wise on chemical aspects of HIOA – particularly coral skeleton calcification. Students connect through coral images, analyse given written arguments for their structural elements, and construct their own. Unit 2 adds *rebuttal* and *modal qualifier*, framing HIOA within the broader context of "Sushi as a Lifestyle Food" to enable multi-perspective discussion. Consistent with the structure of the previous unit, students analyse, create, and defend arguments in peer discussions. After both units, students tackle a new SSI to assess skill transfer.

All units will be delivered by the researcher to ensure consistency, particularly when implementing and clarifying TAP elements. As Lazarou and Erduran (2021) note, teacher adaptions can reduce comparability, though researcher presence may itself influence outcomes – a noted limitation. After the intervention, students' arguments will be analysed for structural and con-tent quality using qualitative content analysis (Mayring, 2022), following the pilot study approach.

Preliminary Findings

In the pilot study, seven main topics from students' arguments formed the inductive coding categories:

a. chemical reactions within the carbon cycle
b. shift in chemical equilibrium
c. pH
d. formation of limestone
e. solubility of salts
f. environmental changes and climate change
g. other

These categories addressed only HIOA's scientific aspects, neglecting its social dimension. The main intervention was therefore expanded with a second unit emphasising the social perspective.

Disciplinary content in students' arguments varies greatly pre- and post-intervention. Initially, categories (a), (c) and (e) dominated, while (b) was absent. Post-intervention, (b) appeared in ten arguments, (f) gained prominence, and overall depth improved – likely due to scaffolds. Arguments showed stronger interconnectedness – shown as an example for category (b) in Table 1. However, misconceptions – such as confusing calcium carbonate solubility with decom-position – persisted, indicating the need to address these in teaching material design.

Table 1: Interconnections between category (b) and other codes, pre-intervention (left) and post-intervention (right)

	a	**b**	**c**	**d**	**e**	**f**	**g**
b	0		0	0	0	0	0

	a	**b**	**c**	**d**	**e**	**f**	**g**
b	8		2	10	2	9	0

For structural analysis, a deductive category system based on TAP was applied. Challenges in assigning sequences to warrants or their backing – requiring intense communicative validation (Steinke, 2004) and sometimes allowing multiple categorisation – led to merging them into a single category, reasoning, consistent with McNeill and colleagues (2006). This refined coding system now underpins teaching materials development and the deductive coding approach in the main intervention study.

Structural analysis showed that students used TAP before and after the intervention, though its significance was low beforehand. Table 2 illustrates how the application of TAP becomes more nuanced – such as in the use of modal qualifiers and also how chemical equilibrium comes into focus.

Table 2: Comparison of students' arguments pre-intervention (left) and post-intervention (right)

The calcification of coral skeletons is impaired because of the greenhouse gas CO_2. CO_2 reacts with water to form H_2CO_3, which is an acidic solution. This causes ocean acidification and lowers its pH value. When calcium carbonate reacts with acidic solutions, it dissolves, ***thus*** *impairing the calcification of coral skeletons.*	*The concentration of dissolved CO_2 in seawater increases, and* ***this presumably leads to*** *the impairment of coral skeleton calcification. Calcification requires dissolved CO_3^{2-}, and the increase in dissolved CO_2 shifts the equilibrium of the carbonate-carbonic acid system away from CO32-.*

These findings suggest that implementing TAP implicitly through scaffolds may lead to an intuitively appropriate use, thereby laying the foundation for later explicit instruction. Consequently, the next phase involves developing teaching materials that include "[e]xercises that asked students to distinguish [between] claims, warrants and data,", providing a "foundation for more demanding exercises which asked students to construct their own arguments." (Osborne et al., 2016, p. 841).

Since teaching material evaluation and redesign is scheduled for completion by June 2026 and the main intervention study begins in the winter semester 2026/27, the summer school provides an excellent opportunity to review the DBR study analysis and incorporate feedback before implementation.

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Upper secondary students' actual learning pathways in electro-chemistry

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Focus of the Study

Electrochemical principles underlie life-necessary reactions like photosynthesis and cellular respiration, it facilitates medical, technological and industrial progress. Still, students experience the same, and more, difficulties with electrochemistry as over 30 years ago (see Garnett & Treagust, 1992a, 1992b; Sanger & Greenbowe, 1997a; 1997b). This abundance and persistence of difficulties may stem from interactions between naïve or alternative conceptions of pre-requisite knowledge with electrochemical concepts. Here, naïve conceptions refer to students' intuitive sense of mechanisms derived from everyday experience (diSessa, 1993), whereas alternative conceptions more broadly encapsule non-canonical conceptions about formally introduced scientific concepts (Taber, 2019). Central to electrochemistry is the electron and electrostatic interactions. This project, therefore, aims to delineate upper secondary students' conceptions of electrons and electrostatic interactions and how these interact with their actual learning pathways, their conceptual development over time, in electrochemistry.

Review of Literature

Students' difficulties with electrochemistry are not limited to explaining reactions in lab sessions (Haigh et al., 2012) or recognising everyday redox reactions (Tarkin & Uzuntiryaki-Kondakci, 2017). Students also experience considerable difficulties in their understanding of electrochemical cells. Common alternative conceptions include the notion that electrons migrate in the electrolytic solution or that the electric current in electrolysis produces ions. They also struggle with the function and mechanism of the salt bridge in a galvanic cell, frequently attributing it to creating a closed circuit for electron migration. Moreover, many students understand reduction and oxidation in electrochemical cells as separate and independent reactions (Nakiboglu et al., 2024). The idea of reduction and oxidation as independent reactions reoccurs across educational contexts and frequently coincides with difficulties in discerning the process of electron transfer. Students frequently attribute electron transfer to the wrong chemical species and suggest that electron transfer coincides with the breaking or formation of ionic bonds (Brandriet & Bretz, 2014). Additionally, many students struggle with the activity series of metals, justifying the high reactivity of alkali metals and the halogen group with the octet rule (Wang & Barrow, 2013). Such alternative conceptions, concerning the mechanisms of electrolyte solutions and the salt bridge, the movement and transfer of electrons in electrochemical cells and redox reactions, and understanding chemical reactivity suggests that students lack adequate understanding of underlying mechanisms. This is supported by research indicating that electrostatic interactions are commonly absent in students' understanding of the atom, often invoking gravity as the governing force (Taber, 2013). Consequently, concepts like ionization are understood through naïve ideas of inherent stability through filled electron shells and the octet rule. This may lead students to conclude that the full shell of Na^+ makes it more stable than Na (Tan et al., 2019), that atoms may ionize spontaneously to achieve full shells (Taber, 2009) and that chemical bonding is adequately understood through octets (Wang & Barrow, 2013). Such alternative conceptions ignore the underlying electrostatic interactions, fundamental to redox reactions, and may impede on students continued learning in electrochemistry.

Theoretical framework

This project adopts an educational constructivist paradigm (Taber, 2024) and diSessa's (1988) knowledge in pieces framework. Learning, then, is a process dependent on the human cognitive architecture and the learner's available interpretive resources, such as conceptual structures and epistemological sophistication – including appreciating the nature and limitations of chemistry models. Here, conceptual structure subsumes a learner's domain specific understanding as an interconnected network of knowledge, assumptions and beliefs (Wang & Barrow, 2013). Such conceptual structures involve a complex coordination of multiple interacting knowledge fragments (diSessa, 2013) and function as interpretive resources for understanding new information (Talanquer, 2009). Novices' conceptual structures, however, are commonly organised around phenomenological primitives (p-prims). P-prims are naïve ideas sub-conceptual, context-de-pendent fragments of knowledge developed from everyday experiences, like vacuums impel, the assumption that nature has an inherent desire for fullness (diSessa, 1993, 2018). Such p-prims may make canonical explanations appear counterintuitive and can contribute to both intuitive and canonical conceptions (diSessa, 2018). Learning, thus, occurs in pieces, in an iterative and interpretive process entailing both acquisition of new knowledge and reorganisation of existing conceptual structures (diSessa, 2013; Taber, 2024).

Research Questions

1. How do students' conceptions of the electron and electrostatic interactions interact with their explanations of electrochemical phenomena?

2. How are students' understanding of prerequisite electrochemical knowledge reflected in their learning of electrochemistry?

Research Design and Methods

Data collection

Examination of students' learning pathways through changes in conceptual structures requires thorough exploration of students' conceptions over time (Brinkmann & Kvale, 2018; Cohen et al., 2018). The project employs a longitudinal design with semi-structured interviews where students are interviewed 2-3 times per term over three years. This generates rich accounts of students' conceptions, enables in-depth characterization of students' conceptual structures and ensures comparability over time and between participants (Brinkmann & Kvale, 2018). Currently, 26 students from the same teaching cohort, enrolled in the natural sciences programme at a Swedish upper secondary school participate. Each set of interviews is accompanied by a distinct interview protocol probing an overarching area of electrochemical prerequisite knowledge, identified in prior research (see Nakiboglu et al., 2024), focusing specifically on how students conceptualise the electron and employ it in explaining chemical phenomena.

Protocols are informed by and adapted from prior literature, supplemented with follow-up question inventories and intra-interview techniques (e.g., rephrasing and summarizing) to clarify and probe responses, supporting identification of shared and individual patterns, consistent with learning as personal construction (diSessa, 2018; Taber, 2024). The protocols aim to generate extensive data on students' conceptions of electrons and their influence on electrochemical understanding over time, prioritizing authentic accounts of students' actual learning pathways over statistical generalizability.

Data analysis

Interviews are transcribed verbatim and analysed through thematic analysis, an immersive qualitative approach to open-ended enquiry (Robson, 2002). Transcripts are processed iteratively and coded systematically in NVivo via line-by-line analysis to fragment, examine, and compare data (Corbin & Strauss, 2008). This produces dense coding schemes where brief excerpts may receive multiple codes because responses reflect conceptions related to several concepts, allowing characterization of both the comprehensiveness and complexity of students' thinking at a sub-conceptual grain size. Related codes are then aggregated and interrogated through tabulation to visualise themes (Gibbs, 2007) which, together with their supporting excerpts, form the results. Substantial transcript excerpts are reported to demonstrate authenticity and interpretive validity across published stages. The final stage synthesises prior analyses into an overarching account of students' learning pathways, integrating findings on their conceptions and use of electrons in electrochemical understanding.

Preliminary Findings

Currently, three interview sets have been performed. The first interview set has been analysed and is being developed into a manuscript on students' conceptions of electrons, Coulombic interactions, and underlying conceptions (e.g. p-prims). Preliminary findings suggest that students' reasoning is strongly influenced by naïve conceptions of completeness and equilibration, expressed through reliance on the octet framework and notions of a natural drive toward balance via shell completion in explanations of electron configurations and chemical reactivity. This leads to deterministic views of electron configurations, an inconsistent use of Coulombic principles and considerable variation in ideas about electrons.

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Inclusive science education, with a specific focus on students with ADHD

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Focus of the Study

This doctoral study focuses on inclusive science education, with a specific focus on students with ADHD. The project investigates ways of orchestrating inclusive science education that values diversity and actively engages all students in meaningful learning. Among neurodivergent students, those with ADHD are at the highest risk of leaving lower secondary school with incomplete grades. Compared to their peers, students with ADHD are also less likely to qualify for admission to a national upper secondary program (Bortes, Nilsson, & Strandh, 2022; Creelman, 2021). In the long term, this may negatively affect these students' opportunities to pursue higher education and future employment. In addition, students with ADHD risk missing out on the scientific knowledge necessary for active participation in society, both now and in the future. Taken together, these concerns highlight a need for increased knowledge about how inclusive science education can be designed and implemented. Although research on inclusive education addressing students experiencing difficulties has expanded in recent years, it remains limited (Comarú, Lopes, Braga, Batista, & Galvão, 2021). Moreover, teachers report frustration due to lack of the necessary tools and conditions to fully meet the needs of diverse students (Chow, de Bruin, & Sharma, 2024).

Theoretical background

The theoretical background of this project draws on multiple theoretical perspectives that address different conceptualisations of inclusion, as well as diverse understandings of the overarching aims of science education, including questions related to curriculum content and pedagogical approaches.

In education that embraces diversity, values different perspectives, and engages students in collaborative work, inclusion can be viewed as *creation of communities*. Here, the goals of the education are the same for everyone, all students participate in discussions, and individual solutions are avoided (Nilholm & Göransson, 2014). Teachers play an important role in promoting inclusion in the science classroom. It is not only a matter of organization, but a process related to mindset. For science education to become more inclusive changes are needed at all levels of the educational system, not least at the classroom level (Ainscow, Slee, & Best, 2019). Viewing *inclusion as creation of communities*, traditions in science education must can be challenged. Science education research that addresses diverse students and the design of inclusive science education should be is uncommon, which, according to García and Greca (2023), is due to a dominant focus on preparing future workers for science-oriented jobs. This focus favours more traditional, fact-oriented teaching and excludes diverse learners. In line with García and Greca (2023) I argue that the predominant aim should instead be to enable learning that provides *scientific literacy* for everyone.

The concept of *scientific literacy* can be interpreted in different ways (Osbourne, 2023). With inclusion as creation of communities in mind, one way to discuss *scientific literacy* and overarching aims of science education is thru *Vision II and III* (Roberts, 2007; Sjöström and Eilks, 2018). Here science education can be interpreted as something that contextualizes the content and thereby makes these contexts accessible and meaningful to all students (Vision II). It can also be related to an education that promotes the development of care for others and one's own moral compass, enabling students to take a stand on issues, act on these commitments, and contribute to change (Vision III) (Roberts, 2007; Sjöström and Eilks, 2018).

For a science education that strives to be inclusive, meaningful and relevant, the *didactic questions* (Klafki, 1995) provide a foundation for planning, conducting and evaluating teaching. The question *Why?* is used to highlight relevance and significance of the content for the students. The question *What?* concerns the content and its structure, whereas the question *How?* deals with the ways in which the content is made accessible and meaningful to students. In my project, the question for *Whom?* becomes central. This question can be linked to a focus on accessibility and used as an addition to each of the other questions (Klafki 1995; Wickman, 2014).

Aim and research questions

The overarching aim of this project is to contribute to theoretical and empirical understandings of inclusion in science education, with a particular focus on students with ADHD.

The project is divided into three sub-studies, each with a specific research question:

Sub-study I, interview study with teachers:

How do teachers describe their experiences of teaching science to students with ADHD?

Sub-study II, interview study with students:

How do students with ADHD describe their experiences of science education in lower secondary classrooms?

Sub-study III, participant-oriented design-based study:

How can science education be designed and enacted to promote inclusion for students with ADHD?

Research Design and Methods

Sub-studies I and II generate data through individual qualitative semi-structured interviews (Kvale & Brinkmann, 2009) and are analysed using thematic analysis (Braun & Clarke, 2024). Participants in sub-study I are 14 Swedish lower secondary science teachers. Participants in sub-study II are students with ADHD, aged 13-16 years, who attend science education in lower secondary schools in Sweden.

The findings from Sub-studies I and II will constitute point of departure for the participant-oriented sub-study III, which aims to develop and evaluate science teaching designed to support learner diversity with a specific focus on students with ADHD.

The third sub-study will be conducted in collaboration with 1-2 in-service science teachers who, at the time of the study, teach students diagnosed with ADHD. In collaboration with the participating teachers, the researcher will plan a teaching sequence informed by the findings from sub-study I and II. Participating students will be invited to comment on the plan, which may then be revised based on their feedback. Data will be generated through classroom observations conducted during the lessons, as well as trough individual audio-recorded follow-up interviews with participating teachers and students.

The generated data in the project will be analysed using thematic analysis (Braun & Clarke, 2024) and interpreted through the lens of previously presented theoretical perspectives.

Parts of the project involving students with ADHD have been reviewed by the Swedish National Ethical Board (Dnr 2025-05747-01).

Preliminary Results

At present, the analysis of sub-study I is ongoing, and participants for sub-study II are being recruited. By the time of summer school, sub-studies I and II are expected to yield tentative results.

Preliminary findings from sub-study I indicate that teachers experience challenges in the science classroom when their students with ADHD encounter scientific language, and when concepts and models are presented in abstract forms. Teachers report that fruitful learning situations are perceived when scientific concepts and models are connected to students' interests and everyday experiences. Furthermore, teachers also describe students with ADHD as being more dependent than their peers on the teacher's responsiveness to spontaneous questions, including questions that redirect the content of the lesson in new directions. When such questions are not acknowledged by the teacher, teachers claim that students with ADHD often lose focus during the rest of the lesson.

Students with ADHD have previously been described as having difficulty searching for information on their own. In line with this, preliminary findings from the present study suggest that teachers perceive classroom activities to run more smoothly when the amount of information is limited and preselected by the teacher. According to the participating teachers, oral argumentation is perceived as a success factor, compared to writing, for students with ADHD. However, teachers also report that these students often struggle to distinguish between scientific arguments and other types of argument, often due to impatience when searching for and evaluating information. They further experience that many students with ADHD have difficulty making their own choices, and that progressing in tasks involving searching for information, evaluating it, and taking a position is often easier when such choices are made in collaboration with the teacher

The preliminary results from sub-study I indicate that a more inclusive science education for students with ADHD is possible when teachers identify possible barriers for diverse learners and take these into account when planning and conducting science teaching. However, some barriers, including maintaining the focus and interest of students with ADHD during lessons, appear more difficult for teachers to address, highlighting the need for further knowledge on how inclusive, meaningful, and relevant science education can be designed. The preliminary results also indicate a need for greater understanding of how to support students with ADHD in developing their own values and in taking a stand on questions with scientific content, a topic that can be addressed in the project's sub-study III.

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We need to talk: Disruptive transformative dialogical approaches to education for sustainable development in pre-service science studies teacher education

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Keywords: Science Studies, Pre-service teachers, Transformative Learning, Disruption, Interactive Visualization

1. Focus of the study

Education plays a pivotal role in promoting students as active transformation agents to tackle sustainability issues. In the context of the Swedish educational system, this vision on student's role is defined throughout curricula and specified under the banner of 'learning for sustainable development' (Skolverket, n.d.). Students are encouraged to address the complexity of environmental and societal challenges, engaging in democratic processes and developing critical and holistic thinking. Subjects like *Naturkunskap* (science studies) exemplify how to address sustainable development (SD) in conjunction with health and energy, recognizing the intersections between science and social science, and enabling students to critically reflect upon their present and future practices and choices (Skolverket, 2012).

Nevertheless, the effective implementation of ESD in teaching practices does not align with its curricular structurization. Swedish teacher express uncertainty on the integration of all dimensions of sustainability in their teaching, with nature-oriented subjects facing challenges to embrace pluralistic and holistic perspectives (Skolinspektionen, 2023). In turning our eyes to student teachers' training, research reports on the challenging expectations they face in feeling and understanding sustainability-related topics in connection to their role as science educators (e.g. Yavuzkaya et al., 2024). A further problematization is found on how pre-service teachers perceive their 'neutrality' in value-laden topics such as climate change (see Rydin et al., 2025) and draws criticism to the role of 'pluralism' in addressing the 'root causes' of sustainability-related issues (Andersson, 2017, p.12).

Understanding sustainability-related topics or issues can be difficult, especially those framed in geographic and temporal distant contexts (e.g. Ward et al., 2024). For this reason, visualization can serve as a powerful tool that provides immersive and sensory experiences, presenting geographical and time-distant realities that can trigger persistent and long-lasting emotional responses towards these (e.g. Sheppard, 2005). Furthermore, visual systems can enhance understanding the complexity of environmental issues science and promote pedagogies for engagement with these (Jones et al., 2025). The use of dynamic and interactive visualization communication has been proven to facilitate pre-service science teachers' learning and understanding of sustainability topics from broader interdisciplinary perspectives (e.g. Karpudewan, 2024).

The complex nature of sustainability-related topics, and the integration of ESD at Swedish universities hinder future science studies educators' understanding of sustainability topics and their role in raising awareness and promoting pro-sustainability mindsets. In parallel, research sheds light on the value of visualization to bring awareness on complexity and provoking affective responses to sustainability-related issues. This thesis empirically investigates how pre-service science studies teachers navigate sustainability topics. We contribute by creating learning and dialogical spaces supported by interactive visualization as a novelty in the context of pre-service science studies teacher education. This contribution could shed light on how said spaces allow for critical reflections on emotions and awareness on sustainability issues in teacher preparation programmes, with potential transformative outcomes. By investigating this, I argue for a transformative shift in the way pre-service science studies teachers are trained and the learning opportunities they are offered to navigate their beliefs, experiences and thoughts with regards to ESD, and in connection to their future professional role.

2. Theoretical framework

The theoretical foundations of this thesis lie in the work of various exponents on the need for transformative, holistic and critical views on education.

2.1 Transformative learning theory

Jack Mezirow's transformative learning is defined as "the process by which we transform problematic frames of reference (mindsets, habits of mind, meaning perspective) -sets of assumptions and expectations- to make them more inclusive, discriminating, open, reflective and emotionally able to change" (Mezirow, 2009, p.3). Combining constructivist, humanist and critical social theory assumptions, learners can become aware of the systems of oppression, inequalities and injustice. This acknowledges the role of critical reflection- or 'reframe'- and emotions as inherent components of a process in connection to experiences and relationships with others and the world (Baumgartner, 2012), including environmental, spiritual and self-concept issues in what is defined as 'integral transformative learning'.

2.2 Third-order learning

Stephen Sterling is a strong advocate for transformative and critical approaches to ESD and reforms in higher education, contributing to ESD literature through the notions of 'deep learning' and change (2001). Criticizing the unsustainable nature of the current educational system and the need to reclaim authenticity, Sterling defines different orders of learning, namely first, second and third. While first-order learning plays out within the system boundaries that remain unchanged, second-order learning involves critical reflections of values and assumptions that define first learning: "thinking about our thinking" (p.9). Third-order learning, however, calls for "deep awareness of alternative worldviews and ways of doing things", a 'breakthrough' that can only be conceived through reflective and intentional learning that challenges the assumptions and values of cultural and educational systems.

2.3 Disruptive Learning Theory

A relevant piece of empirical research that draws from transformative learning and third-order learning is found in the work of Tillmanns (2020), who created pedagogical interventions involving visual cues and critical questions to trigger emotional reactions on teacher students, leading to deep learning within sustainability topics through the questioning of anthropocentric perspectives and realizing interconnectedness between different dimensions. Such reflections ultimately translated into reconfiguration of responsibility towards the environment and society, and a change of agency among participants, leading to the foundations of the ‘disruptive learning theory’ and its three phases: disruption, deep learning and action.

3. Research questions

In combining interactive visualization with pre-service science teacher education, this thesis is ground on the following *tentative* research questions.

1. How can pre-service science studies teachers engage with ESD-related content in a transformative way?

2. What aspects of interactive visual interventions can induce ‘disruption’ for dialogical learning experiences?

3. How can dialogical transformative experiences in pre-service science studies teacher education encourage critical reflection on sustainability-related systemic issues?

4. ... (future work in progress...).

4. Research methods

The thesis is aimed as a compilation of four papers, rooted in 4 separate studies, of which 1 has been submitted for review, while data collection for the second has recently concluded. All studies will be carried out in cooperation with a teacher education course in science studies. The course explores sustainability-related topics, challenges, and concepts from an educational and historical perspective. In pursuing cooperation with this course, the studies in this thesis will be integrated as seminars that build upon the course’s syllabus and serve as learning opportunities for the students, while strengthening the methodological design of the studies.

Group case studies have been conducted for both the first and second study. The choice of a group case study responds to the constructivist features present in the transformative learning theory and allows for the observation of contemporary phenomena in the context of a small and direct group. Both studies included interventions designed around three interactive visual exhibits at a local science museum. Data in Study 1 was collected using semi-structured interview protocols for two group interviews and specific questions for two visualization-based interventions and a group discussion. This study included 3 students from the university course. All data collection moments intended to address the participants’ views regarding sustainability-related content in teacher education; emotions elicited by sustainability topics; and the use of visualization to present sustainability-related content.

Study 2 makes use of the work of Tillmanns (2020) as a suitable theoretical framework to refine the pedagogical interventions supported by interactive visual exhibits from Study 1. 9 participants were included in this study, where engagement with the interactive visual exhibits was encouraged through interventions, this time supported by critical questions that exposed controversy and motivated a critical discussion. Interview protocols were designed for post-intervention discussions, focusing on sustainability awareness, disruptive responses and responsibility. The focus on responsibility derives from one of the results highlighted in Study 1.

5. Preliminary findings

Data collected in Study 1 was thematically analysed and led to the definition of 5 themes and 11 sub-themes, presented in Table 1.

Table I. *Themes and sub-themes that emerged from the thematic analysis.*

Themes	Sub-themes
1. *Sense of responsibility for approaching sustainability*	1.1. As an individual 1.2. As a teacher 1.3. The role of the collective
2. *Affective responses to sustainability issues*	
3. *Role of interactive visualization for enhanced learning experiences*	3.1. Advantages of interactive visualization systems 3.2. Limitations of interactive visualization systems
4. *Awareness of complexity and reconsideration of practices*	4.1. Insufficient prior knowledge 4.2. Knowledge brings up difficult questions 4.3. Complexity raises awareness.
5. *Advantaged views about sustainability*	5.1. Disconnection from the issues 5.2 Perceived advantage

Source: Authors' own creation

The results highlight the pedagogical value of interactive visualization to enhance pre-service teachers' understanding and sense of responsibility, both as individuals and future educators, toward sustainability. Interactive visualizations served as a platform for participants' reflections on multiple aspects of sustainability considering their own choices, affective responses and advantages, prompting awareness of complexity. The study addresses the need for co-developing capacity in pre-service science learning that aids future teachers in confronting science content through the required complexity and holistic thinking embedded in ESD.

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Scaffolding scientific learning in teaching–learning sequences contextualised in free-choice science play-spaces

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Focus of the Study

Situated within the field of Science Education, this study explores the scientific learning processes that emerge around free-choice science play-spaces in a Spanish preschool. It is grounded in a view of early childhood that recognises children as curious and competent learners who actively construct knowledge through interaction with their surroundings. In line with this view, this study focuses on the interactions taking place both during and following play in a free-choice science play-space centred on mixtures, and on the role these interactions play in children's scientific learning. More specifically, children's interactions with materials, peers, and adults are analysed.

Particular attention is paid to teachers' role in revisiting, extending, and building upon what occurs during play. In this sense, scaffolding strategies aimed at establishing connections between play experiences and scientific phenomena are examined. This analysis extends beyond play time, examining the strategies used by teachers across a teaching-learning sequence deliberately designed to extend on the scientific ideas that emerge in the play-space designed.

This focus on scientific learning in play-based contexts aligns with an understanding of play as a meaningful activity in which children explore the environment, interact with it, respond to questions that arise from this interaction, and integrate their discoveries in significant ways (Glauser-Abou et al., 2022).

Although numerous studies emphasise the importance of teaching science in ways that are aligned with the developmental characteristics of children, relatively few have explicitly examined the potential of play as a context for scientific learning (Fridman et al., 2020; Glauser-Abou et al., 2022). This body of research is even more limited in the Spanish context (Mateo & Sáez-Bondía, 2022). In response to this gap, the present study aims to explore how play contextualized in free-choice science play-spaces can contribute to scientific learning, with particular emphasis on the role of interactions in this process. Moreover, drawing on findings by Sliogeris y Almeida (2019), which show that combining different forms of play (ranging from open-ended to more directed play) can enrich children's scientific learning, a teaching-learning sequence that builds on free-play through progressively more structured activities is designed, implemented and evaluated following the Design-Based Research methodological approach.

Free-choice science play-spaces and the scientific learning occurring within them constitute an ongoing line of research for the research group to which this project belongs. Over several years, this group has sought to better understand the contribution of these play-spaces to scientific learning in early childhood education. The present study is expected to further advance this line of research.

Theoretical Framework

Free-choice science spaces originate in non-formal educational contexts. They were initially implemented in settings such as museums, where spaces were organised into different proposals with which visiting children could interact freely (Bamberger & Tal, 2007). As this initial model entered into dialogue with pedagogical approaches that emphasise learner autonomy, it gradually evolved. This evolution was further shaped by the growing recognition of space as an educational agent capable of shaping what unfolds within it (Mateo & Sáez-Bondía, 2022). From this process emerged what are now known as free-choice science play-spaces.

Increasingly present in formal educational contexts, these spaces are composed of different proposals that children access freely and autonomously, according to their interests and needs (Pedreira & Márquez, 2019). Each proposal incorporates materials arranged in ways that promote scientific action without the need for direct instruction. The associated learning goals vary in complexity and allow for different levels of response, thereby accommodating the diversity inherent in early childhood. In this way, each proposal becomes a scenario where play and scientific learning converge (Mateo et al. 2023).

This way of conceptualising and organising space goes beyond physical enrichment, giving rise to dynamic learning environments shaped by active networks of interaction (Kokko & Hirsto, 2021). These interactions appear to foster the development of scientific competences associated with the three levels of scientific activity proposed by Pedreira and Márquez (2019): experience with reality, explicit articulation of ideas, and the evolution of ideas.

Experience with reality involves sensory exploration of the environment, enabling young children to observe and manipulate materials, discovering properties and relationships among them. The explicit articulation of ideas refers to verbal or non-verbal communication and is closely linked to the role of language. It involves skills such as comparing, classifying, identifying, predicting, naming, describing, explaining, arguing, or justifying. Finally, the evolution of ideas encompasses skills that reflect changes in children's ways of thinking, such as generating questions, relating variables, or conducting simple checks. This evolution involves the questioning and revision of prior ideas, giving rise to new ways of interpreting and understanding the world (Pedreira & Márquez, 2019).

Studies such as those by Zuazagoitia et al. (2023) and Mateo and Sáez-Bondía (2022) suggest that different types of interaction promote different forms of scientific activity. Specifically, peer interactions appear to have a stronger influence on experience with reality and the explicit articulation of ideas, whereas adult guidance plays a more prominent role in supporting the evolution of ideas. Nevertheless, didactic experiences involving free-choice science spaces in formal educational settings remain relatively scarce. This underscores the need to further investigate the interactions that emerge in these spaces, their contribution to children's scientific learning, and the ways in which teachers can build upon what occurs during play.

Research Questions

This study is aiming to answer the following questions:

What interactions emerge during preschoolers' (aged 3 to 6 years) play in a free-choice science space about mixtures and how do they contribute to children's scientific learning?

How can teachers extend and build upon what occurs during play? Are strategies used to develop the everyday ideas that emerge during play into ideas that are closer to scientific ones? Which ones? Do these strategies vary in the different moments of the sequence?

How do children respond to the strategies employed by the teachers? What scientific ideas and skills are promoted and how?

Research Design and Methods

This study is framed within a Design-Based Research (DBR) approach (Guisasola Aranzabal et al., 2021), which seeks to address educational problems through the design, implementation, and evaluation of research-informed teaching–learning sequences. Beyond generating context-specific solutions, DBR seeks to refine design principles by enabling an understanding not only of what is learned, but also of how learning occurs, under what conditions, and which design features contribute to it (Romero-Ariza, 2014).

The proposed approach focuses on the role of interactions throughout the learning sequence. A micro-analytic perspective is adopted, analysing specific moments within the sequences to contribute to a macro-level understanding. In this sense, the analysis of moments within the de-signed and evaluated sequences can be framed as case studies (Simons, 2011).

Data are collected through audio and video recordings, as well as through the collection of children's productions. Data analysis draws on strategies from observational methodology (Por-tell et al., 2015) and discourse analysis (Gee et al., 2011). The sequence is implemented in three early childhood classrooms with children aged 3, 4, 5 and 6 years old respectively. Approximately 50 children and 6 teachers participate in this study.

The teaching–learning sequence begins with play in a free-choice science play-space on mixtures, followed by more guided activities aimed at deepening the scientific ideas embedded in the space.

In addition, interviews are conducted with the participating teachers. During these interviews, video excerpts of their interactions with children are jointly viewed and discussed. The inter-views aim to deepen understanding of the scaffolding strategies employed and their underlying intentionality, as well as to contribute to the development of a category system for analysing teaching strategies across the sequence.

Preliminary Findings

At this stage, available results correspond to the first study within the doctoral project. This study explores the relationship between peer interaction and the development of scientific skills during play in a free-choice science space on mixtures, involving children aged 5–6 years.

Using a Design-Based Research approach and observational methodology, children's actions were analysed through video recordings. Results show a spontaneous emergence of scientific skills, fostered by peer interaction and primarily associated with experience with reality and the explicit articulation of ideas. Interaction with materials also plays a key role, supporting both individual and collective action and promoting the emergence of new skills. These findings do however point to the need to move beyond these interactions to support the evolution of children's ideas, highlighting the potential role of teachers in this process.

In addition, the sequence on mixtures, designed collaboratively with the participating teachers, has been implemented and video-recorded in three early childhood classrooms. A total of 39 sessions, lasting between 30 minutes and one hour, have been recorded.

Interviews with the participating teachers are currently under analysis. A category system has therefore been developed based on the framework proposed by van de Pol et al. (2010) and is being refined as new themes emerge during the analysis. Preliminary findings suggest that, although the underlying intentions of scaffolding strategies vary considerably, they can be broadly categorised as metacognitive, cognitive, or affective (van de Pol et al., 2010). In addition, the means through which these scaffolding strategies are enacted are being identified. Facilitated by a research stay with a group specialising in early childhood science learning, the interviews were replicated with educators trained by this group, using video recordings of their own teaching practice. These interviews are expected to shed light on differences between the scaffolding strategies employed by teachers with specific training in science education and those without such training.

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Investigating students' decision-making on wind turbine trade-offs regarding raw material demand

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Focus of the Study

The use of renewable energy, such as wind turbines, is considered an SDG as it reduces carbon dioxide emissions associated with energy use. However, wind turbines also have environmental impacts due to the harmful extraction of raw materials required for their manufacture (Atilgan & Azapagic, 2016), resulting in trade-offs. School students are often unaware of these impacts and tend to perceive energy plants dichotomously as clean or dirty (Hüfner, 2020). From an ESD perspective, this highlights a need for deeper educational engagement. This PhD project aims to develop a chemistry teaching unit that helps school students better evaluate the trade-offs associated with wind turbines. Therefore, two intervention studies are conducted: Study 1 explores students' perceptions, emotions, and attitudes toward the trade-offs, while study 2 examines how they engage with additional learning materials and make decisions about these trade-offs.

Theoretical Background

Life cycle assessments identify environmental impacts of wind turbines, showing that they primarily affect the abiotic resource depletion potential of chemical elements (Atilgan & Azapagic, 2016). These impacts can vary depending on decisions in three areas: the energy plant itself (Atilgan & Azapagic, 2016), the raw materials used (Schreiber et al., 2019), and the pro-cessing of the raw materials (Li et al., 2019).

The trade-offs of wind turbines are receiving increasing attention in the media, particularly their need of rare earth elements (REE). This makes them a relevant topic for ESD, which aims to support "learners to take informed decisions and responsible actions" (UNESCO, 2017, p. 7). Therefore, it is essential to address both content knowledge and decision-making skills. Currently, most students are lacking a differentiated perspective: while students distinguish the impacts of renewable and non-renewable energy plants as clean and dirty, scientists attribute impacts to both, differentiating them according to the types of impacts (Hüfner, 2020), as shown in life cycle assessments.

Differentiated weighing is central for socioscientific decision-making and has been addressed through both competence-based assessments (e.g. Bögeholz et al., 2017) and process-oriented frameworks (e.g. Langlet et al., 2022). The process-oriented PAAWDR-framework divides the decision-making process into six steps: perceiving, analysing, arguing, weighting, deciding, and reflecting (Langlet et al., 2022). In the context of climate crisis, the perception is particularly noteworthy as emotions such as hopelessness and helplessness (Hickman et al., 2021) can hinder learning (Pekrun et al., 2007) as well as reaching ESD goals. These emotions make constructive solution approaches significantly relevant (Ojala, 2012).

Research Questions

The project aims to design a complete teaching unit that uses the trade-offs involved in wind turbines to promote students' decision-making skills. The following research questions are considered relevant for this purpose:

1. How do students perceive different facets of the trade-offs on wind turbines?

    1.1 Which area would they like to deepen?

    1.2 Which emotions occur while being confronted by the trade-offs?

2 What information is relevant for students in their decision-making process of the trade-offs regarding wind turbines?

    2.1 Which criteria are important to them?

    2.2 How does their evaluation change?

    2.3 Why does their evaluation (not) change?

Research Design and Methods

Both intervention studies are conducted with 10th and 11th grade students using a mixed method design. Study 1 focuses quantitively on the perception of the trade-offs (RQ 1, N = 129). Study 2 examines qualitatively the weighting, deciding, and reflecting steps (RQ 2, N = 22).

The trade-offs addressed in both studies cover the three areas mentioned: energy plants (contrasting wind energy and natural gas plants), raw materials (contrasting the use of a higher amount of copper to REE in the generator of an energy plant), processing (contrasting pyro-metallurgical and hydrometallurgical methods). In study 1, the trade-off interventions are presented as videos with a duration of two to three minutes. In study 2, they are addressed in several lessons. Moreover, the subject of solution perspectives is addressed, using examples from the sustainability strategies sufficiency, efficiency and consistency.

Study 1

Study 1 was conducted in 2025 with an online questionnaire (duration: 30 min) including a pre-test, video interventions on the trade-offs, a post test, and a video on solution approaches. In addition, there were brief intermediate tests after each video. They assessed the emotions dimensionally using the Self-Assessment Manikin (Bradley & Lang, 1994). The emotions were further assessed categorically pre and post using a 5-point Likert-scale (adapted from Duffy et al., 2020). Moreover, students' attitudes towards wind turbines were assessed, and in the post-test, they selected the trade-off topic and solution approach they would like to explore further.

Data with more than 30% missing values or unusually fast processing times (RSI > 2; < 25 s on intervention pages) were excluded, leaving n = 99. Analyses were conducted in *IBM SPSS Statistics 29.0.0.0*. The topic selection is described via frequency distributions (RQ 1.1). Since the emotion variables are not normally distributed (Shapiro-Wilk-test: $p < 0.001$), Wilcoxon test is applied for the categorical emotions and Friedman test is applied for the dimensional emotion assessment (RQ 1.2).

Study 2

Study 2 is currently being conducted with online questionnaires (total duration: 75 min) alongside of a teaching unit structured with the PAAWDR-framework and will be completed in May 2026. In a pre-post design, attitudes towards and evaluations of wind turbines are assessed. The post-test also includes the students' reflection on their change in their evaluation of wind turbines. Additionally, interim surveys capture their predominant emotion, criteria ranking and decision for each trade-off after finishing its individual teaching sequence.

The open-ended pre-post evaluation (RQ 2.2) und post-reflection (RQ 2.3) will be analysed using a Qualitative Content Analysis according to Mayring (2014), mainly deductively based on theoretically derived criteria used in the criteria rankings. The rankings are presented descriptively and then compared with each other and with the open evaluation in terms of frequency (RQ 2.1).

Preliminary Findings

First results for RQ 1 (study 1) indicate that students are predominantly interested in the trade-off area of energy plants (62.6%). Regarding solution approaches, efficiency was chosen most frequently (35.7%), although the choice is more balanced.

In the pre-test, emotions associated with wind turbines were primarily (mean > 3) positive (relieved, relaxed, light-hearted, enthusiastic, happy, grateful, interested, hopeful). From pre- to post-test, relief ($p < 0.001$, $r = 0.38$), relaxation ($p = 0.028$, $r = 0.24$), light-heartedness ($p = 0.003$, $r = 0.33$), happiness ($p = 0.006$, $r = 0.31$), gratitude ($p < 0.001$, $r = 0.45$), and hope ($p = 0.003$, $r = 0.33$) decreases and concern increases ($p = 0.011$, $r = 0.27$), with weak to moderate effect sizes according to Cohen (1988). No significant changes were found for pride, enthusiasm, interest, anger, fear, frustration, shame, confusion, hopelessness, disappointment, sadness, and boredom.

Dimensional emotion measures show a decrease in mean valence from pre- to post-test (see Figure 1), with significant decreases from the pre-test to after the second trade-off video ($p = 0.009$) and third trade-off video ($p < 0.001$). After the fourth video (on solution approaches), valence significantly increases compared to the last trade-off video ($p = 0.020$) and did not differ significantly from the pre-state. The arousal remained unchanged.

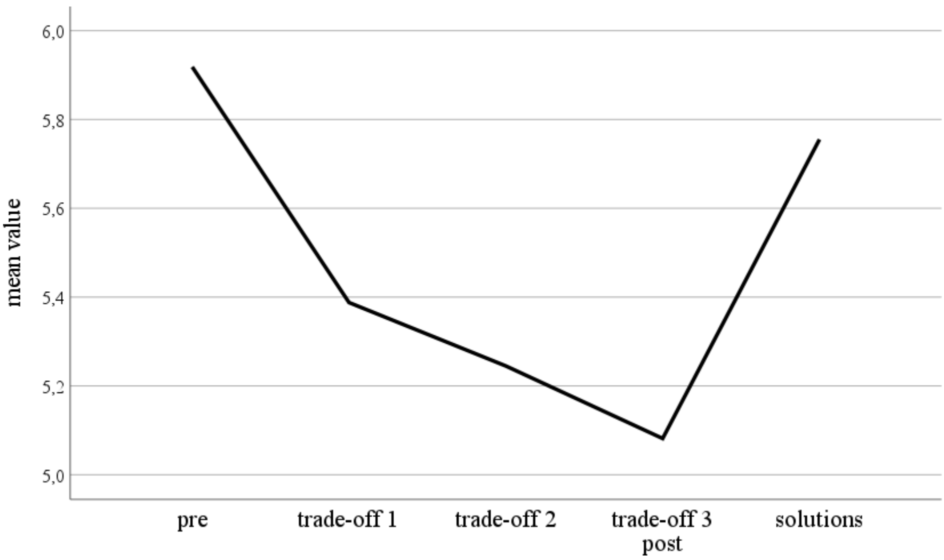

Figure 1: Arithmetic mean of the emotional valence

As a potential solution to the climate crisis, wind turbines evoke more positive emotions than climate change itself (cf. Hickman et al., 2021). However, the positive valence decreases when trade-offs are addressed, but can be restored through solution approaches, in line with the recommendation of Ojala (2012). Whether these topic emotions are linked to attitude changes, as in Broughton et al. (2013), requires further analysis of study 1. Broughton et al. (2013) also observed changes in emotions after additional teaching. For this analysis, as well as for the analysis of RQ2, the results of study 2 still need to be obtained and analysed. This will also raise questions about how these findings on emotions can be used to further develop the teaching unit, and whether a third study is needed that repeats a teaching sequence for one trade-off with a larger sample size, given the small and mostly incomplete dataset in study 2.

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The role of representations in teaching and learning modern physics: The case of general relativity

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Focus of the Study

Guidelines on education in Europe are recently including Modern and Contemporary Physics in secondary schools to increase students' literacy in science and interest towards physics, but teaching and learning such topics can be challenging (Levrini & Fantini, 2013). Advanced math plays a strong structural role (Karam & Pietrocola, 2009) in them, and they are often perceived as too abstract and not anchored to everyday experience. While academic approaches rely on mathematical representations, and those theories are presented through evocative (but often misleading) images and narratives in science communication, we find a lack of secondary school approaches that make use of meaningful representations accessible to students. This is evident with General Relativity (GR), a theory that consists in an identification between mathematical (curvature) and physical (gravity) concepts, formulated using differential geometry and tensor calculus, mathematical formalisms inaccessible to secondary school students (Levrini, 2002). On the other hand, analogies and pictures commonly used to present concepts such as space-time curvature to general public are not suitable for learning it without the risk of generating misconceptions. With this study, we aim to identify and develop simple representations of GR concepts adaptable for secondary school, and to validate them through the design and testing of a learning path that reflects authentically the content of the theory and uses re-sources accessible to students. In the end, we want to outline how fundamentals of GR can be taught and learnt at secondary school level, knowing the importance that this theory has in the understanding of the observations and discoveries in astrophysics, such as gravitational waves and black holes, and its applications, such as GPS.

Review of Literature and Theoretical Background

Physics learning can be enhanced using multiple representations (Ainsworth, 2008): visual, verbal, graphical, and mathematical representations of the same concept highlight complementary aspects, enabling students to reason qualitatively and quantitatively, and supporting deeper conceptual understanding. Studies in Physics Education Research have analyzed several types of representations used in GR, mostly focusing on visual analogies and models for understanding the concept of curved space-time (e.g. Kraus et al., 2018). Some of the most discussed ones describe space-time as an elastic rubber (Postiglione & De Angelis, 2021) or paper sheet that can be stretched or warped around massive bodies, allowing us to visualize the bending of straight lines (geodesics, such as the trajectories of free-falling bodies in space-time), due to the curvature (Ryston, 2019). However, these types of representations based on an extrinsic definition of curvature can generate the misconception that space-time must be curved into a "higher-dimensional something else". Instead, analysing the internal geometrical properties of a curved environment (for example, parallel geodesics can naturally converge or diverge), such as the Earth globe (Andersen, 2020), appears to be a more accurate way to grasp the notion of intrinsic curvature, with the possibility to naturally extend it to motion in space-time. Also, the role of space-time diagrams has been analysed: for example, it has been shown how qualitatively warping the time axis on such diagrams one can find a representation in which free-falling trajectories are the straightest possible lines in space-time (Kersting, 2019), in agreement with the theory. Visual and graphical representations like the ones mentioned above have been included in learning paths; however, there still appears to be a lack of mathematical representations, since most proposals present content in a qualitative way and do not include formal or quantitative aspects, according to our analysis of representative teaching proposals (e.g. Kersting et al., 2018). These approaches can thus be enriched with other tools and representations to promote a conceptually meaningful and mathematically accessible integration of GR into secondary school curricula.

Research Questions

RQ1. What kind of reasoning, representations and conceptual resources do experts and university students use to understand General Relativity basic concepts?

RQ2. What kind of representations and conceptual resources can be adapted to construct a conceptually meaningful and mathematically accessible learning path for General Relativity into secondary school curricula?

RQ3. What kind of representations and conceptual resources are most useful for secondary school students to understand General Relativity?

Research Design and Methods

To address RQ1, we are collecting university students and researchers' responses to an open-ended written questionnaire, in which participants are asked to discuss what kind of representations have been useful to them to understand what "curved space-time" means and which of these representations they use when solving a GR problem. The answers are being examined using Grounded Theory (GT) to let patterns emerge directly from the coding of qualitative data (Chong & Yeo, 2015). Answer to RQ1 will inform us of the authentic ways of thinking and representations used by people that deal with GR. These representations can be adapted and, together with the ones already explored by literature, can be included in a suitable GR learning path that integrates qualitative and quantitative aspects of GR. The development of such a learning path will provide an answer to RQ2. The learning path is intended to be improved within the Design Based Research (DBR) framework, which involves iterative cycles of design, testing, evaluation and refinement informed by empirical evidence emerging from classroom experimentations (Anderson & Shattuck, 2012). Evaluating the impact of this learning path on students will also provide an answer to RQ3, through a qualitative analysis based on GT of students' reasonings during activities and a basic statistical quantitative analysis of correctness of answers to written tasks, collected across multiple implementations of the learning path.

Preliminary Findings

Regarding RQ1, we completed an exploratory phase, also used to validate our questionnaire. Three university students and three researchers in astrophysics at University of Ljubljana were selected to participate in this first study and their responses to the questionnaire were analysed. While researchers mostly referred to visual analogies and historical or thought experiments, already explored by the literature, students pointed out that, for them, the notion of curved space-time remained difficult to grasp without an explicit analysis of the geometric consequences of curvature, through mathematical concepts such as metric and geodesic deviation. These first results informed us that simple geometrical insights about these topics could be useful for our learning path for secondary school. We proceeded then to design a prototype of it, based on six forty-five minutes sessions, which consist of interactive lectures and hands-on activities. The structure of this learning path is summarized in Figure 1.

Figure 1. Overview of topics, activities and representations included in the learning path.

Session	Topics	Activities	Representations used
1	Principle of equivalence, locally inertial reference frames.	Recognizing inertial reference frames and forces acting on different observers according to GR	Force diagrams
2	Space-time coordinates, motion in space-time	Drawing space-time diagrams of the motion of different objects	Space-time diagrams
3	Geodesics, laws of motion in GR	Recognizing whether an object is following a geodesic in space-time	Space-time diagrams, equation of motion, visual analogies (shape of geodesics on coordinate grids vs motion of planes on maps)
4	Intrinsic curvature, geodesic deviation	Drawing geodesics on 2D surfaces, recognizing geodesics deviation to tell if a 2D surface is intrinsically curved	Space-time diagrams, visual analogies (geodesics deviation in space-time vs motion of planes on the globe)
5	Einstein's equations, space-time metric	Discussing the effects of non-uniform gravitational field on the curvature of space-time	Einstein's equations, metric factors, analogies (real lengths on maps vs real time measurements in space-time diagrams)
6	Consequences and application of GR (lensing, time dilation, GPS)	Calculating gravitational time dilation factor, applying GR corrections to GPS	Ray diagrams, time dilation equation

The activities include open and closed conceptual questions, explicitly designed to grasp students' reasonings. So far, the prototype has been tested in a secondary school in Ljubljana (N = 21) during autumn 2025, as part of an optional course in advanced science. Students were allowed to work in pairs in answering tasks on worksheets, which have been collected. We are in the process of statistically analysing the correctness of responses in terms of percentages and we will then proceed to do a thematic analysis of the students' answers. So far, we observed that students were able to follow and apply the new GR principles and definitions to situations proposed. For example, percentages of correct answers are above 80% in tasks where students are asked to draw forces acting on observers according to GR or to decide if those observers in proposed situations were inertial or accelerated and if they follow geodesics in space-time or not. The geodesics deviation criterion for curvature has been well applied as well, since by observing the behaviour of geodesics 87% of students were able to tell that a cylindric surface has an intrinsic flat geometry and 93% of them observed correctly that space-time can be treated as a curved environment when gravity is not uniform by observing the diverging of free-falling trajectories on space-time diagrams. Instead, students struggled to draw space-time diagrams specifically for a free-falling object when asked for the first time (5% of correct answers). New data to the questionnaire will be collected and analysed by the end of winter 2026 and agreements with schools to test the learning path on different students are being established. By means of repeated administrations of the questionnaire in university contexts and the parallel improvement and testing of the learning path for secondary school, we expect answers to the three research questions to be progressively improved.

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Analysis of low-achieving students' argumentation patterns on local and global socio-scientific issues

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Focus of the Study

The project addresses the affordances of Education for Sustainable Development (ESD) and the resulting participation of all students in related discourses. ESD aims to enable students to understand complex global challenges and to behave accordingly. In science education, these challenges are addressed through socio-scientific issues (SSI), which link controversial science-related questions to ethical, social, and political perspectives (Högström et al., 2025). Abilities that students need to compete with these questions include argumentation (UNESCO, 2017). This PhD project focuses on low-achieving students. They are defined as learners who do not reach minimum standards in science-related competences (KMK, 2010). Findings from large-scale assessments such as PISA indicates that this group of learners is not well prepared for reflective participation in societal decision-making processes, as the OECD (2023) calls for. Low-achieving students often experience greater difficulties in the required competences, which increases the risk of their exclusion from societal discourses (Weirich & Burblies, 2025). Research further suggests that these students benefit from structured support in argumentation learning environments to articulate, justify, and reflect on their viewpoints (Osborne et al., 2016).

Against this background, the PhD project investigates how low-achieving students engage in argumentation when discussing SSI in groups. The study focuses on identifying recurring argumentation patterns, that is, systematic ways in which claims, evidence, and reasoning are constructed, and on analysing the quality of these arguments across different levels of complexity. By comparing students' argumentation in local and global SSI, the project examines how contextual framing influences the structure, type, and quality of argumentation among low-achieving students. Argumentation is examined through both local and global contexts, as science-related decisions affect students' immediate living environment and global ecological and social challenges. The two contexts, local and global, constitute the two conditions of the pre-sent study.

Theoretical Background

A central objective of ESD is for learners to acquire sustainability-related knowledge and to engage reflectively with tensions between different objectives (UNESCO, 2017). In the school context, increasing attention is being paid to how low-achieving students in lower-secondary schools can be enabled to engage actively (OECD, 2023). This group is particularly affected by limited educational and participatory opportunities and is characterized by not reaching minimum educational standards in science education (KMK, 2010; Weirich & Burblies, 2025). Reflective engagement with abstract global issues is challenging for this group of learners.

To reach the aims of ESD, science instruction must be designed in a way that highlights the relevance of the raised issues for students' everyday lives. SSI offer an approach for engaging students with socially relevant and scientifically grounded controversies in ESD, fostering critical evaluation of information and reflective, informed decision-making (Khishfe, 2025). Sustainable development requires engagement with concrete, contextually experienced problems as well as global interconnections and issues of justice. For ESD, this differentiation of perspectives is central, as sustainable development is situated between local action and global responsibility (United Nations, 2015).

Argumentation allows scientific knowledge to be connected with social and moral considerations (Sadler & Zeidler, 2005). It is understood as a process of developing, structuring, and evaluating claims (Cakinoglu et al., 2019). In the context of SSIs, argumentative engagement is closely linked to scientific reasoning, in which learners integrate scientific, moral, and pragmatic aspects (Sadler, 2004). Aziz and Johari (2023) distinguish three types of reasoning patterns that describe how students' arguments can be categorized: (1) rational, evidence-based reasoning; (2) integrated, multi-perspective reasoning; and (3) intuitive or emotionally influenced reasoning.

Osborne et al. (2016) describe a learning progression for argumentation that represents a staged development, in which learners progressively establish increasingly complex links between claims and evidence. Additionally, argumentation quality can be analysed using Toulmin's (2012) model of informal argumentation. Dawson and Carson (2017) confirm that this model provides a reliable framework for analysing students' argumentation structure.

Research Questions

Despite the broad theoretical grounding of ESD, SSIs, and argumentation, there remains a research gap regarding the argumentative practices of low-achieving students in local and global SSI, as argumentative learning in science education has been extensively investigated with high- and average-achieving students (Dawson & Carson, 2017; Khishfe, 2025; Sadler, 2004).

This PhD project aims to investigate the argumentation patterns and quality of arguments of low-achieving students when engaging with local and global SSI contexts. The following research questions are addressed:

RQ1: How do group discussions of low-achieving students unfold in local SSI versus global SSI?

RQ2: Which argumentation patterns and types emerge in these discussions? RQ3: What is the quality of the arguments articulated?

RQ4: How do argumentation structure, type, and quality change as the complexity of the discussion prompt increases?

Research Design and Methods

To address the research questions, a mixed-methods comparative study is conducted in lower-secondary schools in Germany. The study is embedded in a four-lesson unit that is implemented by trained student workers and video-recorded. The aim of the unit is to capture students' small-group argumentative interactions that are situated within either a local or a global SSI.

At the beginning of the instructional unit, a subject-specific introduction to the topic of water is provided to establish a shared knowledge base for subsequent discussion and argumentation.

For this purpose, so-called mini water labs are developed. These interactive learning environments, in the form of small boxes, are designed to stimulate discussions about SSI. The mini water labs address water as an essential resource and operationalize this topic in both local and global SSI by providing contextualized scenarios that prompt students to develop, justify, and compare their arguments with those of others. The SSI are introduced through discussion prompts that foster scientific reasoning and enable the integration of scientific, ethical, and societal perspectives. Students work in small groups to externalize individual viewpoints and argumentative reasoning, which become observable through peer interaction and discussion and thus accessible for analysis. The discussions are structured in accordance with the design principles proposed by Knobloch (2011) and supported by subject-focused scaffolds that sustain and deepen the argumentative exchange. These scaffolds align with the learning progression by Osborne et al. (2016) and guide the gradual increase in argumentative patterns throughout the instructional unit.

Before and after the instructional unit, control variables are assessed (Fig. 1). Based on these data, students are categorized for subsequent analyses; e.g., students who achieve less than 50% on the prior knowledge test are classified as low-achieving. The sample is expected to comprise approximately N = 150 students from lower secondary schools, with n = 75 students per instructional unit, organized into approximately 25 small groups of three students each.

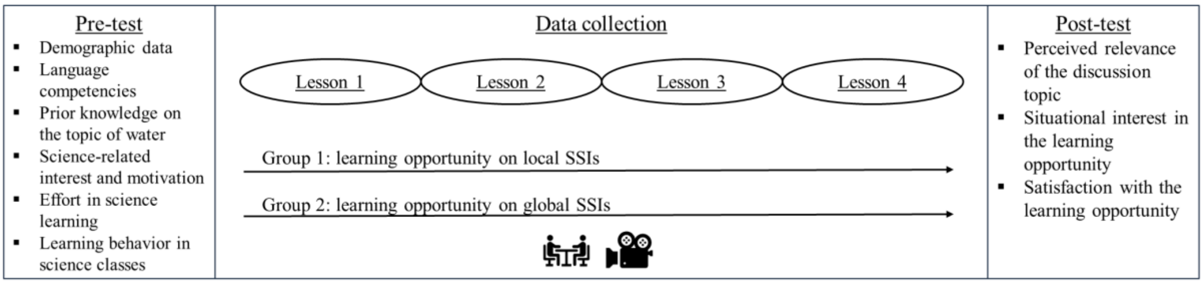

Figure 1: Study design

Data analysis is conducted using qualitative content analysis. Drawing on established category systems, the video-recorded small-group argumentations are coded using an event-based approach to capture students' argumentation structure (Osborne et al., 2016), addressing RQ 1. The types of argumentations are classified according to the categorization of arguments proposed by Aziz and Johari (2023), addressing RQ 2. The quality of students' arguments is subsequently analysed using Toulmin's (2012) model, addressing RQ 3. To address RQ 4, argumentation structure, types, and quality are systematically compared across successive discussion phases to examine how they change as the tasks become more complex.

Preliminary Findings

A synthesis of SSI characterizations from the literature was conducted to identify characteristics that distinguish SSI. The review provides the basis for developing contextualized problem scenarios in the mini water labs that elicit students' argumentation.

The next phase of the project focuses on developing and pilot testing the mini water labs, including the instructional materials and scaffolds. Initial pilot data are expected in summer 2026 and will enable a first analysis of the design of the mini water labs and the development of the instructional materials. Additionally, the pilot data allow for comparison of students' argumentative engagement in local or global SSI across the four RQs.

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Contribution to teaching core practices for model-based inquiry instruction through the lens of teacher identity

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Focus of the Study

In the initial training of Biology and Geology teachers within the Secondary Education Master's programme, we develop a programme based on the Model-Based Inquiry (MBI) approach, in which preservice teachers experience and analyse teaching–learning sequences (TLSs). Given the difficulty of transferring this approach into classroom practice, the programme incorporates the framework of representation, decomposition, and approximation of practice (Grossman et al., 2018), operationalised through Teaching Core Practices (TCP) for the development of MBI sequences (Delgado Mayoral et al., 2025). This practice-based approach, focused on professional practices rather than on changing teachers' thinking, has had an indirect impact on teacher identity, motivating the analysis of the transition from a scientific identity to an identity as science teachers in the study presented at this summer school.

Theoretical Framework

The MBI approach integrates inquiry and modeling as complementary scientific practices (Jiménez-Liso et al., 2021; González-Herrera et al., 2023), widely supported in Science Education for its benefits to students, such as making student thinking visible, promoting participation in authentic scientific practices, and enhancing scientific reasoning (Windschitl et al., 2008). Inquiry focuses on expressing and discussing initial ideas based on phenomena or questions and on evidence-gathering through experimental design and data analysis (Marquez et al., 2025), whereas modeling involves the construction of explanatory and predictive models. Both processes are mediated through argumentation, although they can also be developed independently (Couso et al., 2020).

Research points to teachers' difficulties in implementing this approach and to a limited transfer of training to classroom practice (Windschitl et al., 2018). To support this transfer, teacher training should focus on specific teaching actions, with the framework of TCP, based on Grossman (2019), being ideal. In this context, our group has designed a training programme focused on TCPs for MBI.

The training programme (90 hours) is based on the theoretical framework of TCP and MBI and combines the representation (experience) of TLSs as students with their decomposition (reflection on how they learned and on the TCPs carried out by the science educators) and approximation to practice through progressive implementation with secondary students, analysed using videos of their own teaching (decomposition) and refined in a subsequent implementation. To evaluate its effect, we have constructed a systemic network TCPs to support students' Expression–Discussion of Ideas, along with a rubric to assess and improve teacher training in MBI TLSs (Delgado Mayoral et al., 2025).

During the training process (involving the systemic network and rubric), preservice teachers with a scientific background, when carrying out these TCPs, experience an impact on their professional identity that facilitates the transition toward a teaching identity. This analysis is framed from a sociocultural perspective of identity as a social and dynamic construction based on recognition in specific contexts (Gee, 2000; Avraamidou, 2016), drawing on the professional identity domains proposed by Hanna et al. (2019), which align with dynamic models of teacher identity (Holland et al., 2001; Suárez & McGrath, 2022).

Research Questions

El profesorado de Secundaria con formación científica suele identificarse más con la ciencia que con la docencia y reproducir prácticas tradicionales (Beijaard et al., 2000), mientras que la implementación de enfoques de indagación y modelización resulta especialmente desafiante para el profesorado novel (Danielson & Warwick, 2014). En este contexto de formación inicial, se evalúa el impacto del programa formativo en su identidad profesional a partir de las preguntas de investigación planteadas:

- ¿Cómo evoluciona la identidad profesional de cada docente en formación inicial a lo largo del programa formativo centrado en TCP-MBI?

- ¿Qué tendencias (similitudes-diferencias) se observan en la identidad profesional grupal de los docentes en formación participantes?

- ¿Qué detonantes explican dichas tendencias en la identidad profesional de los participantes (acciones docentes clave, exposición a un nuevo enfoque de enseñanza, experiencia en los centros educativos, compañeros, tutores, etc.)?

Research Design and Methods

The training programme in TCP for the science teaching course of the Secondary Education Master’s is structured as a progressive sequence integrating experience, reflection, and practice. It includes an initial interview about participants’ prior experiences and expectations, a second interview after approximately 20 hours of training focused on the analysis of MBI sequences, and a first implementation during the practicum, which is video-recorded.

Subsequently, participants review the video and conduct a guided analysis of students’ scientific practices and the TCPs that facilitate or hinder them, situating themselves with respect to their own TCPs for the MBI approach. Collective sessions are audio-recorded as a record of progress. The programme concludes with a second implementation, a comparative analysis of both video recordings, and a third individual interview to assess progress and reflect on the training process.

The interviews revealed comments relating to teacher identity, so we used the identity framework as an interpretive lens to analyse how preservice teachers see themselves, act, and feel from the beginning of the training programme, and their transition toward the science teaching profession through the MBI approach.

This study therefore focuses on the analysis of 24 interviews (3 per 8 participants) and, following Braun and Clarke (2022), was conducted using an inductive–deductive thematic analysis. The analysis, carried out with Atlas.ti, began by identifying themes and coding based on the professional identity domains proposed by Hanna et al. (2019), organized into internal and external components, and continued with interpretive codes of both semantic and latent nature. In a second round, the TCPs were incorporated to explore their relationship with identity development, ultimately grouping the codes into themes and constructing a joint narrative of the process.

Preliminary Findings

As an example (Table 1) of this thematic análisis process, a general first interpretation of one of the participants is shown, along with an example quotation from the final interview and the codes assigned.

Table 1. Sample of thematic analysis

<table>
<tr><td colspan="3">Participant: Paulaaut. Final interview</td></tr>
<tr><td colspan="3">General interpretation: We consider that the training programme has contributed to the development of Paula's teacher identity, supported primarily by emotional and relational factors. There is evidence that she has understood the pedagogical purpose of the TCPs for MBI and appropriates them by adapting them to her context and justifying her decisions (professional autonomy). Thus, she does not merely apply them mechanically but understands and reflects on them. She has opened the door to becoming a teacher.</td></tr>
<tr><td>quote</td><td>Identity Domains Codes</td><td>Interpretative Codes</td></tr>
<tr><td>"I think the video allows you not only to observe what you are doing, but in that moment you're moving from desk to desk, so you don't see everything at once. With the video, you can actually see more clearly how each group has been working, even if not everything is perfect. But it does let you observe those details more closely."</td><td>Task perception</td><td>Awareness of the need for active and distributed observation of students' work

Limitations of real-time observation

Video as a tool to broaden the teacher's perspective</td></tr>
</table>

So far, some codes linked to the identity domains have been identified, while their relationship with the TCPs for developing MBI, as well as the definition of the analysis and the graphical representation of the data at both individual and group levels, remain to be completed. This process will allow us to interpret and discuss the trajectory toward the construction of a science teacher identity.

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Shared practices for a shared future: Rituals in climate change education

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Keywords: climate emotions, ritual pedagogy, climate change education, secondary schools, qualitative video ethnography

Focus of the Study

Contemporary societies are shaped by profound ecological, social and existential crises, with climate change constituting one of the most significant threats to long-term human existence (IPCC, 2024). In this context, climate change education is widely regarded as essential for enabling a viable and secure future, as it equips young people with the knowledge, orientations and capacities needed to navigate and respond to climate-related challenges (UNESCO, 2025). At the same time, engaging with the topic of climate change frequently triggers emotions such as worry, fear and uncertainty in young people (Ojala, 2023). Such emotional reactions can be interpreted as appropriate responses to the ongoing ecological crisis (Clayton, 2020). The question of how to address students' "eco-anxiety" (Brophy et al., 2023, 633) within formal education has been examined in science education research and in German-speaking scholarship, under the term Umweltangst (Unterbruner & Otrel-Cass, 2010). An open pedagogical question is how to support students in coping with such feelings, since coping is closely connected to agency (Ojala, 2012). Meaning-focused coping and constructive hope have been identified as important resources for engaging with climate change without denying its seriousness (Ojala & Chen, 2024). Reviews of school-based climate education programmes show that learners' emotional engagement is rarely supported through structured pedagogical spaces (Jackson et al., 2025). Against this backdrop, this dissertation explores how, within the context of climate change education, ritual practices can be employed as pedagogical approaches that support climate-related learning processes by enabling the collective processing, articulation and transformation of emotional experiences associated with the climate crisis.

Review of Literature / Theoretical Background / Theoretical Framework

Drawing on Christoph Wulf's et al. (2001) ritual theory, this dissertation understands rituals as collective, embodied and symbolic practices through which people generate shared meaning, orientation and community. Rituals work through repetition, rhythm and performative action. They stabilize relationships and create continuity, especially in times of uncertainty and crisis. At the same time, rituals are never merely fixed routines. They remain open to variation and reinterpretation, allowing participants to renegotiate identities, responsibilities and ways of living together (Wulf, 2023). From this perspective, the normative aims of Climate Change Education (CCE) become pedagogically effective not primarily through abstract knowledge alone, but through lived shared practice. Rituals are valuable here because they offer a concrete social form in which these values can be rehearsed, experienced and sustained over time (Wulf, 2023), thereby cultivating a classroom community grounded in mutual recognition, shared commitments and care. In ritualised practices, learners do not merely “learn about” emotions, community or responsibility. They practise and embody them in relational situations through attentive listening, mutual recognition, shared commitments and collective care. This is particularly important for climate change education because engaging with the climate crisis can give rise to feelings of eco-anxiety and being overwhelmed among young people (Ojala, 2023).

Research Question

This dissertation investigates how pedagogical rituals in climate change education can be collaboratively developed, implemented and iteratively refined within everyday school practice. Based on this aim, the study is guided by the following research question:

How can pedagogical rituals be used in climate change education, and how do they contribute to climate-related learning?

Research Design and Methods

The dissertation is embedded in the citizen science climate change education project “Stories from the Future” (https://geschichtenausderzukunft.uni-graz.at/de/), in which secondary school students (10–15 years) investigate their own research questions relating to climate change and communicate their insights through different formats of digital stories.

Methodologically, the dissertation is grounded in a relational, situated, and performative understanding of social reality. Drawing on Vygotsky’s (1978) sociocultural theory, hooks’ (2003) care-oriented pedagogy and González et al.’s (2005) concept of funds of knowledge, it understands learning and meaning-making as dialogical, socially mediated and rooted in learners’ everyday and community resources. The study is designed as an ethnographic study (Hammersley & Atkinson, 2019) with participatory elements (Kemmis et al., 2014) and is informed by a design-based research orientation (Brown, 1992; Collins, 1992), which frames the close, sustained partnership with the teacher as a collaborative process of iterative refinement. The ritual-based pedagogical practice was implemented in one urban lower secondary school class with 20 students aged 10–12 over ten months. Through iterative cycles of design, enactment, reflection, and redesign, the study examined how ritual-based learning created time for reflective thinking, while a shared teaching plan functioned as a boundary object that documented adaptations and supported joint meaning-making between teacher and researcher as intersecting communities of practice (Wenger, 1998; Otrel-Cass et al., 2009). In April 2026, semi-structured interviews were conducted with 17 students in order to elicit their perspectives on the ritual practice. Drawing on these interviews together with prior video-ethnographic classroom observations, the teacher and the researcher jointly developed a ritual plan, which the students were subsequently invited to comment on and adapt according to their needs in a participatory workshop. This step was framed as a formative intervention (Engeström, 2011). From May 2026 onwards, the ritual was continued in line with the students’ suggestions and was again accompanied by ethnographic observation. At the end of the school year, the teacher will be interviewed in depth to reconstruct her perspective on the ritual practice, its development and the overall research process over the full course of the study.

Following an interpretative–reconstructive approach (Guba & Lincoln, 1994), the analysis triangulates video and audio recordings, field notes, stimulated recall interviews and ritual artefacts (centrally students' diaries). An ethnographic first pass is followed by a Cultural-

Historical Activity Theory analysis (CHAT; Engeström, 1987, 2001) tracing tensions, contradictions and expansive learning movements within the ritual activity system.

Preliminary Findings

The following preliminary findings summarise work-in-progress insights from an ongoing study. They present observations of the first three months of fieldwork, derived primarily from initial classroom observations. These observations indicate emerging insights into the partnership between the teacher and the researcher and into classroom processes with students, as reflected in teacher–researcher collaboration cycles. Illustrative examples from the ongoing work will be presented at the Summer School.

Preliminary Findings on the Teacher–Researcher Partnership

Reciprocal professional learning: The sustained partnership between teacher and researcher deepens both perspectives on ritual-based learning. The interplay of practice-based in-sights and theory-informed inputs supports iterative refinement of the pedagogical design and emerging conceptualisations.

Enabling conditions for joint work: The collaboration cultivates trust and experienced self-efficacy as relational conditions that stabilise the partnership and sustain ongoing inquiry and development.

Boundary-object supported sense-making: The shared boundary object (planning artefact) functions as a concrete, revisable "thinking space" through which practitioner knowledge and research perspectives become discussable, comparable and coordinatable. Across the research cycles, the artefact is continually adapted and refined to reflect emerging questions, needs and insights from the joint work, thereby making the ongoing development of practice visible and actionable.

Growing professional self-efficacy in climate change education: Over time, the teacher develops more confidence in her ability to plan, implement and iteratively refine climate change education projects.

Preliminary Findings on Ritual-Based Learning

Recognition of diversity and lived experience: The ritual creates a classroom space in which students are encouraged to bring in personal stories from everyday life, their worldviews and their emotions, supporting the recognition of learner diversity as a pedagogical resource.

Emotional articulation and sharing as learnable practice: The ritual supports students in attending to emotions, practising language for them and sharing these experiences with peers, suggesting that emotions become communicable and socially held rather than individualised or hidden.

Diary as mediating artefact: The use of a diary enables students to record, externalise and make visible emotional and reflective processes over time, supporting continuity and traceability of the ritual practice.

Mimetic development of practical knowing: Over time, students appear to establish a shared, embodied repertoire of practical knowledge through mimetic processes with teacher and peers, supporting their ability to speak about emotions, share them and document them as part of classroom practice.

Student expertise and engagement: Students respond with high engagement when invited to speak about the teaching practice from an expert standpoint, indicating that participatory reflection can strengthen ownership, voice and agency in pedagogical development.

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Learning with water: Toddlers' embodied and material encounters as early scientific sense-making

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Keywords: science education / early childhood education / embodied learning / water-body-encounters / post-phenomenology

Focus of the Study

Research on early childhood science education has increasingly emphasised the importance of young children's embodied engagement with materials and environments (e.g. Annerbäck et al., 2024; Hackett et al., 2018; Yu et al., 2024). At the same time, developmental research demonstrates that infants and toddlers possess sophisticated capacities for causal learning, hypothesis testing, and information-seeking well before formal language emerges (Goddu et al., 2025, 2025; Gopnik et al., 2004). Despite these parallel developments, there remains a gap between material–relational approaches to early childhood education and cognitive accounts of early scientific learning.

My doctoral project addresses this gap by examining how scientific learning emerges through toddlers' bodily and sensorial encounters with water in early childhood education. Rather than conceptualising science learning as the acquisition of predefined concepts, I explore how scientific sense-making unfolds through embodied action, material response, and repeated engagement with a dynamic and partially unpredictable element. Water is approached not merely as a context or medium for learning, but as an active material participant that shapes what can be sensed, known, and done.

Drawing on posthumanist feminist phenomenology, or post-phenomenology (Neimanis, 2017a) in dialogue with research on causal learning and intuitive science (Goddu et al., 2025; Gopnik et al., 2004), the study contributes to ongoing discussions about how science learning can be understood beyond language, representation, and human-centred epistemologies.

Review of Literature / Theoretical Background / Theoretical Framework

The thesis is grounded in post-phenomenology, drawing primarily on the work of Astrida Neimanis (2017). Neimanis' figuration of *bodies of water* provides a way of conceptualising embodiment as porous, relational, and materially situated. Bodies are understood as constituted through ongoing intra-actions with human and more-than-human others, rather than as bounded entities acting upon a passive world (Barad, 2007; Neimanis, 2017a).

Rather than treating hydrologics as discrete analytical categories, the thesis uses them as sensitising concepts that allow attention to how water makes itself sensible, communicative, differentiating, and resistant across empirical situations (Neimanis, 2017b, 2017a, 2020). This approach foregrounds water's capacity to both connect and separate bodies, to sustain and unsettle, and to resist complete epistemological capture (Neimanis, 2017).

In dialogue with this perspective, the study draws on research on children's causal learning and intuitive science. From this body of work, scientific learning is understood as emerging through active intervention, exploration, and the revision of expectations in response to evidence (Gopnik et al., 2004; Gopnik, 2012). Young children are seen as constructing revisable causal maps—coherent representations of how actions, materials, and effects are related—through embodied engagement with the world (Bonawitz et al., 2012; Gopnik et al., 2004).

Bringing these perspectives together allows the thesis to conceptualise scientific learning as simultaneously embodied, relational, and causal: a process of learning with materials rather than about them.

Research Questions

The overall aim of the thesis is to explore how scientific learning emerges through toddlers' embodied encounters with water in early childhood education.

The guiding research question is:

How does scientific learning emerge through toddlers' bodily and sensorial encounters with water in early childhood education?

This question is addressed through the following analytical sub-questions:

- How do repetition, variation, and material responsiveness shape toddlers' embodied exploration of water-related phenomena?
- How can toddlers' bodily engagements with water be analytically understood as forms of causal reasoning and early scientific sense-making beyond language?
- How do water–body relations challenge dominant notions of science learning, participation, and knowledge production in early childhood education

Research Design and Methods

The study adopts a post-qualitative, sensory ethnographic approach to explore toddlers' bodily and sensorial encounters with water. Learning is approached as an embodied, material, and relational phenomenon unfolding through interactions between children, water, spaces, and pedagogical arrangements. Methodologically, this involves close attention to sensory intensities, movements, rhythms, sounds, resistances, and repetitions in everyday encounters with water.

Empirical material was generated during a four-month period in two early childhood education settings involving approximately twenty toddlers. Data production included video recordings, still photography, field notes, and collaborative documentation practices such as revisi-ing images and videos together with children.

Drawing on sensorial ethnography (Pink, 2015), the study treats sensory experience not as background context but as a primary site of meaning-making. Attention is directed towards how water communicates through temperature, movement, sound, pressure, and transformation, and how children respond bodily to these material invitations. The researcher's body functions as part of the research apparatus, acting as a sensory witness to unfolding relations.

The study is further informed by post-qualitative methodology (Lather & St. Pierre, 2013), where data, theory, and analysis are not treated as sequential stages. Analysis is conducted as an iterative and diffractive process, where empirical moments are read through sensitising concepts such as embodied causality, repetition with variation, and material responsiveness. Ethical considerations were addressed continuously, with particular attention to children's bodily integrity, situational consent, and the handling of visual material.

Ethical considerations were addressed continuously throughout the research process, with particular attention to children's bodily integrity, consent as ongoing and situational, and the relational responsibilities involved in researching with very young children.

Ethical considerations include ongoing consent, attentiveness to children's comfort and agency, and careful handling of visual material.

Preliminary Findings

Preliminary findings indicate that toddlers' encounters with water are characterised by sustained, embodied engagement in which bodily action, material response, and sensory feedback continuously inform one another. Children return to water across activities and contexts, allowing scientific learning to emerge as a gradual attunement to how water behaves, how bodies can act with it, and how effects unfold through movement, resistance, sound, and transformation (Neimanis, 2017).

Across the material, toddlers repeatedly engage in actions such as stepping, pouring, splashing, drinking, throwing, and touching. These repetitions are never identical. Variations in water's state, surfaces, tools, and bodily configurations shape each encounter, supporting early forms of causal reasoning as children explore how changes in action produce different outcomes. This resonates with research showing that causal learning in early childhood emerges through repeated intervention and observation (Gopnik et al., 2004; Gopnik, 2012).

Water responds to children's actions in sensorially salient ways. Cracking ice produces sharp sounds and vibrations; splashing generates movement and resonance; cold water elicits bodily reactions such as withdrawal, laughter, or stillness. These responses function as non-verbal feedback through which information about material properties circulates, aligning with accounts of causal learning driven by embodied interaction rather than explicit instruction (Gopnik & Bonawitz, 2015).

At the same time, water both connects and differentiates bodies. Children move between wet and dry zones, test the limits of containers, clothing, skin, and ice, and encounter thresholds such as overflow, resistance, and dissolution. Learning emerges through these encounters with limits, foregrounding how embodied orientations to water delimit what can be known and done, and highlighting the situated and partial nature of knowledge production (Neimanis, 2017).

Encounters with water also extend beyond the immediate moment through documentation and revisiting. Photographs, videos, and projections allow water encounters to reappear in altered forms, enabling recognition, re-enactment, and reworking of earlier experiences. Such returns resemble iterative hypothesis-testing processes in which prior encounters inform future action, even when children are not explicitly aware of this epistemic work (Gopnik, 2012).

Finally, moments in which water crosses bodily boundaries—such as drinking water or sucking on ice—foreground intercorporeal relations where water becomes part of the body itself. These encounters contribute to early embodied causal understandings related to need, satisfaction, and bodily capacity, while underscoring the porous, relational nature of embodiment emphasised in posthumanist feminist phenomenology (Neimanis, 2017).

Taken together, the findings suggest that toddlers' encounters with water give rise to early scientific learning that is embodied, relational, and processual. Scientific sense-making emerges through staying with water over time, attending to its variability, and adjusting action in response to material feedback. Rather than being primarily mediated by language, this learning takes shape as embodied causal reasoning—knowledge-in-motion developed through repeated sensorial engagement with a lively and partially unknowable material world (Neimanis, 2017; Gopnik, 2012).

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Co-developing spatial computing in climate change play curriculum with Indonesian and Malaysian children in the UK

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Focus of the Study

This study focuses on co-developing a spatial computing (SC) in climate change play curriculum. Previous studies on climate change education (CCE) show that it has traditionally been positioned within secondary and higher education, yet there is increasing recognition of the importance of developing climate literacy from the primary years (Dolan, 2021). Introducing these ideas earlier allows teachers to support more accurate understandings of climate change while fostering pro-environmental behaviours and beliefs during children's formative stages (Nepras et al., 2023). Promoting climate literacy for children requires an innovative curriculum that merges scientific knowledge with eco-centric technological tools, promoting an interconnected perspective on human, natural, and technical systems (Cutter-Mackenzie & Rousell, 2019).

The selection of Indonesian and Malaysian children living in the UK is vital as they encounter unique challenges in CCE. As the climate change curriculum is often crafted with a generalised, Western-centric perspective that excludes local cultural context (Zhai et al., 2025), it may not fully resonate with the experiences of Indonesian and Malaysian children in the UK. This disconnect could hinder children's engagement and understanding of both global and local climate issues, as they struggle to relate to and act upon them (Ali Khan et al., 2021). To address these gaps, educational interventions should adopt decolonised approaches that align CCE with children's sociocultural realities, nurturing a sense of cultural identity and belonging (Mbah & Ezegwu, 2024). Furthermore, with the focus on a participatory and child-centred approach as a methodological intervention in CCE, this study seeks to position children as active contributors in the co-development process (Zhai et al., 2025) of a climate change play curriculum that meaningfully connects their cultural backgrounds and emerging understandings of climate change.

Review of Literature / Theoretical Background / Theoretical Framework

The theoretical background of this study lies in the interconnectedness between SC, climate change curriculum and play-based learning. SC refers to immersive and interactive technologies that support users' understanding of spatial relationships in real-world contexts (Shekhar & Vold, 2019). In CCE, SC has been used through tools such as mixed reality and location-based technologies to support children's engagement with abstract climate phenomena by making them more visible, interactive and experiential (Jowsey & Aguayo, 2017; Tzortzoglou et al., 2023).

Sheppard (2012) introduced the Causes, Impacts, Mitigation and Adaptation (CIMA) pedagogical tools in teaching climate change to provide a holistic view by addressing all four interconnected components. It highlights how causes lead to impacts and how mitigation and adaptation strategies are essential for effectively addressing them. This aids children in understanding the systemic nature of climate change and the importance of integrated solutions through ‘systems thinking’, which focuses on the relationships among components rather than viewing them in isolation (Sheppard, 2012). As children develop a holistic understanding of climate change, promoting critical thinking, resilience, and actionable solutions to empower them as informed, proactive participants in tackling climate challenges (Teixeira & Crawford, 2022).

A play curriculum is a pedagogical framework that supports children’s holistic cognitive, social, emotional and physical development (Edwards, 2017). van Oers (2015) outlines key elments of a play-based curriculum for upper primary learners: culturally responsive tools, inter-disciplinary learning activities, flexible curriculum design and the use of role-play to support learning progression. These elements highlight the potential of play-based approaches in CCE by supporting children’s agency, hands-on engagement, and problem-solving in ways that are developmentally appropriate and meaningful (Broadhead et al., 2010; Trott, 2022).

SC, holistic climate change ideas, and play-based teaching provide complementary approaches to supporting children’s engagement and understanding of climate change through interactive and participatory learning experiences. This interconnected relationship is conceptualised in this study using a triadic process model (Figure 1), which illustrates how these three elements interact dynamically to guide the co-creation of a climate change play curriculum and the interpretation of children’s developing mental models of climate change.

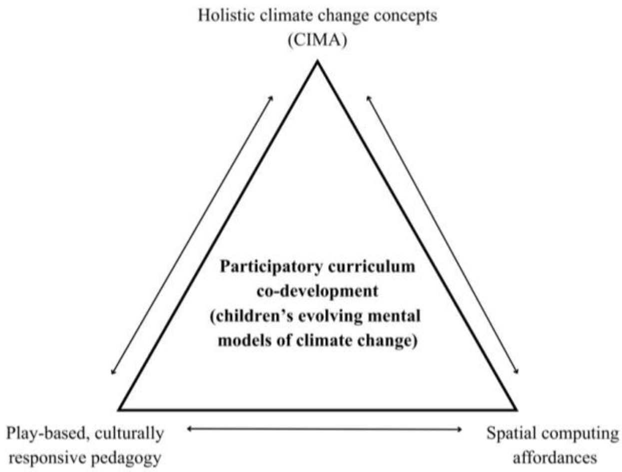

Figure 1. Triadic process model for co-developing SC in climate change play curriculum

Research Questions

Guided by the theoretical framework outlined above, this study addresses the following research questions to examine both the participatory processes involved in curriculum co-development and children’s conceptual understanding of climate change.

1. How to co-develop SC in a climate change play curriculum with Indonesian and Malaysian children in the UK?

2. To what extent do Indonesian and Malaysian children’s mental models of climate change throughout the co-development of SC in the climate change play curriculum?

Research Design and Methods

This study employed a Participatory Action Research (PAR) design, which integrates research (R) and the advancement of knowledge through active engagement (A) with social history and participation ethics (P) (Chevalier & Buckles, 2019). By involving children as co-developers of the curriculum, this research aimed to create a learning environment that values their agency and ensures interventions are meaningful and reflective of their needs and insights (Cox & Robinson-Pant, 2008).

The study was conducted with a small group of Indonesian and Malaysian primary-aged children living in the UK and is set in an informal learning environment. Participatory workshops were the core of the curriculum co-development process and were designed to promote exploration, dialogue and creative expression, while remaining flexible to children's interests and emerging understandings of climate change. Throughout these workshops, children explored climate-related themes through play-based activities, incorporating SC as a mediating resource rather than an instructional focus. The data collection methods used in this study were based on the Mosaic approach (Clark, 2017). By integrating multiple data collection methods in the con-structed Mosaic, triangulation can be achieved, and the children can participate in different activities and choose what they prefer (Stephenson, 2009). The data collection methods include interviews, focus groups, children's drawings, children's reflections, digital artefacts and re-search diary.

The data analysis for this study followed the five steps of reflexive thematic analysis, recognising the active role of the researcher in developing themes (Braun & Clarke, 2021). Drawing on theoretical frameworks, analytical skills, and interpreted findings (Braun & Clarke, 2021), key emerging themes were identified to address the research questions.

Preliminary Findings

At the time of writing, three out of six participatory workshops had been completed, and pre-liminary analysis was carried out iteratively alongside data collection. Preliminary findings from the first three workshops show a shift in children's understanding of climate change, influenced by the utilisation of different types of SC technology. In the first workshop, children demonstrated a basic but coherent understanding of the causes and effects of climate change, often attributing it to human activities such as transportation and energy use. Impacts such as flooding, heatwaves and haze were strongly linked to children's personal experiences in Indonesia and Malaysia. However, while children could link causes to effects, their explanations remained mainly descriptive with little to no scientific reasoning.

The second workshop represented a conceptual shift, as construction- and coding-based LEGO activities encouraged children to think about responding to climate impacts rather than solely preventing them. Climate adaptation became more prominent through action-oriented strategies aimed at protecting human lives. In contrast, mitigation ideas were less explicitly expressed and were often implicitly integrated within technological choices rather than discussed as emissions reduction.

By the third workshop, children showed clearer differences between mitigation and adaptation strategies. Mitigation was usually visualised with cleaner technologies, renewable energy, greening cities, and waste management, while adaptation was associated with survival, protection, and disaster response in specific locations. Children increasingly used future-focused imaginaries, such as solar-powered transport and robot-assisted cities that help maintain engagement with complex climate issues, even when scientific explanations were limited. Overall, the findings indicate that children's ideas and multimodal creative responses were not peripheral but central to how the curriculum evolved across the CCE participatory workshops. In addition, children's climate reasoning increasingly moved beyond individual actions towards collective and place-based solutions. This indicates growing awareness of how climate change is experienced differently across locations and communities, particularly when comparing the UK, Indonesia and Malaysia.

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Collective action as social learning space for school teachers: Case study of Tamil Nadu science forum

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Focus of the Study

Teachers are in large numbers in any educational system. But the focus has largely been on individual teachers while theorising, researching and designing teacher education. Teacher communities and networks have not received the importance of being examined. Many teacher professional development models overlook the existing teacher communities, identities, everyday practices, and meanings created within these communities and networks (Wenger, 1999; Niez, 2007). Teachers are perceived as homogenous categories existing in isolation from a socio-political context, who need to be trained and persuaded rather than empowered (Batra, 2005). The isolated individual teacher working all by herself in a classroom is the dominant trope, not even recognising the school around her as a community. But teachers engage in communities inside and outside of schools. Their professional identity is formed in relation to the networks and communities to which teachers belong. My PhD is a case study of one such network of school teachers, the Tamil Nadu Science Forum (TNSF), which addresses this research gap and widens the scope for understanding teacher learning in collective action.

People Science Movements in India

People Science Movements (PSMs) in India, such as the Kerala Sastra Sahitya Parishad (KSSP) and Tamil Nadu Science Forum (TNSF), popularise science and drive educational change. The majority of the PSM members are school teachers. PSMs viewed the literacy campaign (like the Ernakulam literacy movement) as a ‘second freedom struggle’ for social harmony, utilising unpaid volunteers (Parameswaran, 2016). PSM involvement in literacy campaigns fostered societal action, such as the anti-arrack (women-led anti-alcohol addiction) movement and TNSF’s campaign, which led to the emergence of the women's cycling movement (Dhwani, 2019; Parameswaran, 2016; The Breakthrough Voice, 2020). Despite significant teacher involvement in PSMs across areas such as the environment and education, the literature is scarce on how this impacts their agency, identity, beliefs, and classroom practice. The existing literature lacks an understanding of teacher learning and professional identity formation within long-standing networks, such as KSSP (since 1957), BGVS (since 1989), and TNSF (since 1980). Despite these PSMs including a large number of school teachers, making educational improvement a major goal, their role as teacher networks receives little recognition in policy, professional development, and research.

Tamil Nadu Science Forum (TNSF)

Founded in the mid-1980s by a diverse group including researchers and teachers, TNSF is a voluntary movement focused on science for self-reliance and progress. It conducts popular science lectures, addresses environmental and ethical concerns. TNSF promotes scientific temper through festivals, competitions, and publishing over 300 books and magazines (e.g., Thulir). It also encourages Thulir Illams (science clubs) as informal learning spaces. Since 1992, TNSF has been a key coordinator of the annual Children's Science Congress, training children in research and promoting a social dimension of science, including diversity understanding through a guest-host system. TNSF was a major force in the government's Total Literacy Campaign (Arivoli Iyakkam) in the early 1990s. Its impact ranges from low-cost science teaching materials to educational reform (Venkateswaran, 2009). Inspired by Eklavya and KSSP, TNSF conducts extensive teacher training on joyful, low-cost science experiments and games, producing handbooks. It promoted child-centred pedagogy to reduce school dropouts and organised community dialogues to improve access and quality. TNSF's activities, including stargazing events, are run by self-driven volunteers, with around 18,000 members across the state of Tamil Nadu.

Theoretical Framework

Social learning spaces (SLS)

A social learning space, as defined by Wenger & Wenger-Trayner (2020), is a unique, shared experience where individuals learn collaboratively with the specific goal of creating change. Social Learning Space is different from a Community of Practice (Lave & Wenger, 1991) as it is not necessarily focused on a specific practice. The meaning and identity within SLS are based on the concept of caring to make a difference, rather than the practice-based identity associated with CoP. The human experience of agency is central to learning how to make a difference in SLS. (Wenger & Wenger-Trayner, 2020)

Value creation cycles, as proposed by Wenger & Wenger-Trayner (2020), are organised into eight cycles. This helps to understand how a social learning space contributes to the ability to make a difference. 'Value' here means what is valuable to the participants of the SLS, and in this study, school teachers in TNSF. It places the emphasis on the experience of teachers who care to make a difference, rather than on knowledge and skills. Value creation imbues the negotiation of meaning with a sense of direction. It is driven by the will to make a difference and directed toward the ability to make that difference.

The meaning of value is not just negotiated but also produced through social learning. Perspective of value creation aligns with key concepts in social learning theory, demonstrating that learning to make a difference requires practice, as social learning's value is realised through action. Furthermore, negotiating what constitutes value is a central element. Ultimately, the creation and recognition of value facilitate the experience of becoming, which in turn shapes one's identity. Value creation does not happen in any particular order. It helps to understand how the learning is happening in the space. For the purpose of this study, the descriptions have been modified for school teachers in TNSF, as given below,

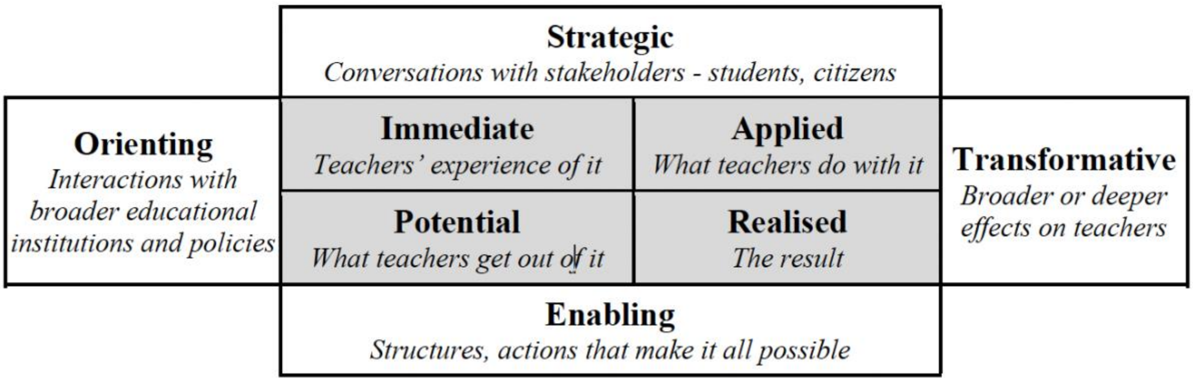

Figure 1: Value creation cycles for school teachers in TNSF (Wenger & Wenger-Trayner, 2020)

Research Questions

1. How are the teachers participating in the network, and what are they gaining from it?
   a. Why do teachers become members?
   b. Does it facilitate social learning, professional agency, and identity formation? If so, how?
   c. How is the nature of learning distinct?
   d. Has it affected their practice? If so, how?
2. What is the network doing to teachers?
   a. What are the structures that exist in the network? How hierarchical is it?
   b. What is the nature of membership and how is it growing? How does the network sustain their interest?
   c. What kinds of actions are getting created in the network?
3. What is the larger landscape in which the network exists? How does the network interact with it?

Research Design and Methods

The study employs a qualitative research methodology. The case study method is employed to gain an in-depth understanding of the purpose and nature of the network, its role in enabling a social learning space, and its impact on teachers (Lodico, Spaulding, & Voegtle, 2010; Cohen et al., 2007). The Tamil Nadu Science Forum has been selected as the case for the study due to its active status for over 40 years, its geographical spread across the state, and the researcher's native language, which facilitates capturing nuances during data collection.

In-depth, semi-structured interviews will be conducted, focusing on the life histories of participants in relation to their involvement with TNSF. Archival documents and reports of the organisation will be analysed to trace the historical context and involvement of teachers in the broader socio-political context. Events at the state and district level will be observed. Social Network Analysis survey will be conducted in one focus district to understand how teachers are networked. Documents, event observations and SNA will help triangulate the interview data collected from teachers and other members in TNSF.

Preliminary Findings

Semi-structured interviews were conducted with 36 TNSF members, 23 of whom are school teachers. Twelve biannual reports consolidating TNSF's activities, reflections and strategies are collected. 76 responses collected for a Social Network Analysis (SNA) survey at one district to understand what and from whom school teachers are learning.

Preliminary findings emerging from the grounded theory coding of interview data reveal TNSF's transformative impact on its members, especially school teachers. The most significant theme centers on the changes experienced by members, detailing personal and professional growth, including substantial changes in their teaching methods, professional trajectories, and the quality of their relationships and networking. Other key areas of focus include the perceived role of teachers. The data also illuminates the internal mechanics of the network, covering the organization structure and processes, including use of technology, the motivations for joining, different forms of participation/engagement (particularly women participation), its collaborations (including with the government), and considerations for the future of TNSF.

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Science education and cosmopolitical proposals: Problematising the entropic limits of sustainability in a climate crisis scenario

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Keywords: Physics, Secondary Education, Sustainability, Entropy, Cosmopolitics

Focus of the Study

We consider that, with the advent of the industrial revolution and the hegemonisation of the capitalist system, connections between the use of natural resources, production systems and economic development gain relevance at both scientific and economic levels. On the one hand, economic development is based on the need for large-scale production and consumption to obtain profit, making use of the development of scientific and technological knowledge. On the other hand, the costs and environmental impacts of this development model have become evident in the contemporary climate crisis scenario. The capitalist model responds to such problems by proposing concepts such as sustainable development, sustainability, degrowth, ecocapitalism, etc., all of them topics of concern in the Science Education (SE) agenda (Avraamidou & Schwartz, 2021).

In particular, the topic of sustainability poses great challenges to educators, because, although it has a necessary character and global appeal, it is crossed by contextual, social, economic, environmental and political aspects, making its conceptualisation and experience local. In addition, to account for its socioscientific character, it demands interdisciplinary approaches. Most SE proposals on sustainability have focused on the importance of Science for educating critical and participatory citizens, who are capable of not only understanding but also devising solutions for global challenges (Bourscheid & Farias, 2014; Laherto et al., 2023), through a diversity of approaches. These include exploring controversies over sustainability, problematising entropic limits for growth and consumption, and engaging in cosmopolitical dialogues with knowledge systems that, unlike Western Modern Science, do not operate under a human-nature split (Lima & Martins, 2025).

This study aims at understanding the processes of hybridisation of discourses about sustainability, with a focus on problematising the ways through which different conceptions of sustain-ability are shaped not only by economic and productive processes, but also by scientific, cultural, and social dimensions.

Theoretical Framework

We have adopted critical discourse analysis (CDA) as our main theoretical-methodological framework (Chouliaraki & Fairclough, 1999). This involves identifying a social problem and its semiotic representation in analyses that integrate conjunctural and textual aspects. The social problem concerns the hegemonic character of conceptions of sustainability, which not only disregards considerations about entropic limits, but also overlooks different worldviews, their specific epistemologies and ontologies, and their consequences for the formulation of alternative models of production and consumption. Semiotic representations of this social problem can be found in educational documents, materials and discursive practices, such as curricula, textbooks, classroom interactions etc. in a variety of formats. CDA starts with a conjunctural analysis of historical, philosophical, social, cultural, discursive and political aspects related to the social problem and is followed by textual analysis, which seeks to outline forms through which social problems are formulated, reified and transformed in discourse. An articulation of both analytical levels seeks to point at difficulties and possibilities to overcome obstacles in solving the problem.

In our case, one exemplary conjunctural aspect concerns, on the one hand, the influence of international development policies – such as the 2030 Agenda and its Sustainable Development Goals (SDGs) –, on SE curriculum development and, on the other hand, the marginalisation of sociopolitical, entropic and cultural aspects of the topic. According to Vries and Mattos (2024), education has become a key political and economic arena shaped by global liberal agendas, with curricula functioning as contested spaces influenced by supranational agencies and competence-based reforms. In turn, topics like Entropy and Thermodynamics are usually included in curricula in a formal decontextualised way (Souza & Leite), reinforcing positivist philosophical traditions.

An example of a particular type of semiotic representation is secondary school Physics textbooks. They are considered to be shaped by curricula and to perform a political and cultural role by mediating and legitimising specific values and conceptions of science, history, and knowledge production (Vilanova, 2011). Considered as cultural artefacts, they comprise hybrid and semiotic texts shaped by multiple discursive formations, materialising scientific discourse in schools and mediating interactions between authors, readers, and (disciplinary) knowledge (Martins, 2006).

Research Questions

What are the challenges and possibilities of teaching and learning about controversial topics, such as sustainability, through an interdisciplinary perspective that considers the cultural, ontological, and epistemological diversity of different propositions?

What is the role of the cosmopolitical proposition in SE, specifically in addressing the relationship between the physical limits of resource exploitation (and its relationship to the concept of entropy) and sustainability?

How are the concepts of entropy and sustainability addressed in both basic education science curricula and physics textbooks? And

How can the discussion on sustainability help students understand the concept of entropy and vice versa?

Research Design and Methods

Ours is a multipaper doctoral thesis, which focuses on the writing of four papers, with CDA serving as the central theoretical and methodological framework (Chouliaraki & Fairclough, 1999). While examining how meanings of sustainability are produced, naturalised, or legitimised, we contend that CDA can reveal the ideological mechanisms through which certain conceptions become hegemonic or marginalised, whether in curricula, textbooks, or classroom practices.

The first paper fosters to establish theoretical connections between sustainability, entropy, and climate change, drawing on discussions from three domains: (i) scientific, emphasising the historical development of thermodynamics and the concept of entropy; (ii) political, reflecting on notions of modernity/coloniality and development policies, including the SDGs; and (iii) educational, considering the principles of education for citizenship articulated in various curricular documents, alongside the influence of international policies.

The second paper analyses the Brazilian Common Core Curriculum (BNCC) and the pre-university education specific guidelines for both VWO (*Conceptexamenprogramma natuurkunde vwo*) and HAVO (*Conceptexamenprogramma natuurkunde havo*), considering three different levels: (i) macro, considering that environmental sustainability exposes social inequalities by associating social justice with consumption, while the debate lacks scientific rigour and remains conceptually imprecise regarding sustainability, sustainable development, and degrowth; (ii) meso, examining curricular changes as historical, political, and epistemological processes from the 1920s to the present; and (iii) micro, considering how these discussions are represented in physics curricula.

The third paper aims at identifying how countries with differing socio-political and economic contexts, such as Brazil and the Netherlands, incorporate concepts of sustainability and entropy into their textbooks. The corpus for the textual analyses therefore concerns excerpts from (i) Brazilian and Dutch Physics curricula which describe skills to be developed through the study of sustainability, in particular those connecting thermodynamics and entropy to environmental issues; and (ii) Brazilian and Dutch school Physics textbooks. These were selected for an analysis of intertextual and interdiscursive aspects, through the identification of (i) epistemic, de-ontic and appreciative modality markers and (ii) genres and sub-genres, which allude to discursive contexts.

The fourth and final paper intends to argue that the cosmopolitical proposition, when articulated with SE, offers a promising approach to fostering dialogue between diverse conceptions of contemporary curricular demands, including discussions on the entropic limits of the universe and climate change.

At this stage, the writing of the first and second papers is already underway. Analyses on Brazilian and Dutch textbooks for the third article are reported in the next section. Following a systematic literature review already carried out, the fourth article is scheduled to be drafted by the end of this year.

Preliminary Findings

First results relate to an initial examination of Brazilian and Dutch textbooks. In the Brazilian case, we identified nine textbooks that were made available for teachers' selection in 2025 and that will be used in schools during the 2026-2029 four-year cycle. With regard to the Dutch context, one book was selected based upon experienced schoolteachers' and SE researchers' advice.

Following CDA, we have explored conjunctural aspects of the construction of educational discourses on sustainability through an examination of curriculum principles and guidelines in both countries. In the Netherlands, upper secondary curricular documents for the HAVO and VWO tracks guide the teaching of Natural Sciences and Physics with an emphasis on sustainability, energy systems, climate change, and the impacts of human actions on the planet. However, there is no explicit reference to thermodynamics, its laws, or the concept of entropy. Preliminary analyses reveal that, although thermodynamics is not addressed as a theoretical field, it is possible to identify content related to thermal physics, such as gas properties, heat transfer, latent heat, and devices such as heat pumps. These topics are presented in a fragmented manner and contextualised through everyday or technological applications, without the integration of a coherent conceptual framework. Sustainability appears in an instrumental way, linked to topics such as energy efficiency, sustainable architecture, and national policies, but without explicitly articulating physical phenomena with their socio-environmental impacts or problematising conflicts, physical limits, or non-scientific forms of knowledge. References to Indigenous knowledge do not lead to discussions of how different epistemologies could be articulated.

In most Brazilian textbooks, entropy is treated as central, with dedicated sections. The predominant approach is qualitative, with frequent use of metaphors such as "disorder" and examples drawn from everyday life. Despite the recurrence of the topic, connections between entropy (or thermodynamics more broadly) and sustainability do not stress the degradation of ecosystems. Although some textbooks claim alignment with the BNCC or with the SDGs, most do not critically explore socio-environmental or interdisciplinary dimensions of the concept of entropy. Future steps in the research include expanding the sample of Dutch textbooks; developing a more systematic understanding of their editorial projects; identifying the pedagogical assumptions that underpin these materials; analysing textual features such as representations of social actors, intertextuality, and genres of different sections and subsections; examining the nature and cognitive demands of the questions proposed; reinforcing the links between textbooks and Brazilian and Dutch curricular guidelines; and exploring Brazilian and Dutch teachers' perceptions of and engagement with these textbooks.

Participation in the ESERA Summer School will contribute to strengthening my academic writing, particularly in English, and to refining the ways in which I communicate my research within international academic contexts. It will also be essential for the development of second and third papers, particularly in refining comparative analysis, systematising data, and strengthening the theoretical discussion regarding how historical legacies of modernity/coloniality have influenced – and continue to influence – the selection and presentation of scientific knowledge, especially concerning sustainability, within the school context. Engagement with mentors and fellow doctoral researchers will facilitate the integration of diverse socio-cultural perspectives, support the argumentation of my thesis, and foster international research collaborations.

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Education in the age of manufactured uncertainty: Science students as agents of transformation

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Keywords: Uncertainty, Agency, Secondary Education, Interdisciplinarity

Focus of the Study

This study investigates how science education can foster the development of students' agency in contexts characterised by complexity and manufactured uncertainties. It is grounded in the understanding that many contemporary problems associated with science and technology require action in scenarios in which hazards are not immediately perceptible, effects are distributed across time and space, and the available knowledge is incomplete or contested. Within the so-called Risk Society, decisions must be made before threats become visible or fully measurable (Beck, 1986), giving rise to what Giddens (2010) describes as a paradox of action, in which inaction tends to prevail precisely because risks are not directly experienced in everyday life. In such contexts, decision-making principles based exclusively on prediction and control prove insufficient, opening space for approaches that recognise the need to act even in the face of irreducible uncertainties, taking into account probabilities, consequences and contested values (Beck, 2009). This scenario highlights the need for a form of scientific literacy oriented towards social transformation in a world marked by volatility, uncertainty, complexity and ambiguity (Valladares, 2021).

Although there is a well-established body of literature on risk in science education (Christensen, 2009; Levinson et al., 2012; Hansen & Hammann, 2017; Schenk et al., 2019; Schenk et al., 2021; Pietrocola et al., 2021), studies that place the dimension of agency at the centre of analysis remain scarce. This perspective goes beyond sensemaking and decision-making understood in a narrow or episodic manner, seeking instead to understand the action of social actors within a broader temporal framework, in which these dimensions constitute only some elements of social practice (Emirbayer & Mische, 1998; Mische, 2009). In response to this gap, the present study proposes to investigate teaching and learning situations that explicitly incorporate risk and uncertainty as constitutive elements of scientific knowledge and social action, exploring the complexity of the problems addressed and their interdisciplinary dimensions.

The research is conducted within the context of formal science education in Brazilian public schools and uses a socioscientific issue, climate change, as a case study. This choice allows for the exploration of a complex problem in which the articulation between individual and collective scales, local and global dynamics, as well as the relationship between present action, past experiences and possible futures, plays a central role. The focus of the study is to understand how students mobilise scientific knowledge in these contexts and how agency emerges and transforms throughout these processes.

Review of Literature / Theoretical Background / Theoretical Framework

The theoretical framework of the study brings together contributions from the sociology of risk, the epistemology of science and social theories of agency, with particular emphasis on the educational implications of uncertainty and complexity.

Beck (1986, 2009) argues that contemporary societies are marked by the production of risks and uncertainties associated with scientific and technological development itself. Unlike calculable risks, manufactured uncertainties are characterised by latent side effects, distributed across time and space, and often irreversible. In such contexts, social action cannot rely exclusively on reliable predictions, but instead requires ongoing processes of evaluation, negotiation and decision-making. Giddens (1991) complements this analysis by emphasising that contemporary risks challenge the traditional relationship between knowledge and action. The so-called Giddens paradox suggests that the less tangible dangers are in the present, the lower the propensity to act tends to be, even though postponing action amplifies future consequences (Giddens, 2010). This condition places agency at the centre of socio-technical decisions, requiring the articulation of scientific knowledge, practical judgement and collective responsibility.

The concept of agency is mobilised primarily through the temporal-relational approach proposed by Emirbayer and Mische (1998). From this perspective, agency is understood as a process constructed over time, involving the interplay between habits and repertoires from the past, the imagination of possible futures and the practical evaluation of present conditions. This conception provides a robust analytical basis for investigating how students act in educational situations that require decision-making under uncertainty, particularly when such decisions involve collective consequences and long-term projections.

Research Questions

How can science teaching strategies foster agency in students when faced with complexity and manufactured uncertainty?

Research Design and Methods

The study adopts a qualitative, intervention-oriented approach, structured as a case study. The research involves the development and implementation of a teaching module in upper secondary education, designed to create complex situations for action in contexts of uncertainty. Data generation includes video recordings of classroom interactions, written artefacts produced by students, and the researcher's field notes. Following the implementation of the module, focus groups are conducted with selected students in order to deepen the understanding of decision-making processes, perceptions of uncertainty and the experience of acting in response to complex problems.

Several interventions have already been carried out with the aim of testing and refining the adopted methodology. The teaching module was organised around activities based on gaming strategies (Bell, 2009) and the construction of storylines (Bell & Harkness, 2007; Shepherd, 2019), enabling students to simulate future scenarios, evaluate possible consequences and propose actions involving different social actors and analytical scales. The activities emphasised the relationship between individual action and collective implications, as well as the articulation between local contexts and global dynamics.

The preliminary analysis of the data collected to date followed an interpretative qualitative approach, focusing on understanding the forms of action mobilised by students when engaging with the problem under investigation. This analytical process enabled the identification of emerging categories related to agency, the mobilisation of scientific knowledge and the evaluation of uncertainties, which guide the further development of the analysis in the main stage of the research.

Preliminary Findings

Preliminary evidence from pilot studies indicates that students demonstrate the ability to distinguish between relatively stabilised problems and complex problems, recognising the limitations of scientific knowledge when it is mobilised in contexts characterised by uncertainty, multiple variables and consequences distributed across time and space. The proposed activities facilitated the explicit articulation of tensions between different forms of action, particularly between individual solutions, technological interventions and collective or institutional strategies, especially when decisions involved medium- and long-term effects.

It is observed that students tend to integrate scientific explanations with practical judgements and normative considerations, indicating that action cannot be reduced to the direct application of scientific knowledge. In these processes, agency manifests itself in a clearly temporal manner, as students draw on past experiences and repertoires, project possible future scenarios and evaluate, in the present, constraints, risks and possibilities for action. The initial findings also suggest that making alternative futures explicit contributes to shifting the discussion from immediate responses towards broader reflections on responsibility, collective consequences and irreversibility.

These findings have informed adjustments to the design of the teaching module, particularly with regard to making the uncertainties involved more explicit and expanding opportunities for students to negotiate decisions across different analytical scales. In addition, the preliminary results have contributed to the refinement of analytical categories related to agency, the mobilisation of scientific knowledge and the evaluation of uncertainties, which will be further developed in the main stage of the research.

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The science classroom in beta: How artificial intelligence, policy and sociotechnical imaginaries affect science teachers' practices

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Focus of the Study

My PhD project examines the interplay between educational policies regarding artificial intelligence (AI), sociotechnical imaginaries, and the practical implementations of AI technologies, with a focus on how this intersection affects teaching practices of science teachers. The studies are situated in a secondary school (students aged 13-16) context in Sweden.

Literature Review

AI is often given attributes of a transformative and disruptive force that will alter the future in various ways. In an educational context, possibilities linked to augmentation, automation and personalisation are presented as solutions to longstanding educational problems , (Akhmadieva et al., 2023; Almasri, 2024; Gezer & Durdu, 2025; Luckin et al., 2022; Luckin et al., 2016; Roll & Wylie, 2016; VanLehn, 2011). Sociotechnical imaginaries, as described by Jasanoff & Kim (2015), are often presented as truth in global policy arenas and in media depictions of AI in education (AIED), with technology entrepreneurs highlighting the possibilities of AI tutors to "solve" educational issues (Nawfal, 2025). However, recent advancements in AIED can be seen through the historical introduction of computers into the school system (c.f. Cuban, 1986; Selwyn, 2022; Watters, 2021). Several previously integrated technologies throughout history have been predicted to alter educational practices. For instance, Larry Cuban describes the historical advancements by providing examples from the introduction of the radio, TV and cinema and how they were predicted to render teachers obsolete (Cuban, 1986). The automation of teaching has to some extent been sought after since the 1950s, when Skinner and Pressey developed early examples of a "teaching machine" (Watters, 2021). However, the technologies do not live up to the promises they have been surrounded by and often lead to ultimate disappointment.

As such, these technologies are introduced with great "hype", integrated in the educational landscape with "hope" that it will change education as we know it. Unfortunately, the hype is seldom met, and the technological implementations lead to "disappointment". This is a cycle described by Cuban (1986) and more recently highlighted by Selwyn (2022). Often, teachers' reluctance towards implementation is made central in the explanations as to why these implementations are not successful. However, contrary to this view, research has shown that more sceptical teachers play an important role of a more regulatory nature when introducing technology in educational settings (Guerrero Cantarell, 2023). Yet, AI is currently in the hype stage, which leads to rapid development and integration into schools across the globe.

Specifically, generative AI have posed new dilemmas for educators as it is used by both students and teachers. With generative AI, not only is automation an issue, but the integrity of assessment is challenged when teachers have to make sure the students are the authors, and not AI (Arıcı, 2024; Atasoy & Kaya, 2022; Farazouli, 2024).

Although the technological advancements in school could at first glance be considered a general phenomenon, not all school subjects are affected in the same ways. It is therefore imperative that more subject-specific research is conducted to better understand the subject context and how it is affected by the introduction of AI. In STEM, recent studies have explored virtual and augmented reality (VR and AR) (Johnson-Glenberg, 2018; Parong & Mayer, 2018; Thomson et al., 2024), self-regulated learning (SRL) using genAI (Ng et al., 2024) as well as dialogic approaches with chatbots (Tang & Putra, 2025). However, much of the focus on AI in STEM and other subjects lies on learner outcomes and perspectives. My thesis, therefore, takes on a teacher-centred approach, where science teachers are given possibilities to define what AI could be in their teaching practice, and provide agency for teachers to express their thoughts and opinions.

Research Questions

The aim, as stated in the draft of my thesis, is to explore how different visions, policies, practices and technologies collectively (re)shape both the future and present of teachers' work, with particular emphasis on science teachers.

RQ1: How do policy guidelines on AI for education shape the implications of AI in an educational context?

RQ2: How do (science) teachers (7-9) envision the future of teaching in relation to emerging AI technologies?

RQ3: How do science teachers respond to the increasing presence of AI in education, and what changes manifest in their planning, teaching and assessment practices?

Research Design and Methods

As this PhD project is to result in a compilation thesis exploring several aspects of AI in (science) education, multiple methods are utilised. See table 1 below for details about data, methodological undertakings and intended analytical approaches.

Aim of study	Research question	Material, partici-pants, and design	Type and vol-ume	Analytical tool	Paper
To aid the understanding of why and how visions of learning and education are framed in relation to development in AI and the introduction of tech-nology in education.	RQ1	Policy guideline documents	11 international policy guideline documents	"Heuristic lens"(Rahm & Rahm-Skågeby, 2023), prob-lematizations.	I
To offer insights into possible trajectories of teachers' work in the age of AI.	RQ2	Co-design workshops	Field notes and audio recording (ca 6 hours in to-tal)	Iterative pro-cess with post qualitative analysis	II
To explore the sociotech-nical imaginaries ex-pressed by secondary-school teachers in Swe-den	RQ3	Semi-struc-tured inter-views	Audio recordings of 15 interviews with secondary-school STEM teachers	Thematic anal-ysis	III
Yet do be decided	RQ3	Classroom observations with three teachers	Yet to be decided	Yet to be de-cided	IV

Table 1. Summary of research design, data production and analytical approach for the studies in this thesis.

Preliminary Findings

In my research, I want to provide agency for science teachers to word the "problems" we are trying to solve by incorporating AI into teaching practices. Therefore, the work encompasses empirical research with science teachers in Sweden at the core. Having explored the global policy landscape (Linderoth et al., 2024), where AI is painted as a disruptive force to which teachers and students have to adapt, the research moves to more narrow studies in co-design (Linderoth et al., 2025) to interview studies with teachers (currently analysing data) and lastly to classroom observations (in planning).

As the first two papers in this compilation thesis are published, the results are available. The first paper indicated that there were three major sociotechnical imaginaries visible in the AI policy guidelines analysed. These imaginaries are cantered around the inevitability of artificial intelligence and that it will reshape education. Another, more negatively coded imaginary is that of an emerging surveillance society, where management becomes ever relevant.

In the second published paper, the research group invited in-service teachers to speculate on the future of AI in teaching, which resulted in a paper based on informed speculations. The results of the paper indicated that teachers did not wish to offload assessment on AI as it was seen as a core aspect of being a teacher. However, a possibility mentioned by the teachers in the study was help in offloading lesson planning and generating teaching material. The first two papers thus indicate that there are strong positions for and/or against the use of AI in both policy and by in-service teachers. Often, these positions are rather black and white, utopian and dystopian.

As the upcoming two papers are not yet finished, there are only tentative results from paper 3. These tentative results suggest that while the participating science teachers all describe AI as an inevitable force that will undoubtedly change education as we know it, few of them integrate genAI (or any other type of AI) into their classroom practice. When used, AI is primarily a tool for generating lesson plans or teaching materials, a teacher-centred use primarily. As such, the inevitability of AI is yet to be seen, when the teachers describe themselves as mostly traditional and book based. Thus, the question that still presses this continued thesis work is whether or not (science) teachers are given a voice in the debate of how and when to use AI in education.

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Prompted AI-tutors to support experimental problem solving

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Focus of the Study

High school students view Artificial Intelligence (AI) positively, recognizing its potential to simplify life and improve fields like medicine, transportation, and education (Rysina & Leven, 2024). Although AI is already frequently used in schools, the use of AI by students, particularly in science experiments, is not well known. Among various applications, AI chatbots are of particular interest.

Therefore, a first study in my thesis focused on examining whether AI tutors can be as effective a support option for experimental problem-solving as traditional incremental scaffolds. It also investigated whether AI tutors can take on the role of other learners in tutoring (Neumann et al., 2025).

In a second study with high school students I will investigate to what extent repeated use and prompting training can improve the outcome of AI support and attitudes towards it.

Review of Literature

Individual and collaborative work

Classroom settings typically favour cooperative and collaborative learning arrangements, which have been shown to yield better outcomes than individual learning. Ding and Harskamp (2011) found no immediate difference between peer tutoring and collaboration, though peer tutoring showed long-term benefits. Similarly, Harskamp and Ding (2006) found that collaborative 11th-graders, whether or not aided by hint cards, outperformed individuals working alone, although hint cards helped pairs solve more problems within the same time frame. Students expressed a preference for choosing their own partners.

Incremental scaffolds

Incremental scaffolds were proposed by Leisen (1999) as a method of inner differentiation. Learners can access various hint cards as needed, which can help them with problem representation, focus, and activation of prior knowledge, etc. (Schmidt-Weigand et al., 2008). Schmidt-Borcherding et al. (2013) were able to show that they contribute to greater motivation and com-parable learning outcomes compared to guided experimentation.

Use of AI chatbots in Science Education

The use of chatbots by learners in science education has hardly been studied to date. Krupp et al. (2024b) examined the solution of physics problems using Google Search and ChatGPT as support. They found that learners who used ChatGPT mostly demonstrated an unreflective approach and that copy and paste was their primary strategy. In another study, Krupp et al. (2024a) showed that the use of prompted AI chatbots, that we call AI tutors in the following, leads to more reflective interaction than with the basic version of ChatGPT. Lieb and Goel (2024) also found that prompted AI tutors provide a better user experience than the basic version of ChatGPT. Kregear et al. (2025) explored AI's potential in laboratory work, finding it useful for support and feedback in physics labs, though they recognize current limitations.

Research Questions

The first study addressed the following research questions:

RQ1.1: Does the use of AI tutors lead to better experimental problem solving and better learning outcomes than the use of incremental scaffolds? (Factor Support)

RQ1.2: Do learners achieve better problem-solving and learning outcomes in collaborative pairs than in individual work? (Factor Social Form)

RQ1.3: Does the interaction of social form and support options influence problem-solving and learning outcomes?

Research Design and Methods

To answer the research questions, a 2x2 design with the factors "support" and "social form" was used in study 1. The learners completed a pre-test, then carried out a problem-solving experiment, for which they received support from AI tutors (AI) or incremental scaffolds and worked alone or in collaborative pairs and finally completed a post-test. The study was conducted in the spring of 2025 with N=203 learners from 12th grade in Lower Saxony.

Problem solving task

In the first study, we used a black box experiment on combining polarization filters, which is used in grades 12 and 13 and is intended to deepen Malus's law (Figure 1 & 2). Students worked on two different black boxes, one after the other (first an easier one, then a more difficult one). The worksheets were assessed and co-coded by a second rater in 25% of cases ($\kappa! = 0.73$). The introduction and processing of the black boxes took 60 minutes.

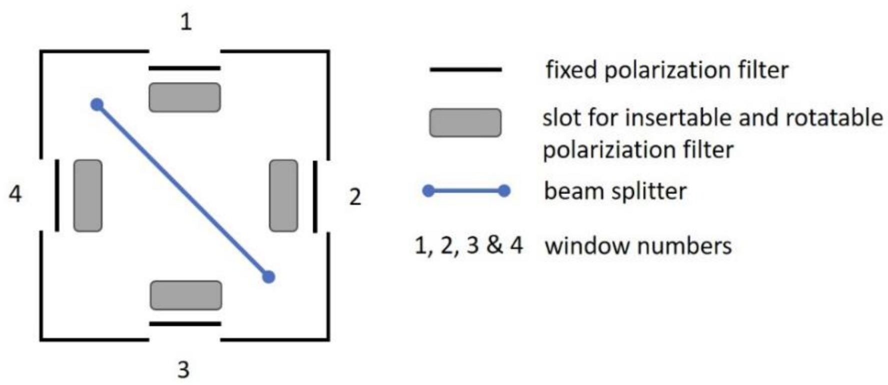

Figure 1: schematic sketch of the black box

Prompted AI tutors and incremental scaffolds

The fobizz platform[1] allows one to create AI tutors and prompt them according to their role (Figure 2). Various language models (GPT 4.0 was used here) can be selected. The learners received a QR code that allowed them to access the AI tutor. The incremental scaffolds are based on the established design by Schmidt-Weigand et al. (2008).

Pre-test

Eight items from Matejak Cvenic et al. (2022) on polarization and light propagation were used. A reliability of $\alpha = 0.54$ was achieved.

Post-tests

In the posttest, four items based on Roskot (2021) for combining polarization filters and three items related to solving the black boxes of the lesson, based on those used by Rode (2016) and Wille (2020) were used. One open-ended item was double-coded by a second rater in 25% of cases ($\kappa! = 0.88$). After excluding two items, a reliability of $\alpha = 0.68$ was achieved.

Preliminary Findings

An Analysis of Covariance (ANCOVA) using prior knowledge as a covariate for the first and second black box (BB1 and BB2) and for the post-test was conducted. For the first black box, we found a significant interaction between social form and support ($F(1,196) = 6.404$, $p = 0.012$, $\Omega" = 0.03$). Adjusted means in the pairwise comparison using Tukey's method for multiple comparisons showed that only AI support in collaborative pairs led to significantly better results than in collaborative pairs with incremental scaffolds ($dif = 0.966$, $p = 0.018$).

For the second black box, a significant correlation for the main effect of support type ($F(1,171) = 7.165$, $p = 0.008$, $\Omega" = 0.03$, $dif = 0.731$) was found as well as for the interaction of social form and support type ($F(1,171) = 12.70$, $p < 0.001$, $\Omega" = 0.06$). The adjusted means in the pairwise comparison using Tukey's method for multiple comparisons subsequently showed significant differences between AI support in collaborative pairs compared to incre-mental scaffolds in collaborative pairs ($dif = 1.699$, $p < 0.001$), incremental scaffolds in in-dividual work ($dif = 1.132$, $p = 0.029$), and AI support in individual work ($dif = 1.369$, $p = 0.002$).

For the post-test, only the influence of prior knowledge was significant ($F(1,198) = 4.143$, $p = 0.043$, $\Omega" = 0.02$)

Therefore, question 1.1 can be answered with "yes" for the second black box and question 1.3 with "yes" for both black boxes.

Discussion and outlook on the second study

The first study demonstrated that learners with support from AI tutors performed better in the experimental problem than those with incremental scaffold support. No differences in conceptual knowledge could be detected in the post-test. However, it also revealed that they

[1] https://fobizz.com/en/

interact with AI tutors as they would with human conversation partners and do not prompt them effectively.

Therefore, in the second study, problem-solving experiments are conducted in upper secondary school at three points in time over the course of a school year. Black box experiments will be used again. One focussing on the charging and discharging of capacitors, a second one focussing on ac-driven RLC circuits and a third one focussing on diffraction gratings.

The sample is divided into a group that receives no further intervention and a group that receives prompting training. Before each lesson, the relevant prior knowledge is measured. After each lesson, the learners must name the solution steps of the experiment from memory in the post-test. In addition, pre- and post-tests measure attitudes toward AI and engagement during the lesson.

This study aims to investigate the question: How do (a) repeated AI use and (b) prompting training affect success in experimental problem-solving? Additionally, how do these factors impact (1) the quality of learners' prompting, (2) their attitudes towards AI, and (3) their engagement in physics classes?

The specific test instruments to be used are still under discussion. In particular, the measurement of attitudes towards AI, knowledge about AI, and the evaluation of prompting are still pending.

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Supporting successful learning pathways in first year physics students through formative assessment

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Keywords: Physics, Tertiary Education, Formative Assessment, Introductory Phase, University, Dropout

Focus of the Study

Similar to universities all over the world, German universities face the challenge of dropout, particularly in physics degree programs. In mathematics and natural sciences, dropout rates are specifically high (e.g., 2020: 50%; Heublein, Hutzsch & Schmelzer, 2022) and dropout occurs particularly early (Heublein et al., 2017). My work addresses this challenge and includes both, a design and an evaluation component. The design aim is to develop a formative e-assessment integrated in a first-semester physics lecture on mechanics and thermodynamics, which is mandatory for physics majors, physics minors, and physics teacher training students. The e-assessment consists of (1) short weekly tests, addressing the mathematics and physics content of the lecture and (2) individual feedback, highlighting gaps in content knowledge and suggesting materials that students can use to help them review the relevant content. The evaluation aim of my work is to investigate this formative assessment, in order to explore how students accommodate with physics learning in the university setting and to probe effective ways of supporting students during their first-year physics courses.

Theoretical Background

Societies of our highly technological world have a need for sufficient STEM workforce and STEM teachers, to promote interest in young learners for those subjects. But there is a teacher shortage in STEM, not only in Germany, but globally (Symeonidis, Guberman, & Cooper, 2025). This need turns into a serious challenge, given that dropout is highest in university STEM courses. In Germany, 42% of dropouts quit their math or science studies within the first two semesters (Heublein et al., 2017). Prior work envisions student dropout and retention as a multicriterial phenomenon, including not only cognitive aspects, but also personal attributes (Tinto, 1975). The cognitive aspects seem to be particularly critical, yet: 45% of dropout students in math or science courses named performance problems as the decisive reason for dropping out (Heublein et al., 2017). Besides difficulties with the content to be learned, students entering universities may also face challenges due to a different learning style compared to school: Less frequent assessments, more self-organized course participation, and more preparatory and follow-up work, require students to employ appropriate learning strategies, effective time management, and self-regulated learning (Schiefele, Streblow, Ermgassen & Moschner, 2003).

To smoothen students' transition from school to university, university physics programs often offer bridge or preparatory courses to promote students' recapitulating relevant prior knowledge. However, students don't necessarily use the courses suitable for them or for whom they are intended (Bosse, Mergner, Wallis, Jänsch & Kunow, 2019). Another approach to promote students' learning is formatives assessment, that is, monitoring students' learning progress and providing some kind of feedback such as change in the learning activities or additional support based on the results in the assessment (Morris, Perry & Wardle, 2021). Formative assessment (e.g., through shirt quizzes) has, in fact, the potential to support students' learning in higher education (Morris et al., 2021).

Given (a) the need for workforce in STEM fields (such as physics), (b) high dropout rates especially in the first year of physics degree programs, and (c) formative assessment as a promising approach to effectively supporting students' learning, my dissertation project focuses on designing and evaluating a formative assessment for first year physics students. The formative assessment is designed as an electronic (e-)assessment spanning the whole semester. This design allows for individualization and students receiving tailored advice in a timely manner. Given that dropout is tied to performance problems, and given that the learning in university settings differs from that in school settings, the formative assessment will address not only assessment and feedback on physics content, but also on learning strategies.

Research Questions

The overarching aim of my project is to gain insights in freshmen's accommodating with physics learning in university settings and about effective ways of supporting them in their first year. At ESERA Summer School, I will particularly address the following two research questions:

RQ 1: *Which characteristics are most important to first- semester physics students to participate in a formative assessment? How do students' preferences change within the first weeks of the degree program?*

RQ 2: *How does students' (self-reported) learning behavior change? Which role does the formative assessment play in this change?*

Typically, students' schedules in the physics degree program are rather busy, and students show a focus on passing the exams. So, we expect that time flexibility and a focus on exam preparation are key characteristics of a formative assessment (RQ1).

The formative assessment is designed to provide students with weekly insights in their current content knowledge, highlighting potential gaps of knowledge and suggesting supportive materials as well as learning strategies. We thus expect that students not only experience the difference in learning in school vs. university, but also that the formative assessment leads them into a way of more self-regulated learning (RQ2).

Research Design and Methods

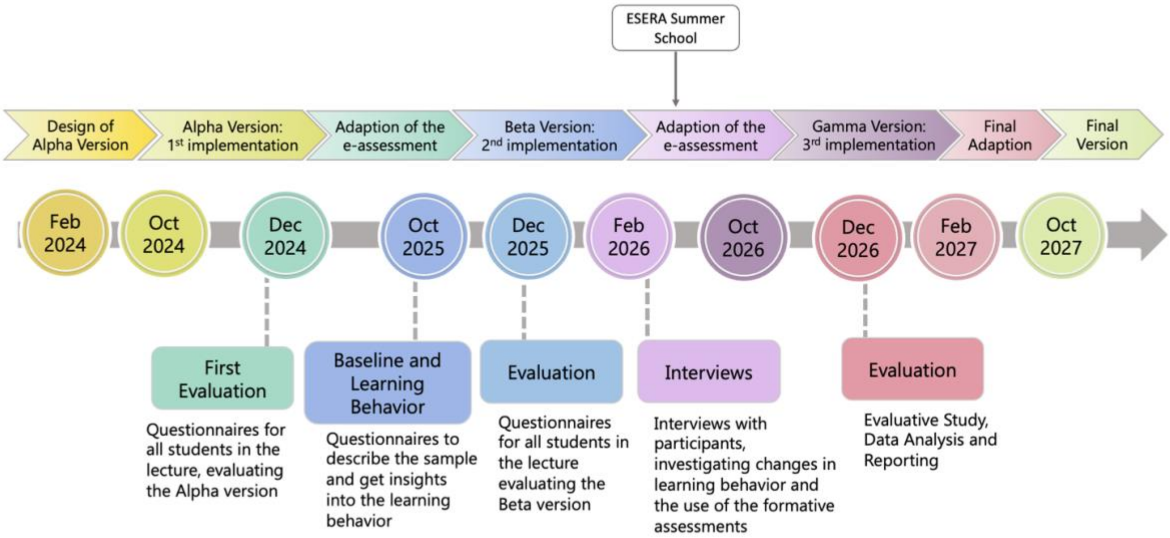

Fig. 1: Timeline of the dissertation project.

Figure 1 shows the main components of the ongoing design (upper part) and evaluation process (bottom part). With the first, Alpha version of the formative assessment, I aimed to identify appropriate physics and mathematics tasks. The Alpha version was implemented with a first cohort in October 2024. Based on findings from the first evaluation in December 2024 and technical improvements the formative assessment was adapted and then started as a Beta version in October 2025 for a new cohort of first semester students. Findings from the currently ongoing evaluation will be included in the Gamma version to be implemented in October 2026 with the third cohort, which will be used as the sample for the main evaluation study.

To investigate RQ 1, I conducted a questionnaire study. All students participating in the lecture of the first semester were asked to fill out a questionnaire about the offered formative assessment. The questionnaire differentiated between students who used the formative assessment and those who did not (yet). This allowed for exploring both, reasons that lead students to participate or to not participate in the formative assessment. The questionnaire asked for design features such as time flexibility, personal interaction or the goal of exam preparation to indicate features that make the formative assessment attractive to the students. The questionnaire was employed in both cohorts. Results from cohort 1 led to refinements in the formative assessment. Results from cohort 2 will be used to analyze, a) if and how students' preferences are stable across cohorts, and b) if the adjustments met students' needs and preferences.

To investigate RQ 2, I employed a questionnaire addressing students' learning behavior at the beginning (October) and in the middle (December 2025) of the first semester. Additionally, I will conduct an interview study with 10 students that used the formative assessment (by the end of the semester, February 2026). The interviews will be guided by three questions on students' learning behavior and learning strategies:

- How did your learning behavior change throughout the semester? What are the reasons for this change? Which role did the formative assessment play for (changing) your learning behavior? Include aspects how your learning behavior at university is similar or different to your learning behaviour in a science course at school.

- Describe your learning behavior preparing for the exam of the first physics course. When did you start preparing and which materials did you use? Include aspects how your preparation for an exam at the university differs from the one in a science course in school.

- Which other aspects of your learning or working behavior changed in your first semester of the physics degree program and why?

The interviews will be analyzed through quantitative content analysis. The content analysis will include categories addressing a) students' learning behavior and potential changes, and b) design aspects of the formative assessment and which of them were regarded helpful by the students and why.

Preliminary Findings

Data from the alpha version evaluation (December 2024) revealed first insights on RQ 1. Students liked the time flexibility of the formative assessment. They also preferred longer time periods to do the weekly assessments including weekends (in the Alpha version weekly assessments were only live for 3 days and not on weekends). This made us change the time slots for the weekly assessments. For the data to be collected in the second cohort, it will be interesting to see whether the students indeed regard the larger time flexibility as central characteristic.

Results from the learning behavior measurement at the beginning of the semester (October 2025) show that students in the first week tend to have at least partly difficulties in structuring their learning activities or to cope with the content to be learned. The following investigations will give insights into how this tendency changes throughout the semester and how the formative assessment may help students adapting to the new learning environment.

By the time of ESERA Summer School, data collection in cohort 2 will be finished and I expect to present first insights on the above research questions, as well as the main ideas underlying my dissertation project as a whole. Participating in the summer school will be valuable to me A) to receive feedback on my data analysis and first results from cohorts 1 and 2, B) to discuss the design process of the formative assessment guiding adaptions of the Gamma version for the future cohort 3, and C) to have a discourse about the rationale of my dissertation project as a whole.

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Effects of mode and extrinsic incentives on test-taking-motivation in low-stakes chemistry tests

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Focus of the Study

Technology-based-assessment (TBA) has been shown to influence students' performance outcomes in chemistry tests. On the one hand, this may arise because the mode itself is a critical factor affecting the validity of performance measurements (Chen et al., 2023). Evidence from the 2018 PISA study indicates that shifting from paper-based-assessment (PBA) to TBA negatively affected student performance in Germany, an effect not observed in international comparisons, highlighting the need to examine how assessment mode influences students' performance (Köller et al., 2019). On the other hand, test-taking-motivation is a key determinant of performance, particularly in low-stakes assessments, which have minimal consequences for students' grades or educational trajectories. In such contexts, students face few or no extrinsic incentives, making their willingness to engage seriously with the task crucial (Fischer, 2019). Test-taking-motivation can vary widely and often declines over the course of a test due to fatigue, with this decline differing across school types. Research suggests that increasing test-taking-motivation could improve a country's ranking in international performance assessments such as PISA by up to 15 positions (Akyol et al., 2021). Although this represents an exaggerated scenario, it underscores the importance of identifying targeted ways to enhance test-taking-motivation. This issue is particularly relevant in chemistry education, where tasks are often perceived as challenging, and the difficulty may be further amplified in TBA. In low-stakes contexts, insufficient motivation can therefore lead to systematic underestimation of student performance. Extrinsic incentives can be introduced to increase students' test-taking-motivation (Jalava et al., 2015). Low-stakes assessments nevertheless remain invaluable tools for monitoring education systems, as they provide information for evidence-based instructional and educational decision-making (Eklöf, 2010).

Theoretical Framework

Technology-Based-Assessment (TBA)

The digital format of TBA enables tests to include more interactive item formats (Jerrim et al., 2018), that range from drag-and-drop tasks, where students match texts or graphics, to simulation tasks requiring interaction with different parameters. These can be a tremendous opportunity in chemistry to improve construct validity, as these items are better suited for testing fundamental chemical concepts and assessing skills than multiple-choice or free-text formats in PBA (Chen et al., 2023). There are also some disadvantages regarding the difficulty of TBA items. It can be assumed that the perceived difficulty of items is also widely influenced by assessment mode (Jerrim et al., 2018). Chemistry items are already very demanding for students because of the complex chemical content (Fischer, 2019). In particular, digital chemistry tasks, such as molecule drawing exercises, may increase cognitive demands (Schüßler et al., 2023).

Cognitive-Load-Theory (CLT)

CLT is an instructional design framework that explains how the human brain processes and retains information. Performance is effective only when working memory demands stay within its limited capacity (Kalyuga & Plass, 2025). Three different types are defined: intrinsic, extraneous and germane load. Intrinsic load is arising from the difficulty of the material. If it deals with complex chemical constructs, the intrinsic load of the task is high. Extraneous load how-ever is posed by the design of the task and the medium. In TBA, extraneous load is caused by digital task processing, i.e. navigating, clicking or moving elements. When students are not used to carry out tests in digital format, the extraneous load can be challenging, while optimized item formats may decrease extraneous load (Wagner et al., 2022).

Test-Taking-Motivation

Students' academic performance is closely linked to their motivation and personal commitment (Jalava et al., 2015). Test-taking-motivation is a situation-specific form of performance motivation and is defined as the willingness to engage with test items and to invest effort and per-severance in completing them (Fischer, 2019). Test-taking-motivation is a key factor of the validity of test results, particularly in low-stakes assessments. Drawing on expectancy-value-theory, motivation is understood as a function of students’ expectations of success, the subjective value attributed to the task, and the perceived costs associated with engaging in it (Flake et al., 2015).

Expectancy-Value-Theory

Expectancy-value-theory explains students’ motivation through three dimensions. Expectancy refers to their belief in their ability to succeed at a task. Value captures how important, useful, or interesting students perceive the task to be. Cost reflects the effort and stress caused by completing the task that may reduce their willingness to engage, even when expectancy and value are high (Flake et al., 2015).

Extrinsic Incentives

Extrinsic incentives are external influences that affect behaviour and performance, where motivation does not originate from the activity itself. Within expectancy-value-theory extrinsic incentives can be understood as factors that reduce the value of a task and therefore decrease the perceived costs of engaging with it, thereby enhancing test-taking motivation (Jalava et al., 2015). Targeted motivational instruction and performance-based incentives represent two promising incentive strategies. Emphasizing the importance of the assessment through a motivational instruction, is expected to increase students’ test-taking motivation. It is more likely to have an effect on female students (Baumert & Demmrich, 2001). Performance-based incentives however are more likely to motivate male students because of their competitive nature (Cole et al., 2018). As part of this incentive, the best classes in the experimental group receive financial rewards.

Research Questions

Despite evidence that both assessment mode and test-taking-motivation can influence student performance, their combined effects remain unclear, particularly in low-stakes-assessments. The present study aims to investigate how assessment mode and extrinsic incentives affect students' test-taking-motivation in low-stakes chemistry tests, taking CLT and expectancy-value-theory into account. Following research questions are proposed:

1. To what extent does the mode of assessment influence the task difficulty in low-stakes chemistry tests?

2. To what extent does the mode of assessment influence the motivation and the costs invested in terms of the expectancy-value-theory in low-stakes chemistry tests?

3. To what extent do external incentives influence the test-taking-motivation in low-stakes chemistry tests?

4. What correlations can be identified between test-taking-motivation, invested costs in terms of expectancy-value-theory, cognitive load and test performance in low-stakes chemistry tests, and how do these differ between assessment modes?

Research Design and Methods

An experimental comparative study with a 2x2 design and a control group will be conducted. A sample of N = 500 secondary school students (9th grade) is planned, who will complete tasks from the Institute for Educational Quality Improvement (IQB) educational trends during a 45-minute period. Assignment is randomised by class, so that participants work either in PBA or TBA. In addition, the groups are assigned to one of two extrinsic incentives: motivational instruction or performance-based incentives. There are going to be five different groups combining the different parameters and the control group, as shown in Table 1. The control group is conducted by the IQB during their pilot study of the test material and therefore only in TBA.

	Paper-Based Assessment (PBA)	Technology-Based Assessment (TBA)
Performance-based incentive	**PL:** PBA with performance-based incentive	**TL:** TBA with performance-based incentive
Motivational instruction	**PM:** PBA with motivational instruction	**TM:** TBA with motivational instruction
Control group		**TK:** TBA without extrinsic incentive

Figure 1: Research design.

The students will undergo a series of questionnaires, including: Control variables (gender, type of school, interest in science subjects, language spoken at home) and the following dependent variables: test-taking-motivation (adapted from Rheinberg et al., 2019), perceived item difficulty, expectancy-value-scale, CLT (adapted from Kriegelstein et al., 2023), usability of the assessment environment (adapted from the System-Usability-Score). The control items and test-taking-motivation will be answered before working on the IQB tasks. Immediately after the completion the students will answer the remaining questionnaires and must also complete the questionnaire on test-taking-motivation a second time. There will be a pilot study to test various possibilities of motivational instruction as well as different questionnaires used for the main study.

Preliminary Findings

The first phase of the project focused on reviewing the current state of research. Which led to the development of a model depicting three factors influencing the measured student performance and item difficulty. The factors are: assessment mode, test-taking-motivation and individual skills. These variables are in turn influenced by different parameters shown in Figure 1. This model forms the foundation of the main study.

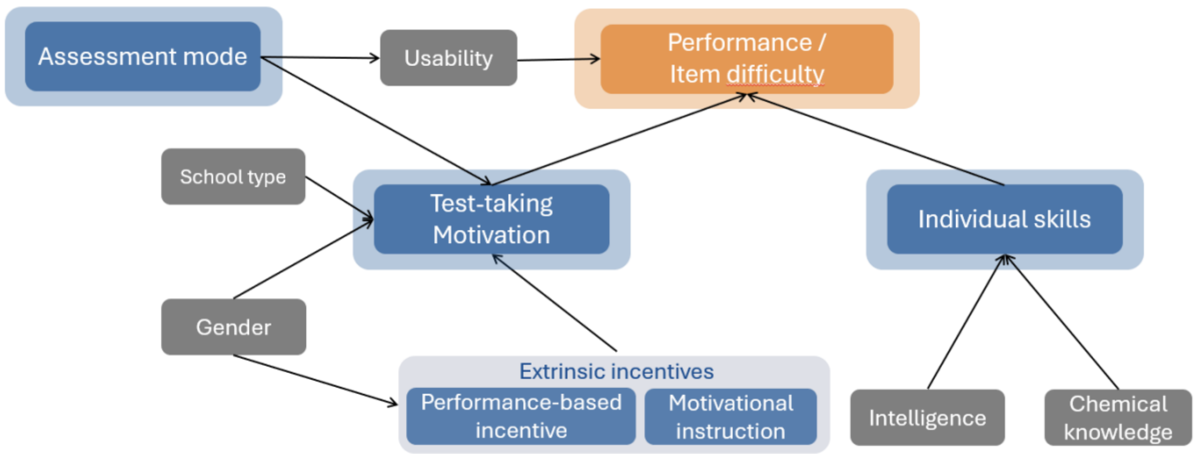

Figure 2: Research model.

The next phase of the project will focus on the pilot study which aim is to identify the most effective form of motivational instruction. Various instructional formats will be examined, differing in both timing (e.g., before testing or after each test item) and type of motivational message. The opportunity to exchange ideas with colleagues and peers during the ESERA Summer School is expected to be an important factor in interpreting these results and in the decision-making process regarding the main study.

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Reconceptualizing science identity through a poststructural feminist lens: Girls' identity negotiations in informal science learning

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Focus of the Study

In modern societies characterized by rapid scientific and technological progress, scientific knowledge is increasingly vital for addressing complex global issues, including health, environmental sustainability, and climate change (Osborne & Pimentel, 2023). While scientific and technological innovation promises a future of equality and inclusion (Yakubu & Nurudeen, 2024), the underrepresentation and marginalization of certain groups, particularly women and girls, persist (Evagorou et al., 2024). Keller (1989) emphasizes that understanding and addressing gender inequalities in science necessitates a critical examination of the deeply ingrained cultural and social structures that shape the relationship between gender and science.

Science is approached not as a neutral or value-free body of knowledge, but as a sociopolitical and institutional practice shaped by power relations, dominant discourses, and normative assumptions about who counts as a legitimate "science person" (Harding, 1991; Hussenius, 2014). These discourses influence how young learners come to perceive science and their potential place within it. More specifically, stereotypes associated with gender, race, and who belongs in science affect how girls are recognized in science (Archer et al., 2015; Dawson et al., 2020), making it more difficult to see themselves as science people (Roberts & Hughes, 2022).

Science identity provides a useful lens for examining these processes, as it foregrounds the relationship between participation, recognition, and belonging in science (Carlone & Johnson, 2007; Avraamidou, 2020). However, dominant science identity frameworks often emphasize relatively stable identity trajectories and forms of external recognition (Carlone & Johnson, 2007) that are closely aligned with the prevailing culture of science. Moreover, these frameworks tend to under-theorize the role of power embedded in scientific discourse and leave limited space for alternative performances of science that encompass creativity, imagination (Shanahan & Nieswand, 2009), teamwork, and human relationships (Hill et al., 2024).

As Kayumova and Sengupta (2022) argue, achieving equity and justice in science education cannot be accomplished by forcing youth to "fit" into existing structures that were never designed for them. Instead, they advocate frameworks that begin with youth's insurgent identities, emphasizing their ontoepistemological perspectives as crucial for transforming science rather than merely fitting within it.

Following this shift, this work moves away from questioning how to produce science identities and instead asks: What forms of science identity work are already being done by girls who live on the margins of science? How can we recognize and legitimize these alternative identities and practices? Focusing on girls aged 9–12, a critical period for the development of science-related self-concepts (Archer et al., 2017; Tai et al., 2006), this study examines how science identities are negotiated within informal science learning contexts. Guided by poststructural feminist theory, the study aims to critically explore how girls engage with, resist, and re-author meanings of science, contributing to more inclusive and justice-oriented conceptualizations of science identity in science education research.

Review of Literature / Theoretical Background

Feminist critiques of science emphasize that the discipline has been historically shaped by masculine, Western, and elitist norms, resulting in exclusionary cultures that marginalize women and other underrepresented groups (Haraway, 1988; Hussenius, 2014). These critiques do not merely address women's underrepresentation in the field but seek to fundamentally change science itself by challenging the unexamined assumptions embedded in its conceptual foundations (Mathai, 2024). By questioning who frames scientific discourses and practices and examining their positionality, feminist scholars highlight the importance of inclusivity in scientific knowledge production (Harding, 1991).

In this study, poststructural feminism is employed to examine how gendered discourses operate within science education. Central to this framework is a poststructural understanding of discourse and power, drawing on Foucault's conception of power as relational and productive rather than possessed (Foucault, 1978). Discourses are understood as historically and socially constituted systems of meaning that shape what can be said, done, and imagined within specific contexts (Baxter, 2003).

Avraamidou (2020) has emphasized the role of the politics of science in determining who is recognized and how that recognition is internalized, particularly for individuals (such as girls and women) who face marginalization in both society and science. In this manner, understanding science identity necessitates more than simply tracing patterns of individual interest, achievement, or recognition. It requires a critical examination of who grants recognition, the values and assumptions that underpin it, and the sociocultural context in which it occurs, including the distribution of power within that context.

Research Questions

RQ1: How do girls aged 9–12 develop, negotiate, and reshape their science identities during their participation in a long-term informal STEM program?

RQ2: Which discourses of science, gender, and scientific participation are revealed through the girls' interactions, conversations, and practices during the program? How do these discourses influence the identity positions available to them?

RQ3: How do the pedagogical design, narrative structure, and collaborative activities of the informal STEM program influence girls' engagement with science, including their feelings of recognition, belonging, agency, and participation?

Research Design and Methods

The research questions align with a qualitative approach, aiming to explore human actions and their underlying motivations (Denzin & Lincoln, 2005). A qualitative case study is a research design that aims to generate context-dependent knowledge, which Flyvbjerg (2006) argues is the only form of knowledge that should exist in the study of human action. Researchers employing case studies should pinpoint both the common and unique aspects of the case. This involves a detailed examination of the case's characteristics, historical context, physical setting, and pertinent institutional and political elements (Stake, 1998). This approach is aligned with the study's goals.

A pilot study was conducted to better understand the social context of the informal learning setting and the research process, and to refine the research design (Glesne & Peshkin, 1992). During an intensive one-week science summer school, data were collected through focus group discussions with six girls, 12-14 years old. The focus group discussions were conducted at the beginning of the summer school program to capture participants' initial perceptions of science.

The primary data collection will occur over six months as part of an informal learning program designed to engage girls in collaborative, narrative-driven science activities. The program uses a mystery-solving format to offer a continuous and meaningful context for participants to interact, negotiate roles, and practice science over time. Data will be generated through multiple qualitative sources to support a rich, context-sensitive analysis. These include: (1) field notes derived from participant observation during the mystery activities, focusing on interactional dynamics, positioning, and participation; (2) audio recordings of children's conversations during activities, capturing naturally occurring talk and discursive practices; (3) semi-structured student interviews, offering opportunities for reflection and sense-making; (4) photovoice sub-missions produced by participants as visual representations of their experiences and meanings related to science; and (5) student-created artifacts generated throughout the program.

Preliminary Findings

Thematic analysis of focus group discussions from the pilot study, following Braun and Clarke's (2006) reflexive approach, suggests that participants challenged traditional narratives framing science as an elitist domain reserved for individuals with innate intelligence.

Science has frequently been described as requiring significant dedication, focus, and time. While this framing positioned science as attainable through commitment rather than innate ability, it intersected with gendered expectations around care and family responsibilities. References to time constraints and work–life balance highlighted participants' awareness of structural barriers that may limit women's participation in science, revealing how societal norms shape girls' perceptions of scientific careers.

Participants demonstrated a clear understanding of gender as a system of power, recognizing pervasive stereotypes and systemic inequalities, such as unequal pay and differential treatment of women in science. Many girls explicitly rejected these norms, expressing critical awareness and resistance to gendered assumptions about capability and belonging.

Girls' future aspirations reflected both agency and constraint. While several participants expressed confidence in their potential to become scientists, drawing on traits such as curiosity and enjoyment of learning, others articulated self-doubt linked to personality characteristics and internalized pressures. Notably, participants' interest in hands-on, creative, and collaborative activities suggested alternative pathways for engaging with science that challenge narrow, performance-oriented definitions of scientific competence.

Together, these preliminary findings indicate that girls' science identity development is shaped by a dynamic interplay of resistance, negotiation, and constraint. They underscore the importance of reconceptualizing science identity to account for power, discourse, and diverse forms of participation, particularly in informal learning contexts.

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Mediating environments in teacher-facilitator discourse on lab instruction: An ecological analysis of pedagogical judgment

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Focus of the Study

The traditional introductory physics lab is characterized by highly prescribed practices, even in comparison to other scientific disciplines (Tiberghien et al., 2001). Professional Development (PD) efforts to change the prescribed nature of lab instruction are challenged by teachers' theory-driven orientations toward lab instruction (Levy et al., 2025), reflecting the central role of deductive reasoning in physics instruction. To successfully carry out confirmation labs that verify pre-established theoretical models within limited instructional time, and despite the inherent uncertainty of experimental phenomena, labs must be structured in a prescribed manner (Wieman, 2015). This instructional approach conflicts with calls from prominent educational associations to promote student agency in experimental research practices (National Research Council, 2013). A recent review of educational research on the instructional physics lab points to the need to better understand what shapes and sustains teachers' orientations (Holmes & Smith, 2023).

Integrating the pedagogical judgment (Horn & Garner, 2022) and the ecological (Ehrenfeld, 2022) frameworks offers a dual lens for examining how orientations are shaped within teachers' *learning ecology*. The pedagogical judgment framework conceptualizes teachers' learning as an interplay between their *pedagogical actions, reasoning* and *responsibility*. In ecological terms, *responsibility* refers to commitments that are formed through interactions with the multiple environments in which the teacher operates (e.g., classroom, school, PD programs). Instructional practice reflects a dynamic balance between an array of orientations and commitments within teachers' *learning ecology*.

This study aims to characterize mechanisms of change in teachers' pedagogical judgment related to lab instruction. It implements the dual lens to analyze teacher-facilitator discourse within a PD program designed to promote reform in the instructional labs. The study seeks to inform the design of PD programs that are responsive to teachers' prior professional experiences within the complex ecological contexts in which they make instructional decisions.

Theoretical Background

A range of research-based instructional strategies has been developed to reform the traditional instructional physics lab, emphasizing students' agency in experimental research practices such as designing valid experimental setups to construct empirical models and examine theoretical ones, drawing conclusions while accounting for measurement uncertainties, etc. (Holmes & Smith, 2023).

However, adopting instructional strategies that challenge deep-rooted orientations is typically a lengthy, nonlinear, and sometimes regressive process (Clarke & Hollingsworth, 2002), as teachers' interpretations of new learning goals tend to align with their existing orientations

(Schoenfeld, 2011). Pedagogical judgment develops through professional discourse about classroom problems, especially when tensions arise between competing views, prompting teachers to articulate and negotiate their reasoning and responsibility (Horn & Garner, 2022). Structured cycles of reflection on practice in Professional Learning Communities (PLCs) have been shown to enable participants to acknowledge pedagogical tensions between goals and orientations dictating their practice (Yerushalmi & Eylon, 2013). Still, the enactment of reformed instructional practices, even in the case of teachers who endorse reformed goals, has been found to be partial or distorted, reflecting the persistent nature of orientations (Levy et al., 2025).

Shifting analytic attention towards the learning ecologies that shape orientations reflected in teacher-facilitator discourse, can inform PD facilitators to better attend to the environments teachers bring into the discourse - on one hand disrupting existing pedagogical judgments, while on the other - preserving teachers' sense of belonging within their learning ecology. The range within which teachers are willing and able to reconsider their pedagogical judgment can be seen as an *ecological Zone of Proximal Development* (ZPD). While Vygotsky's (1978) notion of ZPD focuses on the gap between an individual's independent developmental level and the potential level achievable with expert guidance, the ecological ZPD focuses on the gap between pedagogical judgment sustained within an existing learning ecology and the pedagogical judgment achieved through facilitated discourse. It is suggested that facilitation should involve mediating environments that challenge existing pedagogical judgment without losing the teacher's sense of belonging to their learning ecology.

Research Questions

This study aims to examine teachers' PD as a development of pedagogical judgment (Horn & Garner, 2022) and to characterize the mechanisms that hinder or promote it. To that end, we focus on what underlies the decisions and considerations teachers make before and during lab instruction, as reflected in a PD discourse, by addressing the following question: **Which environments are reflected in facilitator-teacher discourse, and how do they shape teachers' pedagogical judgment?**

Research Design and Methods

Research Context

The study was conducted during the 2025 school year within a 30-hour PLC focused on supporting high school physics teachers when implementing experimental research practices in their instructional labs. The participants (N=18) represented diverse school profiles and teaching experience.

The PLC sessions focused on Deliberation Labs (DLs) - adapted versions of familiar lab manuals, redesigned by one of the two facilitators to grant students more agency in experimental research practices, while considering common constraints such as time and equipment (Levy et al., 2021). The second facilitator is the author of this synopsis. In the PLC sessions teachers experienced the DLs as learners, implemented them in their classrooms, and later discussed in the PLC sessions the insights and dilemmas from their classroom experience.

Data Collection and Analysis

The 2025 PLC sessions were audio-recorded, participants' artifacts were collected, phone conversations and WhatsApp messages between the facilitator and participants were documented.

Data analysis includes identifying discourse episodes in which tensions between competing perspectives were articulated. Selected episodes are transcribed and analyzed using a combined top-down and bottom-up approach. Overarching categories are derived from the pedagogical judgment framework (Horn & Garner, 2022) integrated with the ecological perspective (Ehrenfeld, 2022). Inductive subcategories are developed from emerging themes in the data.

Preliminary Findings

The following demonstrates the analysis approach by focusing on a phone conversation with the second facilitator, which Adam, a participant in the 2025 PLC, initiated to consult about how he plans to implement a DL in an upcoming lesson in his classroom.

Adam described his approach to conducting lab lessons: "*In grade 12 I'm under time pressure (...) I allow them (the students) to 'taste' each of the experiments*." Adam demonstrates the experiment before students carry it out by themselves. This pedagogical action retained agency with the teacher, contrasting with the DL's emphasis on granting agency to students, in order to fulfill his pedagogical reasoning - "covering the material" in time. Responsibility to two environments underlined this reasoning: a commitment to his classroom students, based on his perception of the pace at which they could accomplish the lab tasks, and a commitment to the physics department in the Ministry of Education, as he wanted his students to meet the matriculation exam standards it set. Adam supported this *reasoning* by referencing a third environment of peer teachers, recalling an episode in another 2024 PLC in which he attended. There, his peers expressed discomfort when they realized the struggle required to accomplish an open-ended experiment. Adam anticipated that his students, who lacked prior lab experience, would similarly struggle with the agency afforded by the DLs.

Adam recognized a difference between his pedagogical action and that promoted in the 2025 PLC, particularly regarding the placement of questions highlighting experimental design considerations. He perceived the DL approach as risking efficient management and doubted that the order of questions added value: "*What is the purpose of taking this risk? (...) If I give them the old worksheet and then ask 'annoying' questions (i.e., elaborating on experimental practice considerations after executing the experiment), or give them the new worksheet (where these questions precede execution), I'll get to the same place.*"

The facilitator acknowledged Adam's concern and backed it within a broader context by introducing an example from another peer environment: a PLC that took place in 2023, in which Adam had not participated, where a similar question had arisen. The 2023 PLC functioned as *a mediating environment*, legitimizing Adam's concern by reframing it as a shared professional question rather than negating his existing pedagogical responsibility. Referring to his doubt, the facilitator suggested that placing the questions while students consider how to perform the experiment requires more effort on their part, deepening the learning process provided by the activity. Adam took up this suggestion and elaborated: "*And add to that - it's not that after I explained I then ask an 'innocent' question, rather, he (the student) doesn't know it's extra*", noting that when questions are embedded within the worksheet, students don't experience them as an "extra" demand, but as an integral part of the experimental process. This reframing allowed Adam to reconsider his initial efficiency-based reasoning and to perceive student engagement with the questions as compatible with his instructional goals. The facilitator reinforced Adam's understanding and encouraged him to take the risk of trying the DL in his classroom: *"(The student) doesn't know (that it's extra)! Exactly! He has to deal with it on his own. And we believe that with (teacher) support it works (...) So try It - without demonstrating anything before - And tell me later what happened.*" Relating to the 2023 PLC served as a mediating environment, as it echoed the peer environment Adam had previously mentioned, enabling him to reconsider the relationships among his *pedagogical action, reasoning*, and *responsibility*, while maintaining his sense of belonging to his learning ecology, remaining within his ecological ZPD.

By the end of the conversation, Adam stated, "*The place where I had a question mark and this conversation straightened out my head is where you say - don't lead them, let them start alone*," indicating a shift in his *pedagogical reasoning* that led to a change in pedagogical action, specifically, a decision to try a DL in his classroom.

The findings illustrate how multiple environments were reflected in the discourse, including students in the classroom, the Ministry of Education specifying the matriculation standards, and peer teachers, each playing a distinct role in teacher learning. While some environments constrained change by reinforcing existing commitments, others functioned as mediating environments that enabled a facilitator to disrupt teacher's existing learning ecology and promote reconsideration of pedagogical judgment within the teacher's ecological ZPD.

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Exploring the measurement and meaning of awarding gaps in higher education physics

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Keywords: Physics, Tertiary Education, Equitable Outcomes, Awarding Gaps

Focus of the Study

Degree classifications offer a quantitative determinant of a student's academic success at university, with prized first and upper-second class degrees opening doors to enhanced postgraduate prospects. As a result, graduates with lower degree classifications often find themselves underrepresented in competitive sectors, sifted into lower-paying roles during their early careers and facing longitudinal wage disparities (Feng & Graetz, 2017; Naylor et al., 2016). In seeking to improve the accessibility of degree subjects, particularly in science, technology, engineering, and mathematics (STEM), researchers have identified gaps in attainment for select demographics in the undergraduate cohort, even when accounting for variables such as prior academic achievement. These disparities have since been named awarding gaps.

Awarding gaps in Physics are not often studied explicitly. However, with some reports identifying significant differences in the attainment landscape between STEM subjects (Low & Kalender, 2024), it is essential that these institution-wide disparities are also studied at the more granular, discipline-specific level. This is particularly pertinent in subjects such as Physics, where gaps often arise in students' sense of identity and belonging, and where underrepresentation of minority groups is particularly pronounced (Leslie et al., 2015). Furthermore, subject-specific awarding gap research is broadly confined to intra-institutional studies, leading to limited representation of minoritized groups in the data and results reflecting a narrow subset of students. This points to the need for broader-scale research that utilises cross-institutional or longitudinal datasets to probe the national picture of equitable outcomes in Physics (Daniel, 2019).

This project aims to improve and advise on the standardisation of the measurement of UK Physics awarding gaps, with the aim of ensuring that results are consistent, meaningful, and informative. The research will also investigate the interpretation of awarding gaps in Physics at UK institutions, including how they are defined, understood, and acted upon by key stakeholders. This in turn will motivate robustly evidence-backed interventions that can be tracked longitudinally, providing opportunities for evaluation, revision, and improvement.

Review of Literature

Awarding gaps were first explicitly studied in the UK in the late 1990s, motivated by the introduction of higher education (HE) tuition fees and indications of similar disparities in schools. In early studies, researchers identified barriers encountered by students from lower socioeconomic classifications (Smith & Naylor, 2001), arguably mirroring the evolving financial backdrop in UK HE at the turn of the century (Galindo-Rueda et al., 2004). The ethnicity awarding gap has also consistently been a focus, with researchers recurrently identifying differences in degree outcome for minority ethnic students (Codiroli Mcmaster, 2021; Connor, 1996; Fielding et al., 2008). On the other hand, some minoritised groups are found to be under-represented in awarding gaps research, with a vacuum of studies into the unique challenges they face - for example, the access needs of STEM students with a disability (Reinholz & Ridgway, 2021).

Recent calls for the improvement of Physics Education Research (PER) methodologies (Heckler, 2025) should also be heeded in the analysis of awarding gaps. For example, utilising statistical techniques such as hierarchical logistic regression (HLR) to account for nested data could have a substantial impact on identified patterns and trends, revealing underlying effects that may have otherwise been missed (Van Dusen & Nissen, 2019). Likewise, with recommendations to expand the use of machine learning methodologies in PER (Wulff et al., 2025), there are many possible advantages to utilising them when studying awarding gaps. This is particularly apparent when analysing large datasets to interrogate the national picture, and in heeding calls to improve the predictive power of models in education research (Shmueli, 2010).

Understanding the real-life implications of achieving different awards at university may help to contextualise the impact of awarding gaps on those facing them. Arguably, current attainment gap metrics fail to adequately capture the true inequity of outcomes for students, without a clear theoretical basis to underpin their measurement and meaning (Hubbard, 2024). Additionally, whilst interventions aiming to tackle awarding gaps are widely applied at UK institutions, a recent report by Universities UK found that these initiatives' main weakness was a lack of evaluation of their efficacy longitudinally (Universities UK, 2022). Statistically robust methods are needed to track the trends of awarding gaps over time, in turn providing insight into how effective interventions are at closing them. Studying longitudinal data may also reveal evidence of grade inflation and provide insight into how awarding gaps are affected by nationwide policy changes arising from events such as the Covid-19 pandemic.

Research Questions

1. How do different definitions and analytical methods shape the identification, interpretation, and validity of awarding gaps as a measure of inequity in Physics?

2. Which academic, sociodemographic, and institutional factors are most strongly associated with the magnitude and pattern of awarding gaps in Physics across HE institutions?

3. How are awarding gaps understood, interpreted, and acted upon within physics departments, and how do these interpretations shape equity-focused practice?

Research Design and Methods

The project utilises a rich, tailored from the UK Higher Education Statistics Agency (HESA), detailing the degree outcomes and socio-economic identity factors for over 26,000 UK Physics graduates. Using a variety of statistical tools, this dataset will be analysed to investigate the existing national landscape of Physics awarding gaps and develop a representative model of their underlying patterns and predictors. So far, multilevel logistic regression modelling has been used to analyse predictors of first-class degree outcomes and associated awarding gaps. Looking ahead, the model will be adapted to explore distributions over time, as well as between different degree subjects and HE providers, possibly revealing contributory contextual factors and successful awarding gap intervention policies in Physics departments.

This will be complemented by conducting semi-structured interviews to seek to understand how awarding gaps are interpreted by key stakeholders such as heads of departments. This also provides opportunity to identify good practice and areas of risk, with the aim of generating a toolkit that individual departments can use to approach awarding gaps studies in future.

This mixed-methods approach will ultimately aim to develop an accessible and effective way of measuring and presenting Physics awarding gaps, such that departments can understand and communicate their findings to students and when sharing good practice. This, in turn, will allow a multi-institutional approach to tracking gaps and developing meaningful interventions.

Preliminary Findings

Research has focused on investigating different quantitative methods for analysis of the HESA dataset, starting with a project exploring multilevel modelling techniques. Early findings reveal awarding gaps for many minoritised groups, including but not limited to disabled students, Black students and Asian students. Some academic factors such as degree duration, prior attainment, and year of graduation are also found to be significant predictors of degree outcome. There is a significant degree of clustering evident in the data, highlighting both the importance of multilevel modelling and the possible impact of institutional factors.

Furthermore, results show that differentiating the way the dataset is analysed can change the outputs and the resulting conclusions drawn about awarding gaps in the data. For example, some awarding gaps (e.g. for students whose parents did not attend university) that appear as statistically significant using z-test comparisons become insignificant differences with the introduction of hierarchical structure, when accounting for institutional clustering and possible contributory factors (such as prior academic attainment, course duration, and year of graduation). This suggests that commonly used approaches may either overstate or overlook disparities without fully accounting for structural and discipline-based factors – an effect that could possibly translate into implemented policy and resulting student experience.

Since the hierarchical modelling project, analysis has focused on utilising additional techniques such as random slopes and interaction terms to understand the possible factors contributing to institutional clustering. Preliminary analysis of Physics results compared to other subject areas, alongside how results change when considering ‘good degrees’ (Firsts or 2:1s) as the outcome variable, has also been performed.

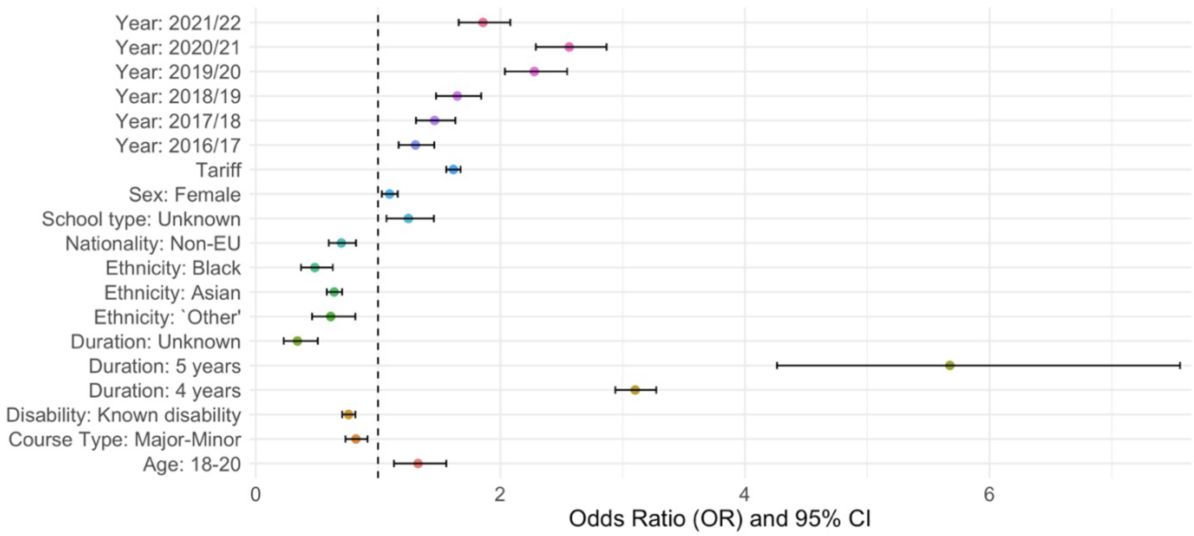

Figure 1 - Forest Plot showing the odds ratio of achieving a First in a Physics degree at UK institutions for statistically significant fixed effects in a HLR model, calculated relative to each factor's reference category

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From the global to the local: Environmental literacy across frameworks, assessments, and practice in a rural Mapuche school in Chile

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Focus of the Study

Environmental literacy, understood as environmental knowledge, values, and practices, is expressed across multiple scales. At the local level, Indigenous and rural communities worldwide tend to hold forms of environmental literacy developed through thousands of years of continuous interaction with their environments, offering pathways toward sustainable relationships with nature (Trosper & Parrotta, 2012). In parallel, global policies, frameworks, and assessments related to environmental protection and sustainability have expanded in recent decades. This is reflected, for example, in the emphasis on environmental literacy within transnational assessments such as the Trends in International Mathematics and Science Study (TIMSS) 2023 (von Davier et al., 2024). Although these approaches coexist, critical and decolonial scholars argue that knowledge produced in the Global North is often prioritised over traditional and local ways of knowing (Kahn, 2010; Gough, 2013). Yet despite these debates, there is limited empirical research examining how these perspectives intersect in practice. The next paragraph defines Environmental Literacy, Traditional and Local Ecological Knowledge, and explains the context of this research.

Environmental Literacy, Traditional and Local Ecological Knowledge

The cultivation of Environmental Literacy (EL) has emerged as an urgent global policy imperative (Xiong et al., 2025). In the first formal definition of EL, Disinger and Roth (1992) conceptualised it as “the capacity to perceive and interpret the relative health of environmental systems and to take appropriate action to maintain, restore, or improve the health of those systems” (p. 2). Building on this definition, EL is understood to encompass not only ecological knowledge but also attitudes and pro-environmental behaviours. Despite its central role, dominant conceptualisations of EL have been criticised for reflecting epistemological perspectives rooted largely in the Global North (Gough, 2013; Kahn, 2010). From this perspective, traditional and local ecological knowledge are recognised as essential for incorporating diverse epistemologies to address complex environmental challenges.

Traditional Ecological Knowledge (TEK) is defined by Berkes (1993) as “a cumulative body of knowledge and beliefs, handed down through generations by cultural transmission, about the relationships of living beings (including humans) with one another and with their environment” (p. 4). TEK is typically associated with societies that have historical continuity in resource-use practices, many of which are Indigenous or tribal. In parallel, Local Ecological Knowledge (LEK) refers to knowledge held by specific groups about their local ecosystems that may not necessarily involve long-term cultural or historical continuity (Olsson & Folke, 2001). Despite the importance of these perspectives, according to Kahn (2010) environmental science has generally denied TEK the status of 'real science,' resulting in the continued cultural and political marginalization of Indigenous peoples and the exacerbation of ecological crises.

Context of the Study

13 Indigenous communities live in Chile, the largest of which is the Mapuche (INE, 2025). The Araucanía Region has the highest proportion of Indigenous populations living in rural areas and forms part of the ancestral territory of this community (Pareja-Arellano et al., 2023). The term *Mapuche* translates as "people of the land" in Mapudungun (Meza, 2009), and native forests are considered sacred within their worldview (Beltrán Véliz et al., 2021). In these contexts, children may develop strong attachments to ancestral territories, understanding humans not as separate from nature but as part of an interconnected whole (Mendoza Mendoza et al., 2025).

In parallel with these local conceptualisations of the environment, many countries have aligned their curricula with standards promoted by international large-scale assessments such as TIMSS (Guerrero & Sjöström, 2025). In Chile, accountability mechanisms such as the Education Quality Measurement System (SIMCE) and the centrally planned curriculum further reinforce these processes of standardisation, often producing high-stakes consequences for schools (Botella & Ortiz, 2018). As a result, situated forms of EL developed by students in rural and Mapuche communities may be overlooked by dominant assessment frameworks. From this perspective, Au (2016) argues that such assessments may define a "good student" through a narrow lens, overlooking knowledge that some learners may hold. These dynamics may disadvantage economically marginalised, Mapuche, and rural students. Whether this occurs in practice, however, remains an open empirical question.

This study therefore investigates how children in a rural Mapuche school understand, value, and enact environmental literacy, and how these understandings relate to global and Chilean frameworks and assessments. Limited research has examined these levels simultaneously. By addressing this gap, the study explores how different forms of knowledge are valued in environmental education and how this relates to standardised assessment patterns.

Theoretical Framework

In 2011, the North American Association for Environmental Education (NAAEE) developed an EL framework (Hollweg et al., 2011). This framework conceptualizes EL as a multidimensional construct, comprising five categories of knowledge, five dispositions, seven competencies, and five categories of environmentally responsible behaviour (Hollweg et al., 2011). Moreover, the framework incorporates local, national, and global scales of knowledge. A summary of the framework is presented in Diagrams 1 and 2.

Diagram 1. The domains of environmental literacy according to Hollweg, et al, 2011.

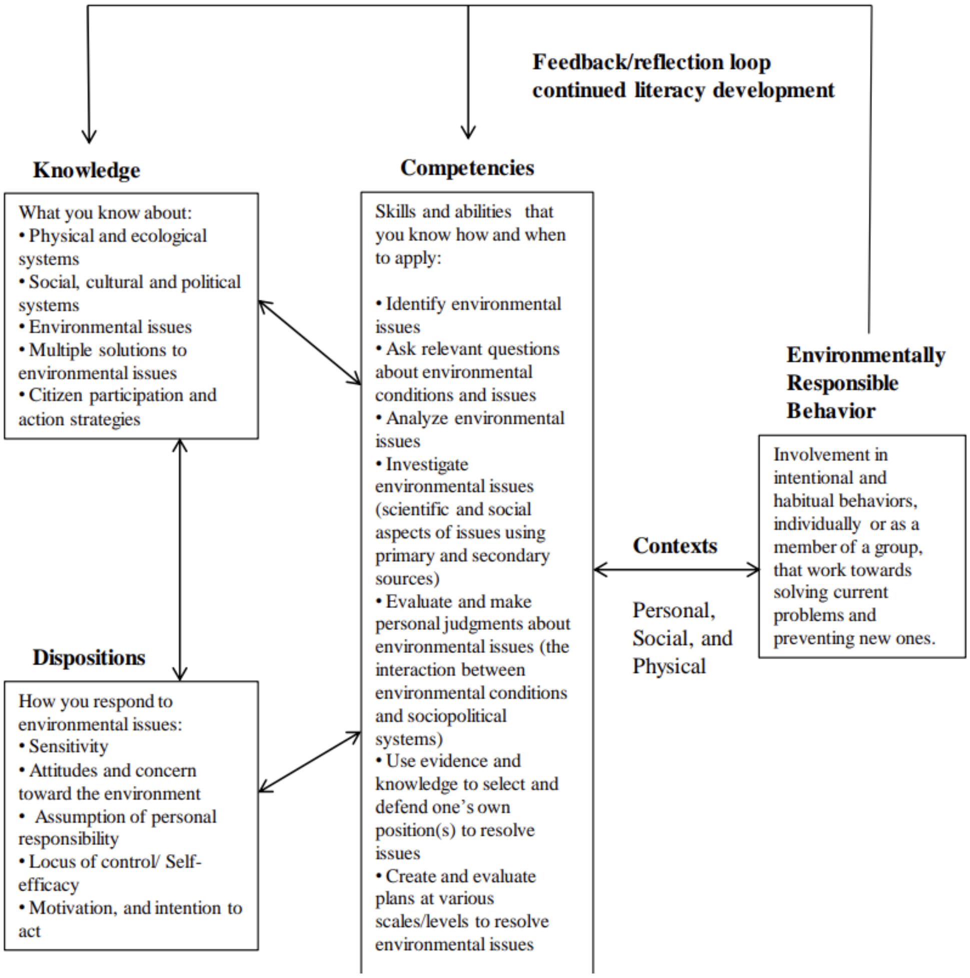
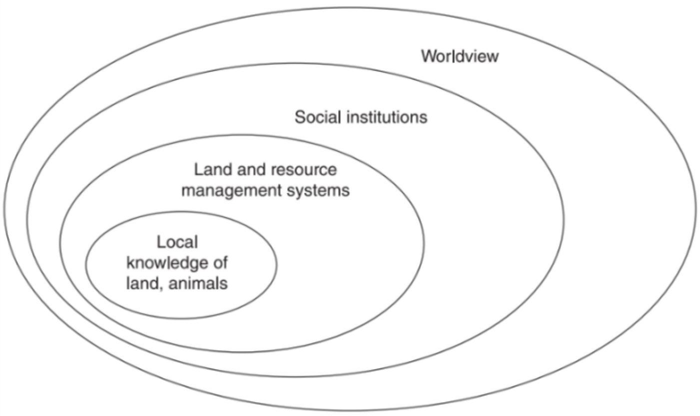


Diagram 2. Example of contexts for environmental literacy

	Local	Regional	Global
Biodiversity	Flora and fauna	Endangered species, habitat loss, exotic invasive species	Ecological sustainability, sustainable use of species

Additionally, to incorporate Traditional Ecological Knowledge into the framework, and in line with curriculum decolonisation, elements from Berkes (2017) were integrated (see Diagram 3).

Diagram 3. Traditional Ecological Knowledge Domain



Research Questions

How does students' environmental literacy in a rural Mapuche primary school relate to global and national frameworks and assessments?

RQ1. What is the dominant conceptualisation of environmental literacy in TIMSS and the national Chilean curriculum?

RQ2. How does environmental literacy vary by socioeconomic and territorial status in TIMSS 2023 data from Chile?

RQ3. How does environmental literacy vary by socioeconomic, indigenous and territorial status in SIMCE 2026 data from Chile?

RQ4. How do students in a rural Mapuche primary school in Chile understand, value, and enact environmental literacy?

Research Design and Methods

This research adopts an explanatory sequential mixed-methods design informed by critical and decolonial perspectives. Additionally, a multi-stage structure is employed to examine the problem at different levels of analysis (Cohen et al., 2018). The study is organised into four stages:

(RQ1) analyses global and Chilean policy documents to understand the dominant conceptualisation of EL and the ways in which TEK/LEK are either aligned with or excluded from these frameworks. Global documents (TIMSS 2023 science frameworks) and Chilean documents (environmental literacy–related objectives in the national science curriculum) are analysed using content analysis. The coding framework is based on the environmental literacy framework proposed by Hollweg et al. (2011) and Berkes (2017).

(RQ2) examines how socioeconomic status and territorial context influence Chilean students' performance on EL–related items using TIMSS 2023 data. TIMSS explicitly identifies EL as an educational objective (von Davier et al., 2024). Environmental science items are used to analyse knowledge and competencies, while contextual questionnaires provide information on students' environmental attitudes and behaviours. As TIMSS does not collect Indigenous status, the analysis focuses on socioeconomic and territorial factors, using regression analysis.

(RQ3) examines how socioeconomic, Indigenous, and territorial statuses influence Chilean students' performance on EL-related items using the SIMCE database. Only knowledge and competencies are included in this assessment. The analysis focuses on the Araucanía Region and applies regression analysis at the student level.

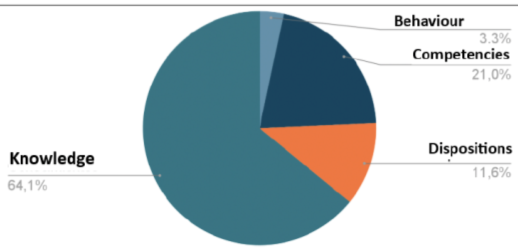
(RQ4) uses a qualitative case study approach to explore situated environmental literacy in rural Mapuche schools in the Araucanía Region of Chile. Schools are selected based on low SIMCE performance to capture forms of EL that may not be fully recognised by standardised assessments. Data are collected through class activities using "draw, show, and tell" methods, interviews, and observations. Narrative analysis is employed to examine students' EL as situated, relational, and culturally embedded (Cohen et al., 2018).

(Integration) quantitative and qualitative findings are integrated through joint displays. The objective of this stage is to examine how local, national, and global knowledge systems relate to one another, identifying areas of alignment and misalignment. Finally, the analysis explores how these relationships help contextualise the quantitative findings.

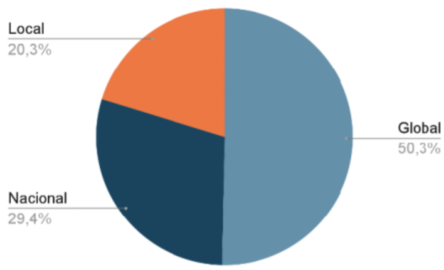
Preliminary Findings

Objective 1

This objective was addressed initially through document analysis of the Chilean science curriculum for Grades 11 and 12. Preliminary findings from the Environment and Sustainability module indicate that the curriculum includes all four components of environmental literacy—knowledge, dispositions, skills, and pro-environmental behaviour—consistent with prior research highlighting a more critical approach to scientific literacy at these levels (Guerrero & Torres-Olave, 2022). However, the curriculum places greater emphasis on knowledge over action, which may limit its capacity to promote meaningful environmental behaviour change (Fang, 2020). While the curriculum incorporates local, national, and global environmental issues, suggesting an effort to decolonise curricular content, Indigenous communities are primarily represented as affected populations rather than as knowledge holders or agents of change. As a result, Indigenous ways of knowing and acting are marginalised, reinforcing colonial epistemologies.



Graph 1. Components of Environmental Literacy in Chilean Curriculum Activities (%)



Graph 2. Contexts of Chilean Curriculum Activities (%)

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University-school partnerships in the supervised teaching practicum in physics: A study on activity, dialogue, and collaboration

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Keywords: Physics, In-service teacher training, Partnerships, Collaboration

Focus of the Study

Interactions between the subjects who constitute school communities and universities involved in supervised teaching practicums and educational projects are permeated by conflicts, hierarchies, dialogue, and collaboration. Hierarchy in social interactions cannot be disregarded, even in contexts that seek to promote more horizontal forms of relationship. In this sense, it is essential to reflect on the power relations that permeate such contexts (Foucault, 1987).

This study aims to examine typologies of partnerships constructed between universities and schools (Jones et al., 2016), particularly within the context of a discipline offered in a Physics teacher education program in Brazil. The discipline under investigation is the only mandatory, year-long course in the program and includes 100 hours of supervised teaching practicum. These hours are distributed across three main components: theoretical classes taught by the course professor, workshops developed by course mentors, and practicum activities carried out in partner schools.

This research investigates university-school partnerships as they are developed within this discipline, considering the multiplicity of subjects involved in these partnerships. Given the complexity and the large number of possible interactions, it is not feasible to analyse all partnership dynamics within the scope of this study. Therefore, the analysis focuses on the supervising teacher, a central subject in the initial education of pre-service Physics teachers and an active participant in continuing professional development processes, who acts as a key point of articulation between the university and the school.

Theoretical Framework

The investigation of the typology of partnerships can be based on its duration and the level of institutional commitment, distinguishing between connective, generative, and transformative partnerships (Jones et al., 2016). Connective partnerships are characterized by initial arrangements of mutual benefit, such as schools providing placements for teaching practicums in exchange for pedagogical support from universities. These partnerships tend to be short-term, more fragile, and to have limited impact on institutional practices, although they may produce specific benefits for students, teachers, pre-service teachers, and school management.

Generative partnerships represent an intermediate stage in which dialogue, cooperation, and the development of collaborative projects are intensified, gradually strengthening trust between institutions. Finally, transformative partnerships, in turn, are typically more long-term and be-come integrated into institutional structures. They focus on both initial and continuing teacher education and promote critical reflection on teaching practices informed by theories of professional identity. Transformative partnerships are grounded in dialogue, trust, and shared responsibility, redefining rules, divisions of labor, mediating artifacts, and shared objectives. Importantly, this typology does not establish a hierarchy of value; rather, each type of partnership is considered relevant according to its effectiveness in achieving its intended educational purposes (Jones et al., 2016).

Cultural-Historical Activity Theory (CHAT) is adopted in this study as the theoretical framework for analyzing university-school partnerships, as it enables an understanding of how sub-jects, rules, divisions of labor, mediating artifacts, and communities are organized around a collective object (Engeström, 2001, 2009). CHAT is grounded in the Cultural-Historical Psychology developed by Vygotsky and his collaborators, which emphasizes symbolic and mate-rial mediation as central to human development (Vygotsky, 2001). Leontiev extended this perspective by conceptualizing activity as being oriented toward an object that responds to socially and historically constituted needs, distinguishing activity from actions and operations, whose meanings can only be fully understood within a collective activity (Leontiev, 2021).

Developments associated with the third generation of CHAT, systematized by Engeström, expand the unit of analysis to activity systems (Figure 1), understood as collective, multivoiced, and historically situated formations, permeated by internal contradictions and by networked relations with other systems (Engeström, 2001).

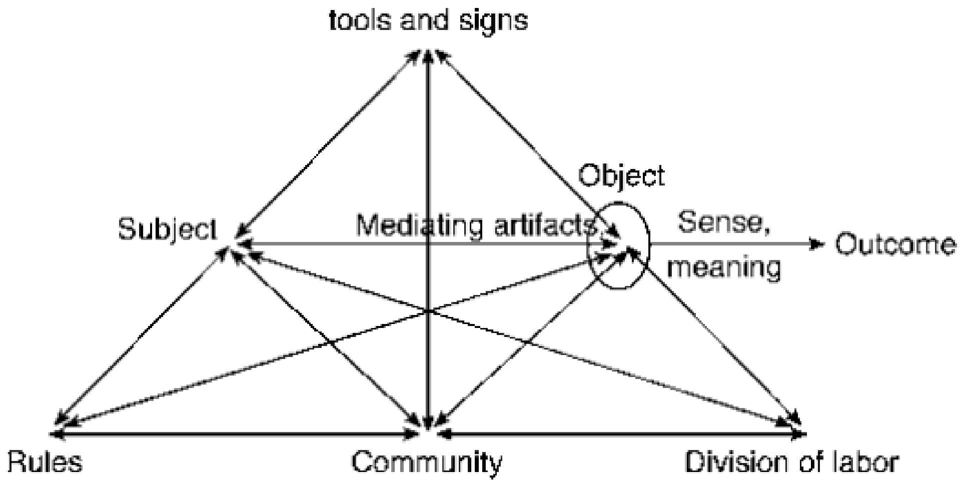

Figure 1: The structure of a human activity system (Engeström, 2001, p. 135).

The network-based analysis of activity systems makes it possible to understand how different interests, forms of power, and modes of work organization confront and reconfigure each other over time. This approach proves particularly powerful for investigating university-school partnerships, as it involves the interaction between distinct systems whose contradictions may both constrain and foster the construction of collaborative practices in teacher education.

Research Questions

This study is guided by the following overarching research question:

RQ1: How are university-school partnerships related to the supervised teaching practicum in Physics constructed and sustained?

This general question is further specified by a secondary question that addresses the core focus of the study:

RQ2: In what ways do interactions between supervising teachers and other participants in these partnerships strengthen or constrain the development of long-term transformative partnerships?

Research Design and Methods

This study adopts a qualitative research approach aimed at analyzing case studies related to a supervised teaching practicum course in Physics. Given the diversity of school contexts and the different forms of interaction established with the university, the investigation is designed as a multiple case study, focusing on understanding the dynamics of the activity systems that sustain these partnerships.

Interviews constitute the primary data collection method, with participants including coordinators, school principals, and supervising teachers from public schools partnered with the practicum course. The interview protocols are designed to examine the processes through which partnerships are initiated, the specific forms of collaboration established with the practicum course, and school leaders' perceptions of factors that facilitate or hinder the development of long-term partnerships, as well as transformations in these relationships over time.

Data analysis is conducted using Discursive Textual Analysis (DTA) (Moraes, 2003), a qualitative methodology suitable for analyzing interview data. DTA integrates elements of content analysis and discourse analysis, enabling the construction of meaning from the analyzed texts. The analytical process involves three interrelated movements: fragmentation of the corpus into units of meaning, categorization, and the construction of metatexts (Moraes, 2003). This process begins with successive readings of the interview transcripts, guided by the theoretical framework, with the aim of producing preliminary interpretations and identifying relevant meanings.

Units of analysis are organized into analytical categories constructed through an emergent process, as these are considered more appropriate to the objectives of the investigation than categories defined a priori. Movement between categories and subcategories occurs dynamically, allowing for the articulation of both specific and broader aspects of the phenomenon under study. The final stage consists of the construction of metatexts, in which categories are described, interpreted, and theorized, resulting in partial claims that, when articulated, support the overall analysis.

In the preliminary analysis, particular attention was given to the category dialogue within hierarchies in university-school partnerships, structured around the subcategories movements toward horizontalization and movements toward verticalization of communication. The analysis focuses primarily on interactions among supervising teachers, education authorities, school management, and university faculty, with the tension between dialogical practices and hierarchical relations emerging as a central element for understanding both the limits and the possibilities of building collaborative partnerships within the supervised teaching practicum.

Preliminary Findings

The preliminary analysis of this doctoral research is based on an interview conducted with a supervising teacher working in a public school partnered with the supervised Physics teaching practicum. The main objective of this initial stage was to understand how university-school partnerships are constituted in practice from the perspective of a subject who occupies a strategic position in these processes, articulating the demands of the school, the university, and initial teacher education.

The findings indicate that the teacher's permanence in and engagement with the school are strongly associated with the alignment between his personal and pedagogical values and those promoted by school management. Even in the presence of adverse objective conditions, such as a long daily commute, the teacher attributes positive meaning to his work at the school due to a management team that prioritizes student learning, supports teaching projects, and allows for a degree of pedagogical autonomy. This alignment contributes to the development of a sense of belonging and to the strengthening of institutional bonds, which also appear to be relevant to the school's openness to receiving pre-service teachers.

Within the partnerships established with the university, movements toward the horizontalization of communication emerge, particularly in interactions between the supervising teacher and the pre-service teachers. The supervising teacher understands the practicum as a space for mutual learning, in which dialogue, divergent perspectives, and the exchange of experiences function as formative elements for both the pre-service teachers and the teacher himself, thus framing the practicum as an opportunity for continuing professional development. These inter-actions resonate with dialogical conceptions of education grounded in collaboration and collective work.

However, the findings also reveal a strong presence of verticalized communication pro-cesses, especially in relationships between schools and education authorities. The teacher points to a progressive loss of professional autonomy associated with the intensified control of pedagogical work, the standardization of curricular content, the mandatory use of digital platforms, and the centrality of external assessments. This context produces tensions between the work prescribed by educational policies and the real work carried out by teachers and school leaders, affecting professional identity and generating instability within school teams.

These dynamics have direct implications for the construction and maintenance of university-school partnerships, as excessive demands, monitoring, and curricular rigidity may con-strain the development of more contextualized and collaborative practicum experiences. The preliminary analysis therefore suggests that these partnerships are traversed by contradictions involving dialogue and hierarchy, autonomy and control, collaboration and institutional imposition.

As the research progresses, data collection is planned to be expanded this year to include interviews with supervising teachers and pedagogical coordinators from the participating schools. This stage will allow for a deeper understanding of institutional dynamics, teachers' working conditions, and the factors that foster or hinder the construction and sustainability of university-school partnerships in the context of the supervised teaching practicum.

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Reimagining climate change education from the ground up: Teachers' perspectives from remote Pakistan

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Focus of the Study

Climate change is a lived and uneven reality, experienced and interpreted differently across places due to geographical, ecological, socio-economic, political, and cultural conditions (Abbas et al., 2022; Reid, 2019). These contextual differences shape how climate change impacts daily life and, consequently, how communities understand and respond to it. Educational responses to climate change, therefore, cannot be assumed to be universal but must be grounded in local realities, resources, and capacities (Abbas et al., 2022; Anderson, 2012).

Climate change education (CCE) has been widely promoted as a key response to the climate crisis, particularly through initiatives led by international and development organisations (Puttick et al., 2024). While such efforts have contributed to global awareness and policy attention, they are often critiqued for being standardised and top-down, with limited sensitivity to local contexts and school-level realities (Stevenson et al., 2017). In many resource-constrained and climate-vulnerable settings, these approaches may overlook the perspectives of teachers, who are central to interpreting and enacting education in practice.

In this study, CCE is understood broadly as the range of educational responses through which schools engage with climate change, including curriculum content, teaching practices, and school-based activities related to mitigation and adaptation (Puttick et al., 2024). The research focuses on Pakistan, a country marked by significant climatic vulnerability and socio-cultural diversity, where climate change impacts and educational conditions vary sharply across regions (Kalsoom et al., 2017). By examining teachers' lived experiences in two highly vulnerable yet distinct contexts, this study explores how teachers conceptualise climate change and the role of education, contributing a ground-up, contextually informed understanding of CCE.

Review of Literature

CCE: Critical Perspectives and Gaps

CCE is widely promoted as a key response to the climate crisis, aimed at supporting awareness, adaptive capacity, and informed action (Anderson, 2012). While CCE is often described as interdisciplinary and transformative, critical scholarship highlights that dominant approaches remain largely top-down and standardised, shaped by international policy frameworks rather than local educational realities (Reid, 2019). As a result, CCE frequently prioritises awareness over meaningful engagement with local climate challenges, limiting its relevance and practical impact in diverse contexts (Puttick et al., 2024).

In Pakistan, these challenges are intensified by structural and contextual constraints within the education system. Formal schooling remains centralised and largely science-driven, with limited integration of climate change beyond curriculum content, and minimal emphasis on teacher preparation or professional development for CCE (Kalsoom et al., 2017). Although national climate policies acknowledge the importance of education, implementation often fails to account for regional diversity, resource constraints, and uneven climate vulnerabilities, particularly in remote areas (Ahmed & Luqman, 2024). This creates a gap between policy intentions and school-level practice.

Contextualisation in CCE

Research increasingly emphasises that effective CCE must be contextually grounded, linking learning to local environments, lived experiences, and community priorities (Puttick et al., 2024). Place-based and context-responsive approaches have been shown to enhance relevance, engagement, and agency, particularly in climate-vulnerable settings (Stevenson et al., 2017). However, global CCE frameworks often adopt generalised approaches that overlook local conditions, cultural practices, and material constraints, reducing their effectiveness in resource-scarce contexts (UNESCO, 2019). In countries such as Pakistan, where climate impacts vary significantly across regions, this highlights the need for educational approaches that recognise local variability and knowledge systems.

Teachers' Role in Contextualised CCE

Teachers are central to the implementation of effective CCE, particularly in formal education settings. Their perspectives, values, and understanding of climate change shape how content is delivered and adapted for learners (Puttick et al., 2024). In remote and resource-scarce regions, teachers often serve as the primary source of education, translating climate knowledge into meaningful, contextually relevant learning (Ali, 2018). Engaging teachers in curriculum development, participatory learning, and the integration of local and scientific knowledge enhances CCE's relevance and feasibility (Reid, 2019). Yet teacher preparation for such roles remains limited in Pakistan (Kalsoom et al., 2017; Mirza, 2015), underscoring a crucial gap in the pro-vision of context-sensitive, teacher-informed climate education.

Research Questions

Building on the gaps identified in the literature, this study is guided by three interrelated research questions:

1. How do local schoolteachers perceive climate change and its impacts within their communities?

2. How do teachers conceptualise climate change education, including its potential role, limitations, and current challenges?

3. How can teachers' voices and lived experiences be used to reconceptualise climate change education initiatives, making them more contextually relevant and grounded in local realities?

Research Design and Methods

This research employed a qualitative, multiple-case study design, guided by ethnographic and participatory approaches to capture teachers' lived experiences and contextual knowledge of climate change education (Creswell, 2013). The study combined ethnographic techniques, observation, informal interactions, and photo documentation, with participatory methods, allowing for an in-depth exploration of how teachers perceived climate change, understood climate change education, and navigated the practical challenges of implementing educational responses in remote, resource-constrained, and climate-vulnerable regions.

Research Sites

The research was conducted in two distinct regions of Pakistan, selected for their high vulnerability to climate change and contrasting socio-environmental characteristics.

1. **Rajanpur District, Southern Punjab**: Situated along the banks of the Indus River, Rajanpur is primarily an agricultural region increasingly affected by water scarcity. The district experiences annual flooding during the monsoon season, prolonged droughts, and extreme heat, significantly affecting agriculture, livelihoods, and local education systems.

2. **Chipurson Valley, Gilgit-Baltistan**: Located at the intersection of the Himalayan and Karakoram mountain ranges, Chipurson Valley lies over 10,000 feet above sea level. This remote region experiences harsh climatic conditions, melting glaciers, landslides, changing seasonal patterns, and deforestation. Its extreme geography and isolation make access to education and resources particularly challenging.

Summary of Fieldwork

Fieldwork began in January 2025 and concluded in May 2025. I first conducted a pilot study in Lahore, comprising two workshops, to test methods and materials. Following this, I travelled to Rajanpur, where I stayed for up to four weeks, conducted four workshops with nine teachers, carried out six additional interviews, and visited schools in villages directly affected by the 2022 floods. In Chipurson Valley, I stayed for up to two weeks, conducted two workshops with 14 schoolteachers, conducted seven interviews, and visited schools in various villages across the valley. Workshops employed participatory techniques, including visual story circles, mind mapping, and local practices such as Pathak (informal sitting) and Behas (debates) to elicit teachers' perspectives.

Data Generated and Analysis

The fieldwork generated over 16 hours of audio recordings, including workshops and interviews, which are currently being transcribed and analysed. Ethnographic observations were documented in researchers' memos and field notes. Additionally, Photographic documentation of both field sites provides contextual descriptions. The data analysis combines narrative analysis (Creswell, 2013), emphasising teachers' lived experiences through vignette-style accounts, with thematic analysis (Creswell, 2013) to identify patterns and develop insights into teachers' perceptions of climate change, their understanding of climate change education, and the con-textual factors influencing their educational responses.

Preliminary Findings

Although analysis is ongoing, several preliminary insights have emerged, revealing the complexity of teachers' experiences and their role in shaping climate change education in these regions. Five major themes have been identified:

1. **Teachers' lived realities in climate-vulnerable communities:** Teachers' perceptions of climate change are closely linked to the specific environmental, social, and economic challenges of their localities.

2. **Understanding of climate change education:** Teachers critically evaluate existing educational responses, noting gaps between policy, curriculum, and practical classroom realities.

3. **Teachers' potential role in CCE:** Findings highlight the importance of placing teachers at the centre of discourse, recognising their multiple roles and capacity to inform policy and pedagogical approaches.

4. **Integrating action and local knowledge:** Teachers emphasise the need for education to go beyond awareness-raising, incorporating actionable strategies and indigenous knowledge relevant to their communities.

5. **Role of developmental organisations:** The influence of national and international initiatives shapes both teachers' work and community perceptions, affecting ownership, engagement, and the contextual relevance of climate education.

These preliminary findings suggest that teachers' voices and local experiences are critical for developing contextually grounded and actionable climate change education initiatives. Ongoing analysis will expand and refine these insights, supporting recommendations for policy and practice that reflect the realities of resource-constrained, climate-vulnerable contexts.

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Reconstructing knowledge-use of faculty members with different levels of expertise while explaining emergent phenomena in Physical Chemistry

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Focus of the Study

The focus of my PhD research is on understanding knowledge use and learning in physical chemistry (PC) at university level. For university students, PC is a notorious difficult subject, evident by the extensive literature documenting naïve conceptions. Although these naïve conceptions are well documented, little is known about the mental processes leading to their expression. Using a fine-grained Knowledge Analysis (KA), following a knowledge in pieces paradigm (DiSessa et al., 2016), I aim to reconstruct this mental process using clinical interviews for the specific context of colligative properties regarding solution processes.

These colligative properties can be explained as emerging from the complex interactions of many particles in a multi particle system (Talanquer, 2010). Emergence, emergent properties, and the difficult to mentally process and reason about them are discussed as one of the causes for many different naïve conceptions and learning difficulties known in chemistry. Explaining those properties, resulting from complex multi particle interactions, one needs to consider complex system behaviour, resulting in reasoning using systems thinking. This, sometimes also called emergent thinking, is considered not intuitive and explicit learning is needed (Chi, 2023).

Through contrasting the knowledge use of students and professors at a university in Germany I contribute insight in the development and usage of an (established) knowledge system through the comparison of novices' and experts' use of conceptual and epistemological knowledge when explaining said phenomenon, representing learning in chemistry.

Theoretical Background

The research on (mis)conception has reached a point of saturation for contexts in PC (Bain & Towns, 2016; Heeg et al., 2020; Natalis & Leyh, 2025), as highlighted by Cooper and Stowe (2018) in their review: "there is little to be gained by simply cataloging misconceptions without paying heed to the mechanisms of their emergence, their organization, and their character" (p. 6060).

To get a hold of the underlying mechanisms of students' emerging, and context depending conceptions, a fine grained and context specific KA is needed. KA is rooted in constructivism and a methodological approach to understand learning from an epistemological perspective. It focusses on the nature and development of knowledge by making learners' knowledge and their us-age in specific contexts explicit. (DiSessa et al., 2016). This way one can understand students' knowledge use in the process of solving problems and constructing explanations PC.

The successful use has already been demonstrated successfully for mathematical models and representations in physical chemistry that are used as a powerful heuristic for explaining and predicting system behaviour (Towns et al., 2019). However, further research is needed to better understand the process of building explanations, based on a particulate scale using the multi-particle-model. This way the explanation is linking macroscopic observations explicitly with particle behaviour and interactions in a complex sub-microscopic system. Mentally modelling this complex system of interacting particles is highly demanding. It requires comprehending and processing complex characteristics, like non-linearity, feedback loops, and emergence, some consider non intuitive and responsible for naïve conceptions about chemistry (Chi, 2019; Luisi, 2002; Tümay, 2016).

Different forms of explanations are constructed in science (Braaten & Windschitl, 2011), that can be differentiated by the types of rationales used to build arguments. For chemistry the most dominant types can be classified as based on phenomenological, mechanical or structural rationales (Talanquer, 2018, 2021). Specifically mechanical rationales, in form of mechanistic reasoning play a significant role in building scientific understanding about complex phenomena. By building on identifying responsible entities, interactions, dynamics and resulting properties on a scalar level below the target phenomenon, one can make sense and explain observed phenomena, or forecast future change. It is challenging to explain emergent phenomena in PC based on the underlying behaviour of multi particle systems.

Key aspects of complex systems are emergence and the existence of emergent properties. To understand and explain emergence, and complex multi-particle systems, systems thinking as a cognitive resource is needed. Systems thinking is a holistic approach and always includes mechanistic reasoning (Krist et al., 2019) to build causal narratives. It is considered central for chemistry and crucial for understanding chemistry (Samon & Levy, 2020). Systems thinking in form of explanations and forecasts of complex systems in physical chemistry, based on the multi-particle-model, is expected to produce mechanistic reasoning that capture the dynamic and com-plex nature of multi particle interactions. For chemistry these probabilistic rationales can be classified as dynamic probabilistic rationales (Talanquer, 2018) or emergent thinking (Chi, 2023).

For utilising such complex reasoning Chi proposes the need of learning this ontological form of reasoning explicitly, as it is necessary to replace existing mental models in one's mind (Chi, 2023). Following the assumption about knowledge regarding KA, it's the reorganisation and not replacing of knowledge systems that is necessary. Both views about learning, though onto-logical different, can be used additionally: New or newly linked (intuitive) epistemological knowledge or resources are necessary, guiding the building of explanations based on the knowledge about the necessary nature of an adequate explanation, in this case for a PC explanation based on the multi-particle-model.

To reconstruct the specific route of explanation building one can use the framework of epistemic games in combination with a resource analysis to connect activated resources with specific forms of resource usage. Epistemic games is a theoretical framework to characterise the epistemological frame that guides the building of an explanation like rules for a game (Sevian & Couture, 2018). The comparison of lesser organised knowledge structure and usage by novice learners with the supposedly higher organised knowledge structure of experts should reveal insights in the development of knowledge and provide understanding of learning PC.

Research Questions

How do people with different level of chemical expertise at university (students and professors) construct explanations for an observed emergent phenomenon in physical chemistry?

How do they reason about said phenomenon?

What resources do they use to construct an explanation?

How and what resources do they use productively to construct said explanation?

How does the knowledge use differ between novice and expert?

Research Design and Methods

As a first part of my research, I conducted an integrative review about the research on reasoning in physical chemistry. This is currently in the final stages of analysis. Research on reasoning in physical chemistry started to focus on deeper levels on granularity of knowledge to understand underlying causes of the vast extend of documented naïve conceptions.

To reconstruct the usage of knowledge by students and professors, I am planning a clinical interview study, beginning in March/April of 2026. First the reasoning will be characterised using the framework of mechanistic reasoning. The route of explanation building will be reconstructed using the framework of epistemic games in combination with a resource analysis to connect activated resources with specific forms of resource usage. Participants will conduct a small experiment on colligative properties and are asked to build an explanation. The video graphed clinical interview is an established method for reconstructing resources use (diSessa, 2014). Analysis of data will be based on knowledge analysis and mechanistic reasoning paradigm.

Preliminary Findings

Through the literature review different distinct theoretical perspectives have been identified, that guide research on student reasoning These perspectives target different levels of granularity on knowledge and knowledge use of students. In most cases theoretical perspectives were used complimentary to connect the levels of granularity and transfer findings about knowledge use in PC over into teaching implications or explanations for emerging naïve conceptions. A significant extend of reviewed literature adopted a KA paradigm to investigate students' knowledge use in PC.

There has been significant attention on the use of mathematics and graphical representations in research. However, there is a notable lack of studies on reasoning and explanation building related to the kinetic molecular model and emergent phenomena, particularly within a high-resolution KA framework. Although research has focused on the use of resources regarding conceptual knowledge, there is a need for more research on epistemological resource use.

The reviewed literature indicates that a diverse range of types of knowledge elements - conceptual, epistemological, and linguistic – are necessary. They can be organised and utilised in specific ways to support qualitative claims based on detailed explanations in physical chemistry. Knowledge works in a complex system on multiple scalar levels. Intuitive knowledge elements are activated in a specific context and need to be organised to enable reasoning and explanation building. The epistemic frame, one's conceptions about the adequate and necessary way to build reasoning and explanation is both intuitively activated as well mediating the organisation of knowledge elements (Rodriguez, 2024; Talanquer & Kelly, 2024).

Through my integrative Review I am investigating to what extend established research perspectives and frameworks to characterise and model student reasoning in physical chemistry are suitable to encapsule complex reasoning and involved knowledge use for emergent phenomena. Also, I am connecting the reviewed research about knowledge as resources on different scalar perspectives for specific contexts in PC to provide an overview of existing insights on knowledge use in physical chemistry.

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Uncertainty about uncertainty

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Focus of the Study

Uncertainty is a defining feature of everyday life, but also of great importance in scientific reasoning (Allchin, 2012; Buffler et al., 2001). In Physics, considering uncertainties in models or when measuring parameters in the lab is a key skill that fosters not only scientific literacy but also, once mastered, serves as a threshold concept (Dawson et al., 2024; Day & Bonn, 2011). Nevertheless, in physics education, it is often reduced to a procedural exercise in error analysis rather than embraced as an epistemic resource (Dounas-Frazer & Lewandowski, 2018).

This research investigates the uncertainties that students have about measurement uncertainties (Holmes & Bonn, 2015; Meyer & Land, 2003). Measurement uncertainty is defined as "a parameter, associated with the result of a measurement, that characterizes the dispersion of the values that could reasonably be attributed to the measurand." (JCGM, 2008). Measurement uncertainty is a fundamental feature of scientific practice, central to data interpretation, modelling, and decision-making, particularly in physics (Redish, 2003).

The Physics Education Research literature indicates that students encounter problems when dealing with measurement uncertainties, such as treating uncertainties as a mistake that should be reduced to zero (Vignal et al., 2024). While this means that students operate with a point-like thinking, the goal is for them to utilise a set-like thinking (Buffler et al., 2001). This means accepting that no true value exists, but rather a range of possible answers.

Existing studies mainly focus on students' misconceptions and conceptual deficits (Volkwyn et al., 2008). Much less attention is paid to students' reasoning processes and decision-making pathways when dealing with uncertainties. Furthermore, the literature focuses on students, and it is rarely investigated how academics conceptualise, teach, and use uncertainties in their research. Apart from that, this is often only done for physics, but what it is like for different sub-disciplines of physics or other scientific disciplines has not been explored.

Therefore, the first goal is to investigate the different kinds of struggles that students and academics may have with uncertainties to find the nature of the problem. As the literature lacks the academics' perspective, they might have further insight into the origin of students' struggles with uncertainties.

The motivation is to inform more useful approaches to teaching and learning uncertainties that better reflect scientific practice and support students' epistemic development.

The findings will have practical implications for curriculum design and laboratory instruction by highlighting productive ways to support students in reasoning about uncertainty as a threshold concept and support general scientific reasoning.

Review of Literature / Theoretical Background

Physics Education Research has shown that students struggle with uncertainty (Wan, 2023). These struggles range from conceptual, epistemological, affective, educational to sociocultural. The following struggles have been identified through several assessment tools and research instruments (e.g., PMQ, SPRUCE, PLIC, E-CLASS). These have been developed to probe students' reasoning about data, uncertainty, and experimental practices (Vignal et al., 2024).

First of all, conceptual and reasoning difficulties are a major issue. This means that students struggle with the meaning and interpretation of uncertainty. Examples of that include the misinterpretation of error bars, spread, standard deviation, or lack of knowledge of the nature of measurement uncertainty (Wieman, 2015).

Furthermore, procedural difficulties persist, which include the struggle of dealing with uncertainties. This, for instance, entails uncertainty propagation or how to quantify uncertainties from scratch (Wigfield & Eccles, 2000).

Apart from that, the literature identified epistemological difficulties. This incorporates problems with how students think about knowledge. Examples include expecting exact answers in-stead of distributions, believing better instruments eliminate the uncertainty, or not recognising that uncertainty informs scientific claims (Wilson et al., 2010).

Moreover, affective issues exist, including emotions interfering with uncertainty reasoning. This encompasses anxiety, low confidence, or frustration, amongst other things (Dounas-Frazer & Lewandowski, 2018).

Additionally, educational problems have been discovered that aim to explain how teaching contributes to the problem. Examples include how often very little time is devoted to teaching uncertainties, uncertainties are often not assessed, and teachers themselves struggle with confidence around the topic (Vignal et al., 2024).

Other issues include sociocultural issues; specifically, how external cultural forces shape misconceptions such as media framing science as delivering certainty or the public discourse framing uncertainty as an error or failure (Wieman, 2015).

Finally, the literature discovered disciplinary issues, meaning different forms of uncertainty are not being distinctly taught. For instance, classical measurement uncertainty is being confused with quantum indeterminacy (Wan, 2023).

Based on this, the gaps in the literature have been uncovered. The literature almost primarily focuses on students and not academics. The research also emphasises outcomes or correctness rather than reasoning or decision-making processes. Therefore, it would be interesting to understand how academics conceptualise and deal with uncertainties, as well as what their decision-making process looks like. Investigating struggles that academics experience with uncertainties as well as how that affects their confidence, could give valuable insight into the origin of the problem. Then, comparing this as well as how academics teach and use uncertainties in their own research to the students would give insight into how well those align with each other. This will give the opportunity to improve the teaching methods around uncertainties. Further-more, it is not discussed how this differs across different physics sub-disciplines or other scientific disciplines. This study draws on these strands of literature to investigate uncertainty not only as a conceptual object but as a practice-oriented and epistemic phenomenon situated within authentic scientific activity.

Research Questions

1.) How do academics from different physics sub-disciplines understand, conceptualise, and make their decisions when dealing with uncertainties, and what difficulties do they encounter?

2.) How do students understand, conceptualise, and make their decisions when dealing with uncertainties?

3.) How do 1.) and 2.) compare, and how do the academics' teaching and use of uncertainties in their research compare to the students?

4.) How does the understanding and use of uncertainties in physics compare to those of other scientific disciplines?

Research Design and Methods

The study adopts a qualitative research design. Data will be collected through semi-structured, one-to-one interviews, allowing participants to articulate their thinking in depth while providing flexibility to probe emerging ideas.

This study will be interpreted within the framework of expectancy - value theory, which highlights how learners' engagement with challenging tasks is shaped by their expectations of success and the value they assign to the task, providing a lens for interpreting affective responses to uncertainty in physics learning (Wigfield & Eccles, 2000).

The first set of interviews to answer the first research question will be done with academics from different UK universities and with different physics backgrounds, since every sub-discipline quantifies uncertainty differently. Section 1 of the interview will gather information on their understanding of uncertainties in general and in physics. Section 2 will ask them about their teaching experiences regarding measurement uncertainties. The goal of Section 3 will be to discover how they use uncertainties in their research and to investigate their fundamental opinions on uncertainties. All the Sections will also include an experimental physics scenario that the participants are asked to answer in a think-aloud way to understand how they conceptualise measurement uncertainties and how their decision-making process works.

The thematic analysis follows an iterative qualitative approach involving close reading of transcripts and identification of patterns. The analysis focuses on participants' conceptual framings, decision-making strategies, and epistemic orientations toward uncertainty rather than correct-ness or performance.

The next set of interviews will be done with students, and the final set of interviews will be done with people from different scientific disciplines. The details of these interviews will depend on the outcome of the first interview set and will be planned once the analysis of the academics' interviews is completed.

Preliminary Findings

Data Collection is still in very early stages, but the first set of interviews will be done and preliminarily analysed before the start of the ESERA Summer School 2026.

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Understanding university instructors' PCK in organic chemistry - From qualitative insights to quantitative measures

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Focus of the Study

Completing a STEM degree offers diverse opportunities in forward-looking industries but is considered challenging by many students. The subdomain Organic Chemistry (OC) is often described as a gatekeeper within chemistry due to its reliance on complex concepts, mechanistic reasoning and multiple representational formats (O'Dwyer & Childs, 2017; Graulich, 2025). These challenges are reflected in high performance-related dropouts (Walpuski et al., 2021). To address these challenges, instructors as 'designers of learning' must plan, teach and reflect on their practice to foster student achievement. Effective teaching therefore requires substantial professional knowledge. The construct of Pedagogical Content Knowledge (PCK) is commonly used to examine such knowledge in primary and secondary education but has seen limited ap-plication in higher education (Fukaya et al., 2025; Sarkar et al., 2024).

Accordingly, this study focuses on analysing university instructors' PCK and aims to develop an assessment instrument using a vignette-based approach that will provide insights into instructors' pedagogical reasoning. By making the knowledge necessary for pedagogical reasoning observable, the project supports intervention evaluation, standardised professional feed-back, and comparable international studies.

Theoretical Background

Pedagogical Content Knowledge (PCK) is a central framework for analysing instructors' pedagogical reasoning. Introduced by Shulman (1986), PCK denotes the integration of subject-specific content knowledge (CK) and general pedagogical knowledge (PK) to make subject matter accessible to learners. Magnusson et al. (1999) conceptualised PCK as comprising five facets: knowledge of assessment, curricular knowledge, instructional knowledge, knowledge of students and orientations towards teaching science. These facets describe distinct aspects of teaching, for example the competence to translate learning objectives into assessment tasks. Individually, they capture different dimensions of practice; in combination they characterise an instructor's personal PCK. More recent formulations, such as the refined consensus model (RCM; Carlson et al., 2019), distinguish personal, collective and enacted PCK. Personal PCK refers to an individual instructor's PCK, while collective PCK describes the teaching community's knowledge and enacted PCK relates to the knowledge expressed in practice. Conceptually, any assessment instrument must reflect this multidimensional structure to provide meaningful construct-validity evidence.

PCK has most often been applied to research on primary and secondary school teachers; its systematic use in tertiary contexts remains limited (Sarkar et al., 2024). Given the discipline-specific demands of chemistry, such as complex concepts, multiple forms of representation and mechanistic reasoning, a high level of PCK is likely necessary for student achievement. A meta-analysis by Fukaya et al. (2025) reported associations between PCK and student learning outcomes, reinforcing the importance of PCK for student achievement. A systematic literature review concerning the state and methods for fostering instructors' PCK in chemistry revealed a shortage of validated, quantitative instruments for assessing instructors' PCK and a predominance of qualitative or self-reported data (Schmidt et al., in prep.).

Chemistry, and organic chemistry in particular, presents numerous complex concepts and learning challenges that instructors must address. High levels of PCK are therefore likely required for instructors to plan, enact and reflect on instruction that effectively supports student learning. However, systematic approaches to analysing the structure, status and development of instructors' PCK in tertiary chemistry remain limited, constraining the ability to draw reliable conclusions from existing research. Organic chemistry is a particularly suitable context for this investigation: as a frequently cited 'gatekeeper' course, overcoming its discipline-specific difficulties is likely to demand advanced instructor PCK.

Research Questions

The following research questions guide the project:

RQ1 What is the status of describing and promoting tertiary lecturers' PCK and what methodological, theoretical or practical research gaps can be identified?

RQ2 How are PCK facets expressed and interconnected in instructors' pedagogical reasoning across different concepts of organic chemistry?

RQ3 What quantitative levels of PCK do organic chemistry instructors exhibit across its facets, and how are these facets interrelated?

Each research question will be addressed in and guide an individual study.

Research Design and Methods

The project combines three different approaches to gain a broad insight into OC instructors' PCK. First, a systematic literature review revealed possible gaps in previous research (Schmidt et al., in prep.). Second, a qualitative think-aloud study using written vignettes, short teaching scenarios framed across instructional planning, enacting and reflecting, will allow for structuring and describing level and interconnectedness of instructors' PCK. Results from this study will serve as basis for the development of quantitative assessment items, which will then be used in an international study on OC instructors' PCK.

For the systematic literature review, identification and selection of publications followed the PRISMA-scheme (Page et al., 2021). After selection, a total of n = 31 unique studies analysing and n = 36 unique studies fostering PCK were coded deductively and inductively. To ensure consistency in the coding, studies were intercoded by a student research assistant. Across all codes, a mean intercoder reliability of $\kappa M = .86$ ($SD = .16$) confirmed a consistent coding strategy.

Study 2 lays the foundation for assessment development. Four vignettes covering core topics in introductory OC will be developed and aligned with the RCM teaching cycle. Vignettes will include stimuli from the literature (e.g., typical representations, documented student conceptions) designed to elicit instructors' pedagogical reasoning. Instructors' responses will be elicited using open-ended questions, each addressing a specific facet of PCK. An estimated 10–12 instructors will work with these vignettes in one-to-one, audio-recorded sessions lasting 45–60 minutes. Participants will be purposefully sampled from instructors responsible for undergraduate OC courses, aiming for variation in teaching role and institutional context with interviews conducted in either German or English. Approval from the faculty's ethics committee is planned to be obtained in January 2026. Informed consent will be obtained for recordings; data will be anonymously collected and stored in accordance with national data protection regulations. Vignettes will be piloted prior to data collection and reviewed by disciplinary colleagues in Ger-many, the Netherlands, and project supervisors to ensure content validity. Transcripts will be segmented into idea units based on the open-ended questions and coded using a combination of deductive and inductive approaches. A priori codes will operationalise the facets proposed by Magnusson et al. (1999) and the competence levels described by Schiering et al. (2022); inductive coding will be used to identify emergent patterns and links in instructors' pedagogical reasoning. A coding scheme will be developed and refined on the basis of the piloting phase. Coing will be carried out independently by two researchers, with discrepancies resolved through consensus; inter-rater reliability will be assessed using Cohen's kappa. Management and coding of transcripts will use MAXQDA, whilst descriptive and sequence analysis will use R. Codes generated in study 2 will guide the creation of an assessment instrument in study 3.

The third study will undertake an international quantitative assessment of OC instructors' PCK. Study-2 vignettes will be converted into suitable item formats (polytomous or closed) according to the qualitative findings. Analyses will follow Item Response Theory principles. Results will yield preliminary insight into the instrument's internal structure and item functioning and will guide subsequent validation work.

Preliminary Findings

The systematic literature review revealed a methodological gap in quantitative research on university instructors' PCK. Most studies either rely on self-reported data, specifically to examine the effects of training methods, or employ qualitative methods to study PCK. Furthermore, most studies are organised around pragmatic analytic frameworks rather than explicit theoretical models. Studies reporting training methods for fostering instructors' PCK typically present implementation details and participant feedback but do not situate these activities within a clear theoretical framework. To address this gap, an assessment instrument will be developed.

Study 2 is expected to produce a discipline-specific dataset comprising verbatim transcripts, segmented response records annotated with facet codes and competence levels, a codebook and a set of exemplar quotations. From these materials, quantitative summaries (per-participant code frequencies, common code sequences and co-occurrence matrices) and initial item candidates including suggested response formats and scoring rubrics will be derived. Data collection is scheduled through mid-April 2026, transcription and coding will follow in May, and preliminary, presentation-ready results are anticipated by mid-June 2026; even with modest sample sizes these outputs will crucially inform item development and response-process validity evidence.

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Beyond lab coats and test tubes: Developing a new instrument for students´ perceptions of an authentic chemistry laboratory

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Focus of the Study

Students' conceptions of an authentic laboratory can be stereotypical, involving people in lab coats or colourful, bubbling test tubes. Students have their own ideas and perceptions of what it should look like (perceived authenticity), however real-life research environments differ (intended authenticity) (Schriebl et al., 2023). To combat these stereotypes, students could visit out-of-school laboratories, as such visits have been shown to produce many positive motivational effects (Itzek-Greulich & Vollmer, 2018). The strength and type of these effects seem to depend on the individual´s sense of authenticity during the visit, which is influenced by personal and environmental factors, as illustrated in Figure 1 (Betz et al., 2016).

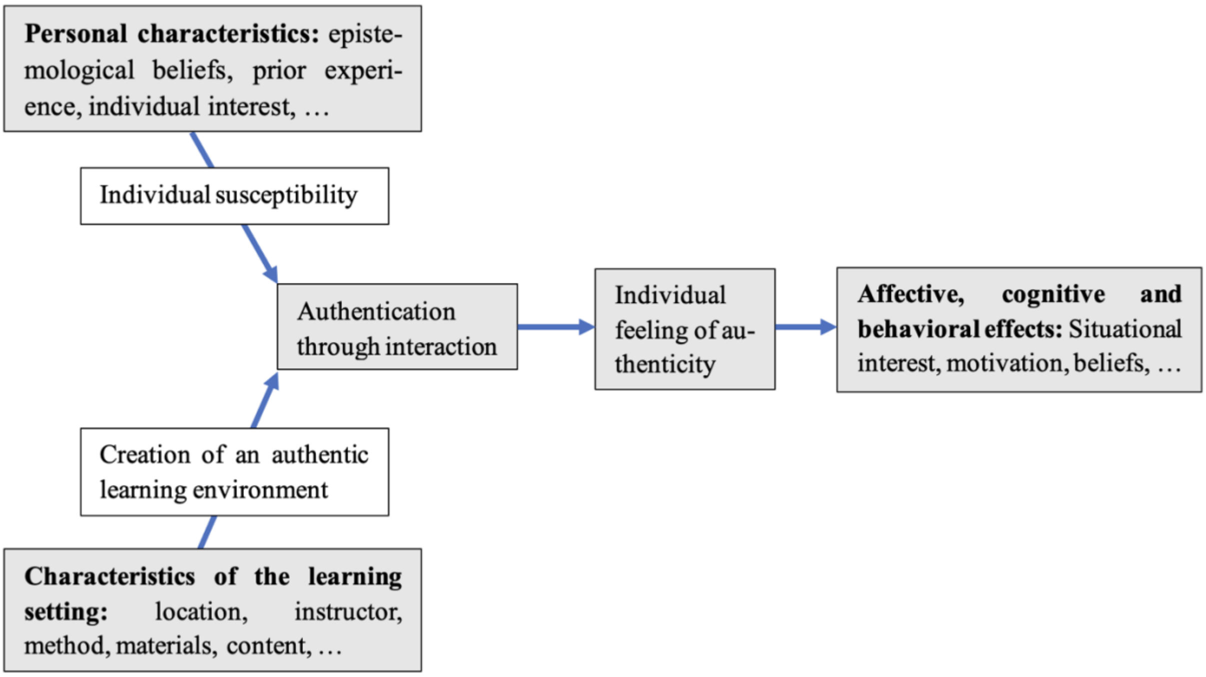

Figure 1: Simplified authenticity model in learning contexts based on Betz et. al. (2016)

Misalignments between students´ internalized expectations and reality can reduce the perceived authenticity of a visit (Hagenkötter et al., 2025). Students who perceive low authenticity may even further decrease their situational interest during such visits (Dietel & Wilke, 2025). To prevent possible negative effects, it is therefore important to gain a better understanding of students' perceptions of laboratories and the underlying reasons behind their views.

Review of Literature

Besides the model shown in Figure 1 (Betz et al., 2016), authenticity in learning environments has been conceptualised in different ways: One approach distinguishes between real-world authenticity (e.g. instructor) and disciplinary authenticity (e.g. equipment) (Schriebl et al., 2023). Another discusses aspects of cognitive realism (e.g. complexity of the learning task) and physical realism (e.g. location, equipment) (Nachtigall et al., 2024). While cognitive realism has received more attention, physical realism has recently been recognised as being at least equally, if not more, important (Hohrath et al., 2024; Nachtigall et al., 2024). Despite this, research in this area remains limited.

In authenticity research a quantitative questionnaire for multidimensional assessment of the perception of authenticity in science education (FEWAW) has been developed, which consists of thirteen Likert-scale questions containing vague phrases such as 'research' or 'scientific materials' (Finger et al., 2022). Studies focusing on those physical aspects such as the person in mathematics (Hagenkötter et al., 2024) or the place and equipment in physics (Schüttler et al., 2021) have used this questionnaire. The questionnaire has been criticised as students may interpret the questions differently due to their varying understanding of research (Hohrath et al., 2024). The questionnaire merely states that 'scientific materials' in the learning environment are considered authentic, without clarifying what materials are why considered authentic.

Qualitative approaches that address similar themes (stereotypical views) do exist: For example, the Draw-a-Scientist Test (DAST) has been used to explore students' images of scientists, and to a lesser extent, research environments. Physical objects besides 'lab coats' and 'eyeglasses' fall under the categories 'symbols of research' and 'symbols of knowledge' (Chambers, 1983). Moreover, drawing-based methods have limitations as answers depend on drawing ability and leave room for interpretation (Reinisch et al., 2017).

Overall, the literature indicates a need for a new type of testing instrument capable of describing what is perceived as authentic in the physical environment without relying on drawings. This new test could explain why a certain place is perceived as an authentic laboratory and which laboratory equipment is considered essential.

Research Questions

The aim of this study is to develop a new instrument that will improve our understanding of what secondary students consider why to be “authentic” in a chemistry laboratory. To achieve this, the following three areas are analysed:

Focus 1: Depictions of laboratories in chemistry school textbooks

a. What devices and equipment are included in laboratory illustrations in textbooks?

b. How does the equipment in research laboratories differ from these depictions?

Focus 2: Students' perceptions of chemistry laboratories in research

a. Which laboratory equipment do students consider typical for research laboratories in chemistry?

b. What criteria do students use to judge the authenticity of laboratory equipment?

c. How can a testing instrument be designed to identify those aspects?

Research Design and Methods

Focus 1 has already been completed following a multi-step process.

A selection of the best-selling chemistry textbooks from Austria and Germany (NRW) was chosen, as the curricula in these regions differ in their emphasis on chemistry. All visual representation of laboratories and laboratory equipment were extracted, analysed and compiled into a frequency list. Additionally, laboratories from each division of the chemistry department at the University of Graz were visited and photographs taken, focusing on modern, larger pieces of equipment.

Because it would be impractical to show students hundreds of different pieces of equipment, only the most common pieces from textbooks and large pieces from the research laboratories were selected. Pictures were used instead of real objects to avoid shifting the focus to the location, and because modern laboratory equipment is not easily transportable. To stimulate discussion, some deliberately inauthentic objects were added (e.g. a telescope,..). An selection of 75 objects was narrowed down to 53 for the pre-test.

For focus 2 a pilot instrument was developed. It begins with a short questionnaire designed to gather statistical data on epistemic beliefs, interests and prior experiences (Urhahne & Hopf, 2004). This is followed by a dyadic interview to enable the in-depth articulation of internalised ideas (Morgan et al., 2016). Further questions aligned with the authenticity model regarding working as a chemistry researcher are then asked (Betz et al., 2016). The main purpose of this is to contextualise the qualitative data. To stimulate discussion, activity-oriented tasks (sorting and ranking) are integrated (Colucci, 2007). Participants are asked to categorise them as typical, non-essential/neutral or atypical, and then to rank the best (top) or worst ones (flop).

The dyadic interviews will be audio-recorded and transcribed and the results of any clustering and ranking tasks will be documented. Data analysis will follow a structured qualitative content analysis approach, using deductive categories derived from authenticity research and inductive subcategories (Kuckartz & Rädiker, 2024). As a complementary form of analysis, the clustering, placement and ranking of the objects will be examined (Lobinger & Brantner, 2020)

A summary of my PhD project can be seen in Figure 2.

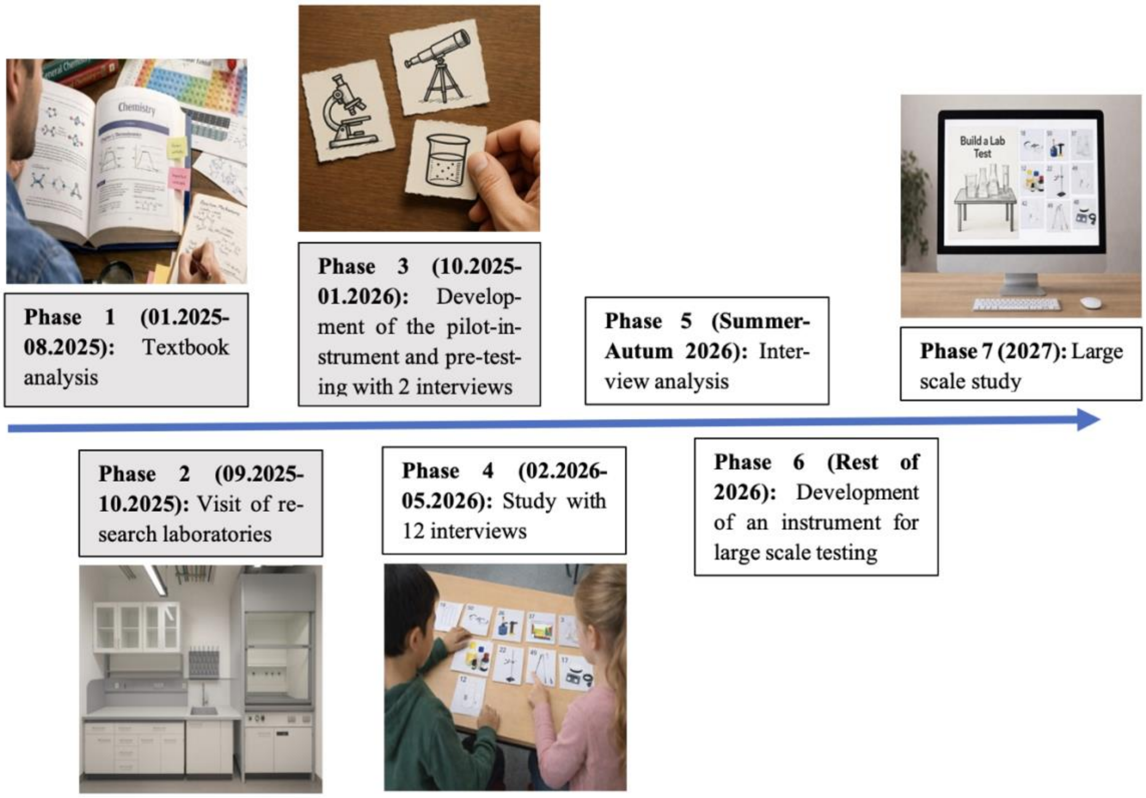

Figure 2: Overview of the PhD progression (Images generated with DALL·E).

Preliminary Findings

The textbook analysis indicates that chemistry textbooks do not accurately depict how chemists work. Scientific laboratories are rarely present (20 out of 2,800 representations) and are often shown in a stereotypical manner (incorrect handling of equipment, colourful tubes, ….). The most frequently depicted laboratory equipment is similar across grade levels and countries. Some pieces of equipment are either completely absent in one country or depicted only a few times, despite being essential in the research laboratories that were visited.

The pre-test primarily served to verify the concept and provide methodological insights. As part of the pre-test two dyadic interviews were conducted with students from the same school but different years. Each interview lasted around 33 minutes, was transcribed, and analysed to determine how the pilot instrument could be optimised. In general, the instrument proved to be effective in identifying authentic equipment (60% of objects were categorised in the same way) and the reasoning for these perceptions (prior usage, material, ...). Based on the results the structure and tasks were revised and the equipment list was shortened. The pilot study will be conducted during the proposal and the ESERA Summer School, and the new data will be discussed and analysed as part of the programme.

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Exploring student decision-making through the journey of taking an undergraduate physics degree

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Focus of the Study

The School of Physics and Astronomy (SOPA) at the University of Edinburgh (UOE) in Scotland offers a range of undergraduate degree programme to students. As of the 2025/26 academic year, there are 13 different undergraduate programmes offered, including both 4-year Bachelor's degrees (BSc) and 5-year Integrated Master's degrees (MPhys). This presents numerous structural pathways that undergraduate students may follow, further nuanced where students may change degree programme or discipline, repeat a year, take a break from their studies, or choose to enter University at the second-year of their studies, the latter an option presented to high-achieving incoming students at Scottish Universities.

While the wide variety of possible structural pathways is clear, less known is what pathways are actually followed by students in practice, and what factors influence this decision-making. Concurrently, there is evidence from within SOPA that demographic factors, such as a gen-der, may influence the pathway followed by a student. For example, work done as part of an undergraduate research project showed that between the 2014/15 and 2023/24 academic years, 42% of BSc degrees awarded on the core Physics programme went to female students, while for the MPhys programme this was 29%, a difference shown to be significant under Chi-squared tests (p=0.05), with an effect size of 1.83 (Hatch, 2025). With this data showing that being a female student is a strong predictor of graduating with a BSc, as opposed to an MPhys, the question has to be asked about the effect other demographic factors, such as social class (Mearman and Payne, 2023), might have on the pathway a Physics student takes.

These long-standing questions have led SOPA to fund this PhD, which is investigating the decisions undergraduate Physics students make. More specifically, this is looking at the `high-level decisions' students make, defined as decisions made during an undergraduate degree that impact the structural pathway a student takes, e.g., choosing to change programme while at University. This PhD also has emphasis on holistically considering the many factors that can impact on student decision-making, as well as taking an intersectional approach in exploring the impact of different demographic factors. The end goal is to better understand student experience throughout taking an undergraduate Physics degree, as well as ensuring findings are made accessible to decision-makers, so as to help inform future policy around this area.

Theoretical Background

This research takes inspiration from previous work done on the student transition into taking a Physics degree, grounded in a broader development within literature moving from considering singles facets involved in transition to holistic consideration of many factors involved (Stafford, 2024; di Martino et al., 2023). Gale and Parker (2014) captured this development, defining three broad conceptualisations of transition. The third conceptualisation, transition as `Becoming', as defined by Gale and Parker, and further developed by Gravett (2021), emphasises that transition into University is part of a wider series of perpetual movements through life, and that transition can be conceptualised as 'Rhizomatic', that is, a complex and non-linear system of interconnecting factors. When put into practice, research methodology associated with this conceptualisation has sought to understand student experience, leading to many researchers deploying qualitative methodologies (Thompson et al., 2021, for example).

While this conceptualisation is associated with a growing research paradigm, there remain gaps in knowledge. Firstly, a need for more discipline-specific research has been acknowledged, especially in the Science, Technology, Engineering, and Maths (STEM) domain (Gale and Parker, 2014; di Martino et al., 2023). Secondly, research has been more focused on the first-year of undergraduate study, leaving experience in latter years of study under-explored. Finally, a regularly reported finding in literature is that student expectations of what studying at University involves can be misaligned with staff members expectations of the capabilities students should have (Mearman and Payne, 2023); Despite this, there remains further scope in literature for incorporation of staff perspectives, especially within a STEM context.

Putting this all in the context of high-level decisions made by students, the conceptualisation seems a good theoretical fit, with decisions made before and during a Physics degree being linked to personal transitions, and the Rhizomatic conceptualisation providing a framework for thinking about the number of potential student pathways, alongside the multitude of motivating factors connected. The conceptualisation also provides a bedrock motivating the methodology of this study. Finally, the presented gaps in knowledge, alongside the influence of demographic factors, form key ideas this PhD is investigating, and gives basis for the research questions presented, and interviewing both staff and students.

Research Questions

What high-level decisions, and associated motivating factors, do staff perceive students to make during undergraduate Physics degree pathways?

What kind of high-level decisions do students recognise they make throughout undergraduate Physics degree pathways, and what do they also cite as motivating factors for these decisions?

Are student and staff perspectives on what high-level decisions are made by undergraduates during the process of taking an undergraduate Physics degree aligned?

Do demographic factors, such as gender or the way a student is funded to study, have an impact on the high-level decisions made by students during this process?

Research Design and Methods

Research Ethics

Ethical approval for all stages of this research has been received from the SOPA Ethics and Integrity Officer. Any party wishing to participate has needed to give written consent.

Interviews

Semi-structured interviews were decided on as the main data collection method. Interviews have been commonly used in prior research in this area (DeWitt et al., 2019, for example), and using a semi-structured format allows an interviewer to gain detailed perspectives from participants, while also allowing time for interesting points raised to be explored. It is anticipated most interviews will be in a one-to-one format, between the interviewer and participant, but paired interviews between an interviewer and two participants who know each other well are also being offered and occasionally taken up. The latter format gives benefits such as al-lowing participants to feel more comfortable in a setting, as well as allowing participants to give complementary perspectives on one another (Wilson et al., 2016). Interview sessions with participants have been advertised as lasting 30 minutes, and in practice have lasted be-tween 20 and 40 minutes.

For staff interviews, participants from within SOPA were directly recruited using purposive sampling, with the deliberate goal of getting participants from a wide cross-section of roles. In total, 12 members of staff participated: 7 identified as Male, and 5 identified as Female; 6 participants described their role within SOPA as Academic with a Teaching and Research Focus, 3 described their role as Professional Services, 2 described their role as a Teaching-Focused Academic, and 1 selected prefer not to say; 7 participants had 15+ years of experience within SOPA, while 2 had 9-15 years, and 3 had 3-9 years of experience. No further demographic information was collected.

Staff interviews sessions took place between October and November 2025 in participant's offices, or meeting rooms where this was not possible, and were all run by the author. Each session followed a protocol that touched on topics including why students initially chose to study Physics, and the changes between degree programmes students choose to make. There were six main questions, some of which had associated sub-questions that were explored where judged necessary by the interviewer.

For student interviews, the protocol will have a similar structure to the staff protocol, covering the same topics. However, the student protocol is further supplemented additional sub-questions based on responses from staff interviews. Recruitment for these interviews (which are happening in this forthcoming semester) will be focused on final-year Physics students, including both BSc and MPhys students. This focus arises due to the need for students to reflect on the entire experience of studying for an undergraduate Physics degree, and to explore the high-level decisions they made along the way.

Recruitment will involve promotion of the study through posters, emails, and talks, through which students will be able to self-select. The self-selecting sample will then be complemented with purposive sampling of students from backgrounds underrepresented in the sample, so as to ensure the diversity of voice that is a core principle of intersectional research (Hunting, 2014). There will also be collection of a range of demographic factors. A key goal of data analysis will be to surface how these demographic factors can combine to influence decisions made by students. It is aimed to do 20 student interviews.

Data Handling and Analysis

All interview sessions are being recorded on a Dictaphone. After each session, audio recordings are transferred to a secure folder on the UoE system, and removed off the Dictaphone. An initial transcription is then produced by passing files through the transcribe feature in Microsoft Word, and gone through manually to correct transcription errors, as well as removing any identifiable information linked to the participant.

Data analysis is being done following the six phases of Reflexive Thematic Analysis (RTA) originally set out by Braun and Clarke (2006). RTA offers flexibility with the theoretical lens a researcher can take, and this work deploys a more inductive, semantic, and descriptive approach, with thematic structures built from the data content in a ‘bottom-up’ manner, and with greater focus on surface-level meanings (Braun and Clarke, 2022). The first phase of ‘familiarisation’ is being done by the author reading through the transcripts and noting down initial thoughts, followed by a second set of generalised notes. It is planned the second phase of ‘coding’ will use NVivo. Codes produced by the researcher will then be printed onto physical cards, and be arranged to physically visualise and develop themes, in line with previous work done by the author (Stafford, 2024).

Preliminary Findings

At the time of writing, analysis of staff interview data is at the familiarisation stage. However, there are already a number of prevalent phenomena, and a selection are presented here. Certain movements between degree programmes have been mentioned, with the most prominent being from the core Physics programme into the Theoretical Physics programme, specifically linked to students wishing to avoid practical laboratory modules. Student's incoming expectations of what Physics involves are not necessarily aligned with reality, for example not anticipating the amount of mathematics involved. Finally, some staff expressed a lack of under-standing of what student's overarching motivations are of getting a Physics degree.

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Characterisation of upper-secondary students' system thinking in chemistry-related contexts

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Focus of the Study

Global challenges such as climate change and biodiversity loss arise from complex systems with scientific, sociocultural and economic dimensions. Addressing these challenges requires learners to make sense of complexity. In chemistry education, this involves understanding chemical phenomena, ex-plaining how and why chemical processes occur and recognising their interrelationships and consequences (Cooper & Stowe, 2018). Ocean Acidification (OA), the dissolution of atmospheric carbon dioxide in seawater leading to a decrease in ocean pH, serves as an example of such a complex phenomenon (Falkenberg et al., 2020). Because OA involves multiple entities and causal pathways, it is challenging for students to understand. This complexity reflects a broader challenge in chemistry education: learners often rely on linear reasoning when con-fronted with complex phenomena (Szozda et al., 2023).

System Thinking (ST) offers a framework for addressing these challenges by focusing on relationships, interactions and consequences within systems (Assaraf & Orion, 2005; Tümay, 2023). ST can be characterised as the ability to view systems holistically, identify interconnections and anticipate outcomes when interpreting phenomena (York et al., 2019). Despite growing interest among educational researchers in ST, empirical research on how students demonstrate ST in chemistry and how it can be supported remains limited. My PhD project aims to contribute to closing this gap.

Theoretical Background and Framework

Chemistry is characterised by emergent phenomena that can't be predicted from individual components and interactions (Tümay, 2016). Emergence is one of the typical characteristics for complex systems (Bielik et al., 2023). Developing an understanding of emergent processes is therefore considered a fundamental aspect of learning chemistry (Seifert, 2022).

Conceptualisation of ST

Early work conceptualised ST as seeing the whole (Richmond, 1993) and recognising structures underlying system behaviour (Senge, 2006). Assaraf and Orion (2005) outline ST as a progression from identifying system components to reasoning about dynamic interactions. Building on these ideas, Gilissen and colleagues (2020) define ST as reasoning about (biological) phenomena using central system characteristics such as boundaries, feedback and hierarchy. For this project a framework by Tümay (2023) was selected. It conceptualises ST in chemistry as an iterative cycle of modelling, predicting and revising explanations, using a CISP-web (Components, Interactions, Structure, Properties) to explain emergent properties. Tümay also describes a novice-expert continuum of ST competence, making it particularly suitable for analysing students' progression.

Ocean Acidification as Context

OA was selected as the context for exploring students' ST with a particular focus on the formation of coral skeletons, which are primarily composed of calcium carbonate. Dissolved atmospheric carbon dioxide alters carbonate equilibria in seawater, reducing carbonate ion availability and impairing calcium carbonate formation. Since calcifying organisms build the base of several food webs, their decline negatively affects other marine species (Riebesell et al., 2018) and humans (e.g. by malnutrition/poisoning, Falkenberg et al., 2020). OA therefore connects atmospheric processes, aquatic chemistry, biological effects and socio-economic impacts, making the context highly interesting for investigating students' ST.

Research Questions

Despite the existence of multiple ST frameworks, empirical studies on upper secondary chemistry students' ST remains scarce.

Phase 1 built a theoretical framework for this PhD project by addressing the following questions:

- RQ1a: How is ST conceptualised in science education?
- RQ1b: Which frameworks are suitable for describing ST in secondary chemistry education?

Phase 2 consists of an empirical investigation of upper-secondary students' use of ST in the context of OA. The aim is to investigate students' ST based on the theoretical understanding developed in the first phase. The guiding research question is:

- RQ2: What characterises upper-secondary students' ST in the context of OA?

The limited empirical knowledge about secondary chemistry students' ST also restricts the development of instructional materials. Therefore, Phase 3 focuses on the suitability of the context OA for fostering ST. The corresponding research question is:

- RQ3: To what extent is the context of OA suitable for fostering secondary chemistry students' ST?

Together, these research questions aim to provide a characterisation of ST in upper secondary chemistry students and insights into their thinking as well as contribute to research about ways to support students' ST.

Research Design and Methods

My project is divided into three phases, each one tending to one of the RQs above.

Phase 1: Theoretical work

To establish a theoretical foundation, a comparative structural analysis (Heinitz et al., 2022) of ST frameworks was conducted (Teplá et al., under review) and the framework by Tümay (2023) was selected.

Phase 2: Development of a ST task

A task using before-and-after images of a fictional coastal landscape with a coral reef was implemented in paired interviews to elicit upper-secondary students' ST in the context of OA. Students explain observed changes, revise their explanations after instructional support and create causal diagram maps to externalise their reasoning. Interview data are analysed using Topic Modelling (TM, Chen et al., 2016) and qualitative content analysis (Kuckartz & Rädiker, 2022). TM supports the identification of recurring patterns in students' explanations, which are then interpreted through qualitative analysis. This approach allows data-driven pattern detection and theory-informed interpretation of students' answers. Students' maps are analysed using the SOLO taxonomy (Niemelä et al., 2018) to assess structural complexity, enabling comparisons of students' explanations before and after instructional support.

Phase 3: Evaluation of the context OA

The revised task will be embedded in a teaching and learning sequence and evaluated using a pre-post design. Planned developments include digitalising the task and using computational modelling tools such as SageModeler (Bielik et al., 2018) to guide students through step-by-step activities targeting selected ST competencies. Data sources will include the pre-post-tests, student-generated models, and completed worksheets and will be analysed using approaches building on phase 2.

Preliminary Findings

At this stage, results from phase 1 and data from the pilot study of phase 2 are available. The pilot study served to test the task design, the interview procedure and the planned analysis methods rather than to draw substantive conclusions about students' ST.

(1) Insights for study design

Pilot data from Phase 2 were used to refine the task, interview procedure, and analysis methods. Paired interviews proved more productive than triads and visual stimuli were revised to reduce unintended foci (e.g. eutrophication). Interview guidelines were also refined to include concise explanations of OA and coral bleaching to avoid conceptual ambiguity. As a result, a refined interview guideline for the main study scheduled for March 2026 is available.

(2) Initial observations from the pilot interviews

The pilot interview data were also used to test the feasibility and usefulness of the planned analysis procedures. Initial analysis indicates that different interview prompts elicit distinct reasoning patterns, supporting a phase-wise analytic approach. As an example, the interview question addressing whether and how OA may affect people living in Austria yielded a five-topic solution determined from a perplexity comparison. TM yielded five interpretable topics:

(1) food supply, fish, prices and availability

(2) political and regulatory aspects

(3) temporal developments, trends and future predictions

(4) definitional and explanatory passages

(5) perceived consequences

Currently, TM is combined with qualitative content analysis to use the topics as deductive categories and, conversely, identify topics from inductive categories. Preliminary analysis of the maps suggests that students' maps are more integrated after the task and that explanations increasingly link phenomena to particle-level mechanisms.

Overall, the pilot study provided insights into task design and data analysis and informed revisions. By the time of the Summer School, data collection for phase 2 will be completed. The Summer School therefore offers an opportunity to further discuss the analytic approach, reflect on the interpretation, refine the methodological integration of qualitative and computational techniques and plan the implementation of the task.

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Visual and cognitive aspects of chemical experiments: the role of visual and verbal signaling in video-based and live demonstrations

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Keywords: eye-tracking, instructional videos, demonstrations, signaling, real- time demonstrations, visual cues, verbal cues

Focus of the Study

This study examines students' understanding of chemical phenomena through real-life and video-based demonstrations in pre-service chemistry teacher education. It is based on the assumption that merely observing chemical demonstrations—even visually appealing ones—does not necessarily result in deep conceptual understanding, particularly at the submicroscopic and symbolic levels. Consequently, instructional design and presentation are expected to play a crucial role in shaping students' visual attention and conceptual understanding.

The primary aim of the study is to compare the effectiveness of real-life and video demonstrations with respect to (a) students' understanding of underlying chemical processes, (b) the allocation and guidance of visual attention, and (c) the identification of critical demonstration elements that are essential for understanding but are often overlooked. Special emphasis is placed on signaling, defined as the use of targeted visual and verbal cues to direct learners' attention toward conceptually relevant aspects of observed phenomena.

Furthermore, the study investigates the effects of adding visual signaling (e.g., arrows, highlighting, symbolic representations) and verbal signaling (e.g., guiding questions, verbal prompts) to both video-based and live demonstrations, examining how these forms of instructional support influence students' cognitive processing and their ability to connect macroscopic observations with submicroscopic and symbolic representations. By combining performance-based measures with eye-tracking data, the study captures learning outcomes and the cognitive processes underlying students' understanding.

The study aligns with current trends in chemistry education research emphasizing visualization, attention guidance, and meaningful cognitive engagement in experimental activities. Its findings are expected to contribute to theory and to the improvement of pre-service chemistry teacher education, particularly regarding the effective use of demonstrations.

Theoretical Background

Chemistry is frequently perceived by students as a difficult and abstract subject [1]. One key reasons is the need to understand processes that are not directly observable, alongside the extensive use of symbolic representation [1]. Research consistently shows that students struggle to connect observable phenomena with particulate-level explanations and symbolic representations [1]. Visualization therefore plays a central role in supporting meaningful learning in chemistry [2].

A widely used framework for analysing chemical representations is the triplet model, which distinguishes macroscopic, submicroscopic, and symbolic levels of representation [3]. While macroscopic phenomena are directly observable, submicroscopic representations (e.g. particle models or animations) and symbolic representations (e.g. formulas, equations) are essential for explaining chemical processes. Research indicates that appropriate integration of these levels supports conceptual understanding and helps address common misconceptions [3].

Experimental activities, including demonstrations and laboratory work, are traditionally considered core components of chemistry education because they link theory with observable phenomena. Experimental activities in general can increase students' motivation and engagement; however, research evidence regarding their effectiveness in promoting deep conceptual under-standing remains mixed [4, 5]. Recent studies suggest that the learning potential of demonstrations depends strongly on instructional design and on how students' attention is guided during observation [5, 6].

Practical constraints, such as limited availability of chemicals and equipment and safety concerns, contribute to the reduced use of experimental activities in chemistry classrooms [7]. In response, video-based demonstrations have gained increasing attention, as they can overcome these limitations. Video demonstrations allow repeated viewing, pausing, and focusing on specific moments, which may support noticing relevant details that could be missed during live demonstrations. However, videos can also overload learners if they contain visually salient but instructionally irrelevant elements [7].

The cognitive theory of multimedia learning [8] highlights signaling as an effective instructional principle for guiding learners' attention and reducing extraneous cognitive load [9]. Signaling refers to cues that highlight essential information and structure learning material [10]. In chemistry education, signaling can be implemented through visual cues (e.g. arrows, highlights, symbols) or verbal cues, such as guiding questions or prompts directing students' attention to key aspects of a chemical process [11, 12]. While visual signaling has been increasingly studied, the role of verbal signaling during demonstrations, especially in comparison between video-based and live formats, remains underexplore [13, 14].

Research Questions

S1:

1. **What differences exist in students' understanding of chemical processes depending on whether they observe a video demonstration or a real-life demonstration?**

   1.1 What differences can be identified in students' understanding of the underlying chemical processes when observing video demonstrations compared to real-life demonstrations?

   1.2 What differences can be observed in students' attention when watching video demonstrations versus real-life demonstrations?

   1.3 Which parts of the demonstrations that are essential for understanding the observed chemical processes are overlooked or perceived to a lesser extent by students?

S2:

2. What is the effect of adding signaling to video demonstrations and real-life demonstrations on students' understanding of chemical processes?

2.1 What is the effect of signaling in the form of attention-directing symbols on students' understanding of chemical processes in video demonstrations and real-life demonstrations?

2.2 What is the effect of signaling in the form of symbolic-level representations (e.g., chemical formulas, equations) on students' understanding of chemical processes in video demonstrations and real-life demonstrations?

S3:

3. What is the effect of verbal signaling added to video demonstrations and real-life demonstrations on students' attention and understanding of chemical processes?

3.1 How does verbal signaling aimed at directing students' attention influence their understanding of the underlying chemical processes in video demonstrations and real-life demonstrations?

3.2 What is the effect of verbal signaling through guiding questions on students' understanding of chemical concepts in video demonstrations and real-life demonstrations?

Research Design and Methods

The study employs a mixed-methods research design combining quantitative and qualitative approaches to capture both learning outcomes and underlying cognitive processes. The research consists of three consecutive studies (S1–S3), each addressing a specific aspect of demonstrations and signaling in chemistry education.

Across all studies, a within- and between-subject design is applied. Participants are divided into two groups to control for order effects and observe paired demonstrations of comparable chemical phenomena. These demonstrations differ only in presentation mode (live vs. video) and, in later studies, in the presence or absence of signaling.

In **Study 1**, students observe three pairs of demonstrations consisting of one live and one video-based demonstration. In **Study 2**, two pairs of demonstrations compare standard versions with **visually signaled** versions. **Study 3** follows the same structure, with demonstrations enriched by **verbal signaling**. The order of presentation is counterbalanced between groups.

Participants are third-year pre-service chemistry teachers enrolled in a teacher education program. The expected sample size is approximately 25 participants per study, with 12 selected for eye-tracking measurements. In Studies 2 and 3, the sample is expanded to include students from cooperating universities, increasing the total sample size to approximately 60 participants to ensure sufficient eye-tracking data.

After each demonstration, students complete worksheets containing open-ended questions assessing conceptual understanding and items capturing perceptions of the demonstration. Based on worksheet performance, 12 participants per study (six with sufficient and six with insufficient understanding) are selected for eye-tracking and follow-up qualitative methods.

Eye-tracking is conducted using mobile eye-tracking glasses for live demonstrations and stationary systems for video demonstrations. Analyzed metrics include fixation duration, number of fixations, saccades, first fixation, scan paths, and predefined areas of interest. Retrospective think-aloud protocols and semi-structured interviews are used to gain deeper insight into students' reasoning. Quantitative data are analyzed using descriptive and inferential statistics, while qualitative data are examined through qualitative content analysis. Ethical standards are upheld through informed consent and data anonymization.

Preliminary Findings

Preliminary findings from a pilot study (Tesárková & Rusek, 2025) provide important insights informing the present project. The pilot investigated differences between live and video demonstrations among third-year pre-service chemistry teachers, focusing on cognitive and affective outcomes.

Analysis of worksheets, discussions, and interviews showed that students primarily focused on visual and effect-based aspects of demonstrations, while underlying chemical processes were often insufficiently explained. Even when macroscopic descriptions were accurate, students frequently struggled to articulate submicroscopic and symbolic explanations.

Live demonstrations were perceived as more engaging and authentic, yet increased engagement did not consistently lead to deeper conceptual understanding. Video demonstrations were often described as clearer and more controllable but still did not reliably support meaningful interpretation. Preliminary eye-tracking data indicated that students' attention was frequently drawn to visually salient but conceptually irrelevant elements, while critical features received limited attention.

These findings highlight the need for systematic attention guidance in both live and video demonstrations. They also underscore the potential of visual and verbal signaling to support the integration of macroscopic, submicroscopic, and symbolic representations, directly motivating the current study.

Planned articles:

- Live vs. Video Chemistry Demonstrations: Effects on Students' Understanding
- Visual Signaling in Live and Video Chemistry Demonstrations
- Verbal Signaling in Live and Video Chemistry Demonstrations

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Bridging the disconnect: A road map to improving diverse student experience

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Keywords: Science, Tertiary Education, Advising, Neurodiversity Focus of the Study

Academic advisers play a critical role in creating a positive learning environment in higher education, yet little research has focused on their perspectives about their roles. Also important, understanding their perceptions and experiences in supporting neurodiverse students. While there has been research into student experiences with higher administration advisement, less attention has been paid to the experiences of academic advisors and their contributions to learning environments. Advisors, working alongside discipline specific faculty managing the program, are best placed to understand student needs and to support students in developing their science identity (Avraamidou, 2019; 2020; 2021; Avraamidou & Osborne, 2009; Shanahan, 2009). As such, it is important to interrogate the roles of academic advisors in creating supportive environments for all students, including those with neurodiversity.

Literature Review

Neuro(diverse) Students and Postsecondary Education

Research into neurodiverse (autism, AHDHD, Dyslexia, etc.) student experience is growing, and "existing studies indicate that wellbeing and employment outcomes tend to be poorer in this population in comparison with their peers" (Hamilton & Petty, 2023, p. 2). Increasing diversity in STEM improves scientific literacy and new ways of understanding the world, and STEM careers provides access to work and environments that support the mental wellness of those identifying as neurodiverse (Bowman et al., 2023; Chown et al., 2019; Jenson et al, 2023; Natcher et al. 2020; Wade-Jaimes, 2020). Diverse ways of thinking and being are critical to novel developments in science, and neurodiverse scientists bring their strengths to improve STEM fields (Jenson et al., 2023).

A focus on deficit bodies supports meritocracy, the idea that you alone can improve your life (whether barriers exist or not) and places the burden of success solely on the student (Nguyen et al., 2023). Chown et al. (2016) considered how struggling with being highly social or having sensory tolerances is a barrier to those with autism spectrum disorder on a highly social and crowded university campus. Those who were diagnosed in the 1990s as having autism but with minimal support needs, are now attending postsecondary institutions and are navigating a system that is not designed with their needs in mind. They can do the work and are highly intelligent people, but some of the processes behind education that are more about networking, marketing yourself to others, and sensory tolerances (like focused attention, sitting for long periods of time, and making direct eye contact) make campus a difficult space for these diverse students to navigate (Chown et al., 2016).

Ableism in Postsecondary Institutions

Ableism, which "perpetuates the myth of a normalized, ideal body or mind to which all people should conform" (Reinholz & Ridgway, 2021, p. 3) limits the potential of students with disabilities to improve their life (Manning & Bozalek, 2024). Ableism conforms to systems of hierarchical-based oppression, and like racism, sorts those into categories (Reinholz & Ridgway, 2021), and "perpetuates the myth of a normalized, ideal body or mind to which all people should conform" (Reinholz & Ridgway, 2021, p. 3). Far worse, "disabilities are pathologized as deviant and even as lazy" (Vandenbussche et al., 2024, p.1) and student differences are not necessarily celebrated, as the right of anyone to study conflicts with the rights of institutions to operate efficiently (Burston, 2015).

Advisors and Student Experience

Since the 1970s, the role of an advisor has been poorly understood (Fricker, 2015; Kaur et al., 2017; Tremblay et al., 2008), and could be due to the influence of gender roles in our society (most academic advisors are women), the overwhelming workload impacting an academic advisors time to reflect on their practice, and the demoralizing debate on whether advising is more of a job than a profession (Diehl et al., 2024; Fricker, 2015; Soria et al., 2024). As well, advising roles may be poorly understood because they are seen as a means of processing paperwork relating to degree progression, but advising involves "a decision-making process during which students realize their maximum educational potential through communication and information exchanges with an advisor" (Fricker, 2015, p. 3) and Aiken-Wisniewski et al. (2010) notes that "this ongoing familiarity with real educational issues based on real students provides the advisor a unique and important vantage point (p. 6).

Central Research Questions

1. What are the challenges that advisors face in enacting their role as advisors?

2. What role can advisors play in improving postsecondary science culture for neurodiverse students?

3. What is a salient framework or heuristic for equitable and inclusive student advisement in postsecondary science programs?

Research Design and Methods

I want to empower academic advisors in their practice to further support students who intersect identities that are disabled, neurodiverse, or historically marginalized (Emery & Anderman, 2020; Mensah-Gourmel et al., 2023; Uttamchandani et al., 2020). I plan to conduct semi-structured interviews with approximately 10 academic advisors (through a convenience and snowball sample) focusing on their lived experiences and reflections through an interpretive phenomenological analysis (IPA) lens (Emery & Anderman, 2020; Smith, 2016). My background and IPA allow for a richer understanding of the experiences academic advisors have while navigating institutional bureaucracy that impacts how they advise neurodiverse students. (Braun & Clarke, 2023; Emery & Anderman, 2020; Smith, 2016).

Preliminary Findings

Currently, I am in the process of gaining ethics approval for my research, and I do not have any data to share. After each interview with an academic advisor, I plan to memo on my reflections while I clean up the interview transcript. I will be using reflexive thematic analysis to guide my analysis and coding of themes, as my former advising experience will be a part of how I find salient themes from my data (Braun & Clarke 2023; Jacobsen & Mustafa, 2019), and I will use those themes to write three manuscripts for my dissertation.

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Promoting students' awareness about climate change mitigation using GIS capabilities via an educational intervention

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Focus of the Study

Geography (Earth Science + Human Geography) in formal education has the power to generate a climate literate generation by contextualising global issues via digital and/or virtual tools. Teachers need not only strong subject-matter expertise, but also empowerment and research-based teaching-learning materials. This study aims to blend lower-secondary school level climate knowledge with geographic information systems (GIS) and finalise this in a form of an online course. This course will be public and free of charge for all Estonian schools to use. As a result, there is a validated and “climate-educationally” effective teaching and learning material, which seamlessly blends two fields of formal Geography education, while cross-generating scientific knowledge to the contemporary geo-educational discourse.

Theoretical Framework

Formal education raises awareness about global climate change (CC) and its mitigation, while CC is mostly discussed in geography lessons (Dawson et al., 2022). There is no coherent definition of what climate change education (CCE) is (Eilam, 2024), but teaching about CC is strongly tied with geography and earth sciences (Dawson et al., 2022; Stevenson et al., 2017), which usually feature at the lower-secondary level. There is a gap between the (desired) curriculum and classroom reality, which usually means little student empowerment and emotional engagement to the CC discourse (Ben Zvi Assaraf et al., 2024; Brommesson et al., 2025; Mogensen & Schnack, 2010). The complexity of CC often results in low detail, but extensive coverage which in turn can be overwhelming for students and drive their interest off (Cross & Congreve, 2021). Students’ emotions also must not be neglected when studying the effects of CCE (Cantell et al., 2019; Ojala, 2023). There is a conceptual model called “the bicycle model for CCE” describing what CCE could ideally be (Cantell et al., 2019). It sets students’ knowledge and thinking skills as factors for moving forward (tires), while values, worldview, and identity are the core (bicycle’s frame) (ibid.). In socio-constructivist theory, students enter the classroom with prior knowledge and attitudes influenced by their social circle, friends, and family (Daniels, 2008). Now with social media, virtual connections challenge classroom-ac-quired knowledge, values and beliefs (Windschitl, 2023). Thus, there is a need to study the in-fluence of social media on students’ conception of CC, additionally to teachers, peers and family (Shepardson et al., 2009).

CC in formal education is often a curricular intervention (Kolenatý, Kroufek & Činčera, 2022). Embedding different forms of geomedia into teaching helps to facilitate a deeper understanding of CC, plus contextualises the learning experience (Mostacedo-Marasovic et al., 2023). Tailoring interventional activities according to students’ present abilities can be done by first assessing their CC knowledge and GIS skills. Age-appropriate and validated instruments, such as tests and questionnaires, covering both CC knowledge and GIS skills cover these topics on a narrow scope and are usually aimed at high schools (Hickman et al., 2021), universities (Di Giusto et al., 2018), or professionals (Siponen et al., 2024). To raise a climate-aware generation with sufficient scientific and climate literacy, the barriers and motivators of students' performance in CCE need to be investigated, as students are reported to have mainly surface-level knowledge of CC and its effects (Feldbacher et al., 2024).

Research Questions

RQ 1. What is the current level and where lies the gap in students' climate change knowledge and GIS skills?

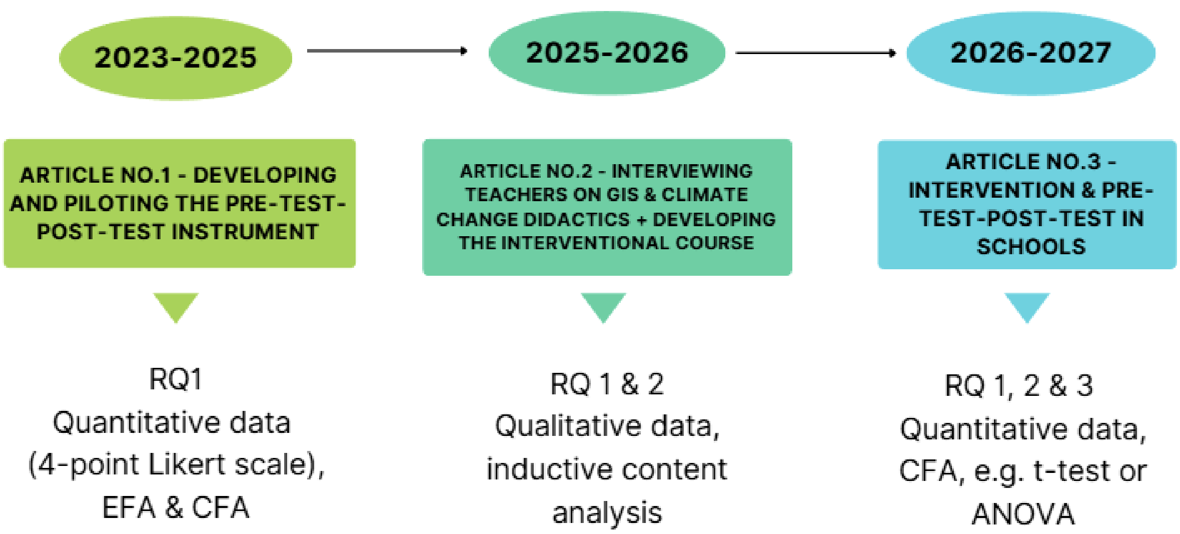
RQ 2. What has been the impact of embedding GIS into the topic of climate change via an educational intervention?

RQ 3. Which factors determine students' conceptualisation of climate, climate change and its mitigation?

Research Design and Methods

This research is divided into separate stages (Figure 1). First, literature review on CCE was done and a based on it, a pre-test-post-test instrument developed (piloted in 2023–2024). In 2025, interviews with purposefully selected Geography teachers were carried out to get their insight about teaching climate change and GIS and to get comments on the content of the prospective online course. In 2026, 8th graders are completing the online course and guided by their Geography teachers who participated in the interviews. Students also fill out the previously developed pre-test and post-test.

Figure 1. Timeline of the research between the years 2023–2027.

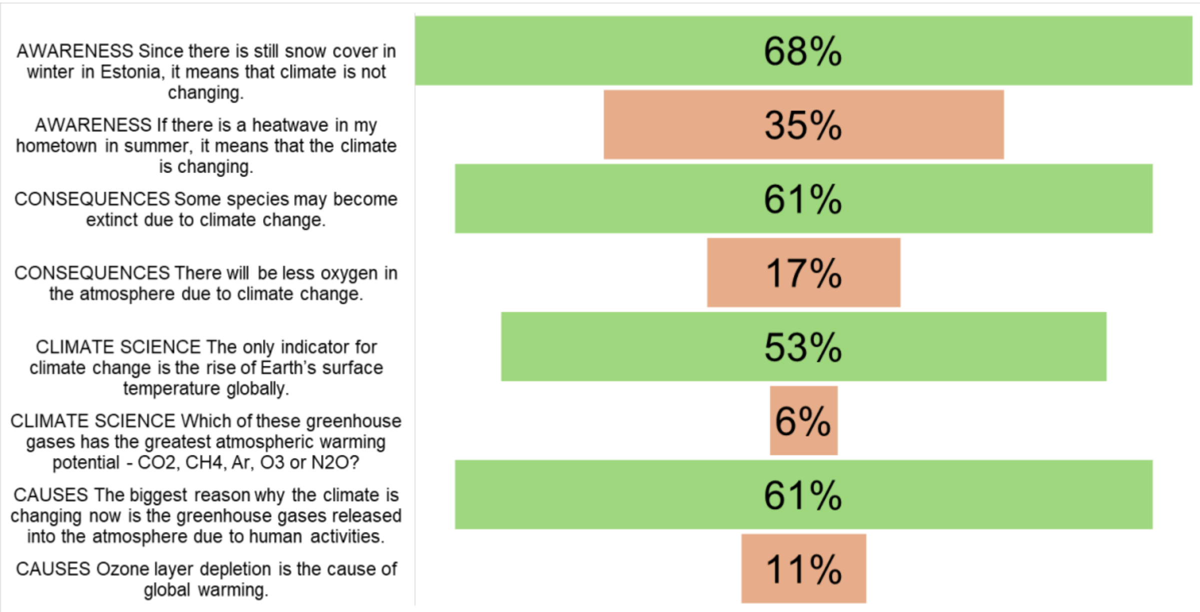


This study uses a mixed-method approach. For RQ 1, an instrument was created, based on previous literature and piloted (Univer, Soobard & Viru, 2025). The instrument consisted of a 4-point Likert-scale questionnaire about values and attitudes regarding CC, multiple choice test on CC and three practical GIS tasks. The answer to RQ2 is combined from teachers' descriptions about teaching GIS and CC, feedback to the interventional course, course's logdata and the results of the pre-post-test. RQ3's answer comes from students' reflections about the intervention, test and questionnaire results, but the conclusions are eventually up for the researcher's interpretation.

Preliminary Findings

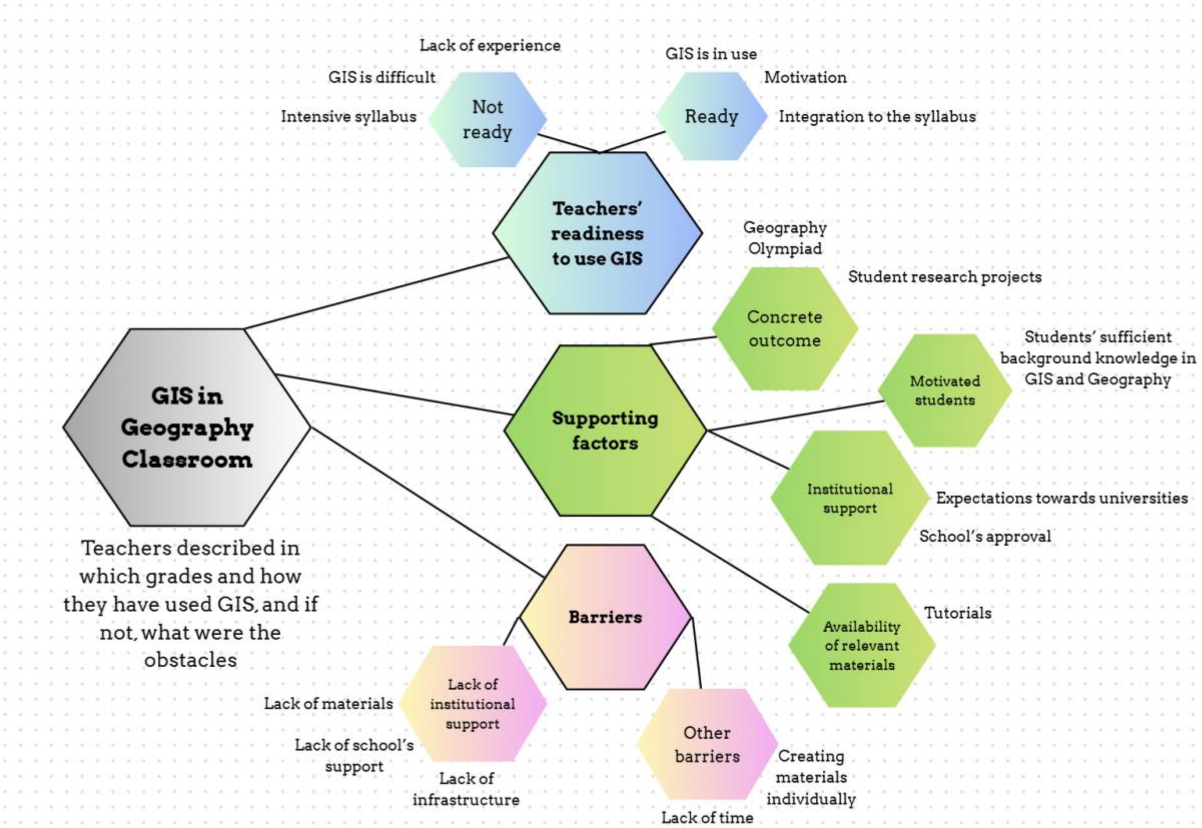
Based on the 1st article's results by Univer et al. (2025), which described the piloting, the pre-test-post-test instrument was deemed fit for further use. Cronbach's alpha showed high internal consistency, while exploratory (EFA) and confirmatory factor analysis (CFA) revealed latent variables, though they were still in correspondence with the bicycle model; unfit items were dropped. Students presented no significant GIS skills as only 19 of them could solve one task out of three correctly. Surface-level climate knowledge was indeed presented (Feldbacher et al., 2024) (Figure 2), albeit students were aware of CC's global and anthropogenic nature. Thus, the awareness did not necessarily constitute sufficient knowledge in CC.

Figure 2. Climate change knowledge test – four assessment categories with their respective highest (green) and lowest (brown) scored item. Modified excerpt from the article by Univer et al. (2025).



13 interviews were conducted with purposefully selected Geography teachers across Estonia. The aim was to get an overview of GIS usage in Geography classrooms, effective CC didactics and which modifications are necessary to the in-development online course. The inductive content analysis (Creswell, 2013) revealed that teachers long for ready-to-use materials and institutional support, whether it comes from school, universities or fellow educators (Figure 3).

Figure 3. Inductive content analysis from the interviews with teachers. Main categories are marked bold; individual codes are floating around the respective sub-categories.



Teachers showed great interest in using the online materials, once published. The online course will be finalized and implemented from March–May 2026, attached with a pre-test and post-test (published in Univer et al., 2025). Both descriptive and factor analyses will be used to interpret the data from tests. Inductive content analysis of teachers and students written comments will be used to explain students' quantitative course results. During the ESERA 2026 doctoral school, first results of this intervention with the online course and tests will be presented and feedback from the participants will be highly valued.

Future of this Study

The thesis cover text should tie three articles and their corresponding RQ's. My expectations to the Doctoral School mentors and the whole group are, to get feedback on the data interpretation and brainstorm on the model construction for effective CC and GIS teaching. Also, is it possible to add a (self-)critical dimension in the thesis, e.g. on critical climate justice or about re-searcher's role in a top-down led intervention? Hopefully, these discussions shape the thesis into more of a refined comment on contemporary education than leave it as a mere report of findings.

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Unlearning coloniality: Developing science teacher identities at the border between Eurocentric and Southern epistemologies in Colombia

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Keywords: Science, Secondary Education, Teacher Education, Decolonial Perspectives

Focus of the Study

Science teacher education in Colombia is shaped by enduring tensions between educational projects oriented toward modernization and integration into the global capitalist system and the country's diverse cultural, territorial, ethnic, and linguistic realities, which are marked by structural inequalities and persistent colonial legacies. Since the mid-twentieth century, reforms pro-moted by state agencies and multilateral organizations have privileged technicist models of teacher education grounded in Eurocentric scientific epistemologies. These models have positioned science as universal, objective, and culturally neutral, reinforcing epistemic hierarchies that marginalize Indigenous, Afro-descendant, rural, and community-based ways of knowing. Despite curricular reforms and national competence standards, undergraduate science teacher education programs in Colombia continue to operate largely within discipline-centered and positivist frameworks, organized around biology, chemistry, and physics as discrete domains. Re-search in science education indicates that such programs often privilege conceptual transmission and standardized competencies, while offering limited engagement with sociocultural contexts, territorial realities, or epistemic plurality (Aikenhead, 2006). As a result, many future science teachers—particularly those from historically marginalized communities—are trained within institutional environments that do not recognize their lived experiences, community knowledge, or prior epistemic trajectories.

This study focuses on how future science teachers in Colombia narrate and negotiate their teacher and scientific identities within a borderland space between Eurocentric epistemologies and local–ancestral knowledges. Teacher–scientist identity is conceptualized as an epistemic and political site where questions of power, recognition, belonging, territory, race/ethnicity, class, and gender intersect. Rather than treating identity tensions as individual deficits or transitional problems, this study understands them as structurally produced and potentially generative spaces for resistance, transformation, and pedagogical re-existence.

The Colombian context is central not only as the empirical site of the study, but also because the researcher is a Colombian scholar situated within these educational, territorial, and historical realities. This positionality informs a commitment to epistemic justice and to producing knowledge that is locally meaningful, while contributing to international debates in science education. In contemporary global contexts marked by socio-environmental crises, growing in-equalities, and renewed struggles for epistemic recognition, examining the coloniality of knowledge in science teacher education is increasingly urgent, as it shapes whose knowledges are legitimized and what forms of science teaching become imaginable.

Theoretical Framework

This study integrates three bodies of scholarship: teacher identity research, science identity research, and decolonial and Southern epistemologies, to examine how identities are formed, contested, and reconfigured within science teacher education.

Teacher identity has been widely conceptualized as a dynamic, relational, and emotionally embedded process shaped by biographical trajectories, institutional conditions, and policy environments rather than as a stable or individual attribute (Beauchamp & Thomas, 2009; Day, 2018). From this perspective, identity is continuously negotiated in response to professional demands, accountability regimes, and moral purposes of teaching. Research further emphasizes that teachers' professional self-understanding is shaped by vulnerability, recognition, and micropolitical interactions within institutions, highlighting identity as an inherently politi-cal construct rather than a purely personal one (Kelchtermans, 2009).

Within science education, teacher identity is closely tied to disciplinary norms that emphasize neutrality, objectivity, and epistemic authority. These norms can constrain culturally responsive and justice-oriented pedagogies, particularly in contexts shaped by neoliberal re-forms and standardization pressures. Identity has also been theorized as a narrative and learning process, constructed through storytelling, reflection, and participation in professional communities (Akkerman & Meijer, 2011). From this standpoint, narrative methodologies are not merely representational but constitutive of identity itself, as teachers make sense of who they are and who they are becoming through discourse and shared meaning-making.

Research on science identity highlights the role of recognition, belonging, and positioning in shaping who is seen—and who comes to see themselves—as legitimate participants in science (Carlone & Johnson, 2007). Building on this work, Avraamidou (2014, 2020) conceptualizes science identity as a "landscape of becoming," emphasizing emotions, affective memory, and intersectionality as central to participation and belonging in science. This per-pective challenges linear and meritocratic accounts of identity development by foregrounding how scientific identities are shaped by power relations and structural inequalities.

Critical science education scholarship has further argued that identity formation in science must be understood in relation to struggles for equity and justice. Calabrese Barton and Tan (2019) introduce the concept of rightful presence to describe how participation in science in-volves not only access but the recognition of learners' cultural, historical, and political identities as legitimate within scientific spaces. This framework resonates strongly with decolonial critiques of science education, which caution that inclusion without epistemic recognition risks reproducing colonial hierarchies.

To conceptualize the intersection of teacher and scientific identities, this study mobilizes a borderland framework, drawing on Anzaldúa's notion of borderlands as sites of contradiction, hybridity, and creative tension. This framework is placed in dialogue with Latin American de-colonial thought on the coloniality of knowledge, which critiques the universalization of Western epistemologies and the silencing of Indigenous, Afro-descendant, and community-based knowledges (Quijano, 2000; Castro-Gómez, 2007; Santos, 2015, 2018). From this perspective, science teacher education becomes a key arena where epistemic hierarchies are re-produced—or contested.

Identity is also understood as discursively produced through processes of positioning, whereby individuals are assigned rights, duties, and moral worth within interactional contexts (Harré & Van Langenhove, 1999). This lens is particularly useful for analyzing how future science teachers are positioned—or position themselves—as legitimate or deficient knowers within Eurocentrically structured teacher education programs. Complementing these perspectives, Roth and Tobin (2007) conceptualizes identity as embodied, ethical, and always in the process of becoming, emphasizing teaching and learning as lived, affective, and material practices rather than purely cognitive achievements.

Finally, research on preservice science teachers underscores that identity tensions are not temporary obstacles to be resolved but enduring features of becoming a science teacher in inequitable educational systems (Beijaard, Meijer & Verloop, 2004; Flores & Day, 2006; Rivera Maulucci, 2013). This insight aligns with participatory and decolonial traditions that position future teachers not as passive

Research Questions

- How do future science teachers in Colombia narrate and negotiate their teacher and scientific identities within science teacher education programs shaped by Eurocentric epistemologies and standardization pressures?
- What tensions emerge between institutionalized scientific legitimacy and local–ancestral knowledges, territories, and community commitments in these identity narratives?
- How do intersecting experiences of territory, race/ethnicity, class, and gender shape recognition, belonging, and positioning within teacher–scientist identity development?
- What forms of resistance, re-existence, and epistemic repositioning are evident in participants' narratives and collective meaning-making?

Research Design and Methods

The study adopts a qualitative, participatory research design grounded in decolonial and Southern methodological traditions. Participants are future science teachers from Indigenous, Afro-descendant, rural, and working-class communities across multiple Colombian regions, enrolled in undergraduate science teacher education programs.

Data are generated through pláticas, a dialogic and relational methodology rooted in Chicana feminist scholarship and resonant with Colombian community practices such as la con-versa and círculos de palabra (Delgado et al., 2023). Pláticas are conceived not as interviews but as intersubjective spaces that prioritize trust, horizontal epistemic authority, and co-construction of meaning. This approach explicitly challenges extractivist research models by positioning participants as co-constructors of theory rather than informants. Over approximately two months, participants engage in four virtual plática sessions focused on:

(1) biographical trajectories and early identity reflections;

(2) tensions between teaching and scientific identities;

(3) coloniality of knowledge, territory, and ancestral knowledges in science education; and

(4) collective consolidation of emerging tensions and categories.

Additional data sources include reflective journals written before and after each session, the researcher's reflexive fieldnotes (sentipensante notes), and an arts-based component in which participants create a collage as an expressive synthesis of identity negotiations and future asprations.

Data analysis follows reflexive thematic analysis (Braun & Clarke, 2006, 2021), informed by decolonial and feminist perspectives. Analytical categories are developed through iterative dialogue with participants, emphasizing co-interpretation and collective meaning-making. A longer-term goal of the project is to translate these qualitative categories into a decolonial teacher–scientist identity instrument, developed participatorily and grounded in territorial and epistemic specificity

Preliminary Findings

Data collection is ongoing. Initial engagement suggests that participants experience Colombian science teacher education as a contradictory space: simultaneously a pathway to professional recognition and a site of epistemic exclusion. Early narratives reflect struggles for recognition and belonging that mirror patterns identified in science identity research, where legitimacy is unevenly distributed and closely tied to dominant epistemic norms (Carlone & Johnson, 2007; Avraamidou, 2014, 2020).

Participants' accounts also resonate with notions of rightful presence (Calabrese Barton & Tan, 2019), as they articulate desires not only to teach science but to do so from their territories, histories, and community commitments. Emerging themes include affective ties to ancestral knowledges, experiences of internalized coloniality, and practices of resistance and re-signification. These preliminary insights reinforce the relevance of a borderland framework and underscore the contemporary importance of decolonial perspectives for understanding teacher–scientist identity development.

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A gender equity programme for science centres and museums

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Focus of the Study

The underrepresentation of women in STEM remains an urgent and well-documented issue. As such, a variety of different kinds of resources, policies, and educational initiatives have been developed to attempt to address this issue. A lot of these resources, policies, and educational initiatives talk about gender equality. But, when taking a closer look, they are often focused only on the gap between men and women. This is a typical practice in research and policy documents on gender and STEM, and while women/girls are undoubtedly an important group underrepresented in STEM, they are not the only group underrepresented in the field.

People from certain racial and ethnic groups, LGBTQIA+ persons, as well as persons with disabilities, are also consistently underrepresented in STEM (European Commission, 2022; National Center for Science and Engineering Statistics, National Science Foundation, 2021; United Nations Educational, Scientific and Cultural Organization, 2022). A reason LGBTQIA+ persons might be underrepresented in STEM is that a lot of studies and policy documents concerning gender and STEM treat gender as something fixed and binary, synonymous with biological sex. Such a conceptualisation offers a narrow and problematic understanding of gender that not only remains oblivious to how society shapes gender roles and expectations but it also excludes important groups from potential solutions. To create a truly gender-inclusive environment I argue for non-fixed/non-binary conceptualizations of gender as social and performative.

Engaging with a non-fixed/non-binary conceptualization of gender is important not only for education purposes but also for public engagement with science. Considering the inconsistent and often binary conceptualization of gender in research, it is unsurprising that the general public would have a similar fixed and binary view of gender. The general public is likely to get their ideas about gender through sensationalized popular media that often focus on gender discourse without covering the definition of gender. The idea that gender is fixed and binary also automatically leads to the thought of gender identities that do not fit in that binary as something unusual, strange, and scary. Instead of something normal that is incomparable to biological sex.

For that reason, my PhD study focuses on gender and STEM with a specific focus on non-fixed/non-binary conceptualizations of gender, the concept of equity, and the importance of intersectionality. These topics of focus are the result of the first paper of my PhD, an umbrella literature review study that has been completed and will hopefully be published this year. To build on these topics of focus and to take a step towards connecting a performative definition of gender to the general public the second and third study of my PhD will focus on the design, development, implementation, and evaluation of a gender equity training module for science museums/centres to promote a gender-inclusive STEM environment.

Theoretical Background

The underrepresentation of women in STEM, often referred to as the Gender Gap, is a well-documented and discussed problem in policy and research reports. And for good reason: women are severely underrepresented in Science, Technology, Engineering and Mathematics (STEM) disciplines across the world. According to the World Economic Forum, women comprise only 28.2% of employees in STEM fields worldwide in 2024 (World Economic Forum, 2024). Similarly, a 2024 global education monitoring gender report by UNESCO shows that in 2018-23, women accounted for only 35% of STEM graduates (UNESCO, 2024).

However, while women and girls are the most thoroughly documented group underrepresented in STEM they are not the sole group underrepresented in STEM. People from certain racial and ethnic groups, LGBTQIA+ persons, as well as persons with disabilities, are also consistently underrepresented in STEM (European Commission, 2022; National Center for Science and Engineering Statistics, National Science Foundation, 2021; United Nations Educational, Scientific and Cultural Organization, 2022).

As briefly mentioned before, gender is conceptualized in an inconsistent manner in research and policy. According to the European Commission's policy initiatives to UNESCO and SDG5 of UNDESA, for example, gender equality is specifically about empowering women and girls (European Commission, 2022; GLSEN, 2020; United Nations Department of Economic and Social Affairs, 2022; United Nations Educational, Scientific and Cultural Organization, 2022). Numerous studies in the field have treated gender as a women's issue in such a way that gender and sex would seem to be interchangeable terms, as if only women are victims of gender inequality (Marosi et al., 2024). Marosi and colleagues (2024) highlight that reports on the representation of minorities in STEM often lack a demographic overview of the gender and sexual minorities in STEM education and workforce, i.e. Lesbian, Gay, Bisexual, Transgender, Queer, Intersex, Asexual and other gender and sexual minorities. (LGBTQIA+ or queer). According to them not only should research move beyond obsolete definitions of gender as fixed and binary towards performative definitions but queer individuals should also explicitly be included in studies on gender (Marosi et al., 2024)

Other researchers suggest similar conceptualizations of gender as a performance. Xu and colleagues (2025), for example, define gender as the socially learnt roles, behaviours, activities and attributes that any given society considers appropriate for men and women (Xu et al., 2025).

Another issue that cuts across current policy reports is that gender equality and gender equity are often perceived as being synonymous and are used interchangeably. However, equality and equity are not the same. Equality concerns providing everyone with the same resources, opportunities, and treatment. However, providing everyone with equal opportunities, resources, and treatment assumes that everyone starts on equal footing. Equity, on the other hand, recognizes that people do not start off on equal footing but have different access to resources, power, and life experiences. Thus, equity concerns giving everyone the resources they need to reach the same outcome rather than giving them equal resources.

The continued use of the word equality in research concerning gender and the indication of the problem as a 'gender gap' suggests an understanding that the problem of underrepresentation in STEM fields is a problem of numbers. Which consequently leads to research into solutions that are similarly focused on numbers. It implies that simply equalizing the number of women and men in STEM would solve the problem. However, our previous research shows that this problem goes beyond numbers, numerical parity will, for example, not solve such problems as teacher bias or wage gaps.

Finally, it is important to note that a lot of the research on gender and STEM presents factors influencing the gender gap as their own separate influence. Our previous research, however, makes it clear that, in reality, these factors are not independent from each other. To provide a concrete example, stereotypes might be perceived as one of the most important factors contributing to the gender gap in STEM, but it is impossible to look at stereotypes independently. Motivation or performance may, for example, influence stereotypes, either positively or negatively. Conversely, stereotypes might influence motivation or performance, either positively or negatively.

In addition to that, gender is not the sole contributing factor to the underrepresentation of underrepresented groups in STEM. Other factors that lead to inequity such as SES, race, or disability are often overlooked in research. But people with multiple marginalized identities have to overcome the stereotypes associated with these identities all the same if they want to fit in in STEM. As such we believe it important to apply an intersectionality lens in research concerning gender equity.

Research Questions

My PhD study as a whole will consist of three papers, of which one is already finished. The main research question for the first paper is: What is the main focus of prior research concerning gender equity in STEM fields? The second paper aims to answer the following question: What are the characteristics of a gender equity training for science museums/centres to promote a gender-inclusive STEM environment? The third and final paper aims to answer the following question: What is the impact of a gender equity training for science museums/centres on people's perception of gender?

Research Design and Methods

The first study of my PhD was an umbrella literature review study. The second and third papers are part of a design-based research, which includes an analysis of the problem through a content analysis of specially-selected exhibits, focus groups with relevant stakeholders, design and implementation of a gender-inclusive training program, pilot testing and redesign.

Table 1. Overview of the papers in my PhD study

Paper	RQ	Methods of data collection	Methods of data analysis
1	What is the main focus of prior research concerning gender equity in STEM fields?	Systematic umbrella review	Content analysis through the PRISMA methodology
2	What are the characteristics of a gender equity training for science museums/centres to promote a gender-inclusive STEM environment?	Focus groups, interviews, exhibits' design	Qualitative, in-vivo and open coding techniques, content analysis
3	What is the impact of a gender equity training for science museums/centres on people's perception of gender?	Focus groups, interviews, training assignments	Qualitative, in-vivo and open coding techniques, content analysis

Preliminary Findings

The second study has not yet started but will be partly based on the umbrella literature review study that was conducted last year and is planned for publication this year. The analysis and findings of that literature review formed the basis of our decision to create a training focusing on non-fixed/non-binary conceptualizations of gender, the concept of equity, and the importance of intersectionality.

By the time of the summer school, it is likely that more data will have been collected through focus group discussions and work on the second paper will have started.

Additionally, by the time of the summer school, I will be close to the middle of my PhD trajectory. At that time, I will need to have almost finalized the conceptualization and design of my empirical research and will be prioritising the development of my research skills (e.g. mixed methods). I expect the summer school to benefit me through receiving feedback from others for the purpose of fully finalizing the conceptualization of my empirical research. I also expect to benefit from expertise that is not available at my institution, especially research methodology training at the PhD level that will help me improve my scientific work and contribute to the finalization of the conceptualization of my empirical research.

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Science teachers integrating new vision on scientific literacy: How do they build their teacher identity and what do they notice?

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Keywords: Scientific Literacy, Secondary Education, Teacher Identity, Teacher noticing

Focus of the Study

To navigate an increasingly complex world with challenges such as the climate crisis and wide-spread misinformation, teachers need to integrate scientific literacy (SL) to enable students to critically evaluate science and society. Over the last 50 years, SL has become an explicit educational goal describing a set of skills and knowledge that are important to teach (Sjöström & Eilks, 2018; Valladares, 2021). Currently, critical thinking, action-taking and citizenship education are, amongst others, discussed as novel aspects of SL. New educational goals also require different teacher competences, such as noticing the personal experiences, attitudes and opinions of students as resources for learning (Sjöström, 2024; Valladares, 2021). These new ideas about SL fundamentally reform science education and shift the role of the teacher, posing new challenges for science teachers who have few or no prior personal experiences with this new form of education (Avraamidou, 2014; Sjöström & Eilks, 2018). Teachers need to develop expertise to fit educational goals including new aspects of SL and to overcome reform challenges, such as working through expectations and overcoming insecurities while adjusting their role as teacher (Avraamidou, 2014). Accordingly, to offer proper support and learning opportunities for science teachers to develop SL-minded teaching expertise, we use an identity lens to examine how they see their role and deal with reform challenges. Furthermore, to understand how science teachers recognize and integrate SL in the classroom, we examine teacher noticing.

Theoretical Background

Scientific literacy

Over time, the concept of SL has been defined in various ways, as understandings of SL are shaped by social, political, and cultural contexts. To conceptualize the diversity of SL definitions, Roberts (2007) described two visions on SL. Vision I is often described as traditional science education with the focus on scientific knowledge and processes for future application. Vision II strives for a pragmatic, contextual approach in science education (Roberts, 2007; Sjöström, 2024; Valladares, 2021). Lately, researchers are expanding on the notion of SL suggesting Vision III with a transformative and emancipatory view on SL, which fundamentally reforms science education (Sjöström & Eilks, 2018; Sjöström, 2024; Valladares, 2021). Despite its importance, the development of science teachers in relation to Vision III reforms remains underexplored, in contrast to Vision I and II.

Teacher identity

Becoming a science teacher who values and engages in reform-based practices in line with Vision III involves more than acquiring a new set of knowledge or skills, and this process may be better understood when considering it as developing a new professional identity. Broadly, teacher identity can be described as the way teachers view and understand themselves as teachers (Engeness, 2020). Teacher professional identity is dynamic, constantly developing, and has shown to be a guiding force in teacher practice. Individuals constantly negotiate who they are and who they are becoming as they encounter new experiences and re-interpret past experiences (Munzer & Van Es, 2024). Reforms in science education lead to new experiences and can both support and create tensions for teacher identity development. Teachers can learn from these changes, but it can also hamper their practice. They have various opportunities to develop their professional identities, but these opportunities differ between in-service (IST) and pre-service teachers (PST), for example lectures and internships in the case of PST or teacher development groups for IST. Thus, we suspect different development paths for IST and PST, which merits researching both. With the Vision III reforms, we expect science teachers will develop new professional identities. However, research on these new emerging identities is currently lacking.

Teacher noticing

How and what science teachers notice in their classroom is important for students learning science (Munzer & Van Es, 2024). To effectively teach Vision III science, teachers need to be able to notice and build on student thinking and engagement, adjusting their instruction to support their students' learning. Attending to important features in the classroom, interpreting them and deciding to act, are nested processes of teacher noticing guided by teachers' prior experiences and frames on teaching and learning (Louie et al., 2021). Developing more awareness of the relationship between one's identity and classroom practice may help teachers to expand or change their interpretations of noticed events that in turn influences their developing professional identity (Munzer & Van Es, 2024). Professionalization activities such as lesson-studies or video-clubs, can provide the opportunity for teachers to reflect upon their teaching (Lee & Choy, 2017). However, IST and PST require different support. It remains unclear how to sup-port teachers in developing teacher noticing aligned with Vision II and III, as most existing research has focused primarily on Vision I.

Research Questions

We translated the challenges above into the following research questions:

RQ 1: How does PST teacher identity develop during a 5-month teacher training course on Scientific Literacy Visions II and III?

RQ 2: How and what do PST notice regarding Scientific Literacy in student thinking and engagement in a lesson study?

RQ 3: How does IST noticing develop in the context of a video-club on Scientific Literacy Vision III?

RQ 4: How do science teacher identity and teacher noticing influence each other during professionalization activities for PST and IST about Scientific Literacy Vision III?

Research questions 1, 2 and 3 will be addressed in individual studies. Moreover, the outcomes of the second and third studies will be used to address research question 4.

Research Design and Methods

To understand how science teachers develop a Vision III SL-minded teacher identity, we opt for a qualitative research approach. Science teachers from the different disciplines will be included, because Vision III is part of their curricular goals.

For Study 1, we collected longitudinal data from twelve PST who participated in a new course. During the 5-month course, PST learned about Vision II and III of SL, and conducted a curriculum analysis and lesson-study. Congruently, identity work was promoted by means of a per-sonal reflection journal. To examine identity, we collected data through semi-structured inter-views on personal experiences with 9 students and personal reflection journals. For analysis of the transcripts and reflection journals, both deductive coding based on the framework Three-Dimensional Space Narrative Structure from Clandinin and Connelly (2000) and inductive coding will be performed in Atlas.ti to identify themes in the development of teacher identity.

For Study 2, we are interested in how and what PST notice in student thinking and engagement regarding SL in a lesson-study. We will use personal reflection journals and audio recordings and videotapes from the lectures at university when PST discuss their lesson-study planning, execution and reflection. For analysis, deductive and inductive coding of the recordings and reflection journals will be performed to identify how and what teachers notice and its relationship with teacher identity.

For Study 3, we aim to create a better understanding of how teacher noticing focused on SL Vision III develops. For this purpose, we will set up a video-club with IST who have different levels of expertise. Teachers are asked to design lessons focusing on a particular Vision III topic that will be determined based on studies 1 and 2. Teachers will gather every two months to analyse fragments of their recorded lessons. Data will be collected through recording the video-club meetings and personal reflection journals. For analysis, both deductive and inductive coding of the recordings will be performed to examine how teacher noticing develops and its relationship with teacher identity.

Preliminary Findings

In the initial analyses of Study 1 we focus on thematic analysis and give two examples of *themes*.

Personal opinions: Both the personal and professional side are relevant in developing teacher identity, as PST experienced both tensions and alignment between personal opinions and their role as teachers. One example reflects on the importance and target group of Vision III:

> "*Because I also notice that my personal opinion on scientific literacy is very different from my teacher's opinion. And I still find that difficult to reconcile (...). Because in my personal opinion, I'm not convinced that people need to be very scientifically literate ... While I do think it's important, it's simply part of citizenship. But I'm still a bit torn."* (PST I)

Classroom conversations: Integrating Vision III in their lessons led to numerous classroom conversations in which the personal opinions and emotions of students were more involved.

> "*I think that with physics, the student is kind of outside the subject. (…) And the moment you implement scientific literacy, it becomes much more present, or something. Yes. I think it's more personal. (…) And I find that very interesting, because then you form a completely different connection with those students. And that's also important for me as a person. Or for me as a teacher, too.*" (PST B)

Analyses for Study 1 will be completed in the first quarter of 2026. Data collection for a pilot Study 2 is planned for the first half of 2026. By the time of the summer school, we will be able to discuss the results of Study 1 and the final design of Study 2.

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Teaching sensitive and controversial issues in the natural sciences: An interview study mapping the associations among determinants of classroom tension and protective approaches.

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Focus of the Study

Should we use nuclear energy to combat climate change? Are vaccines safe? Are you pro-life or pro-choice? While these questions may evoke discomfort, teachers across the globe address such Sensitive and Controversial Issues (SCIs), whether introduced deliberately or arising spontaneously during classroom interactions. In doing so, they foster empathy, multiperspectivity, and critical thinking among students, thereby contributing to the development of active, democratic citizens capable of peaceful coexistence (Karousiou et al., 2025).

Despite SCIs being embedded in secondary education curricula in numerous countries (Chen & Xiao, 2021), their presence in actual teaching practice is limited (Borgerding & Dagistan, 2018; Karousiou et al., 2025). One reason for teachers' uncertainty around implementing SCIs is the diversity of viewpoints these issues can expose (e.g. Pitiporntapin et al., 2016). As Campbell (2007) noted, students in more diverse classrooms, and thus more different viewpoints, are less frequently exposed to discussions on SCIs in the classroom, indicating that teachers may avoid confrontation in more diverse settings. With increasing classroom diversity (Geldof, 2018), it is expected that more topics are becoming sensitive and controversial in society, potentially leading to more Classroom Tension (CT) in secondary education.

When teachers perceive CT, they may adopt protective teaching approaches (PAs), such as carefully selecting their words or referring students to colleagues for further discussion. However, depending on the context, these PAs may hinder the achievement of teaching and learning goals, e.g. when the topic is avoided or minimised (Hess, 2004). Such situations are clearly not ideal, and research is needed to support teachers in navigating CT during the teaching of SCIs effectively, thereby reducing the likelihood of undesirable PAs.

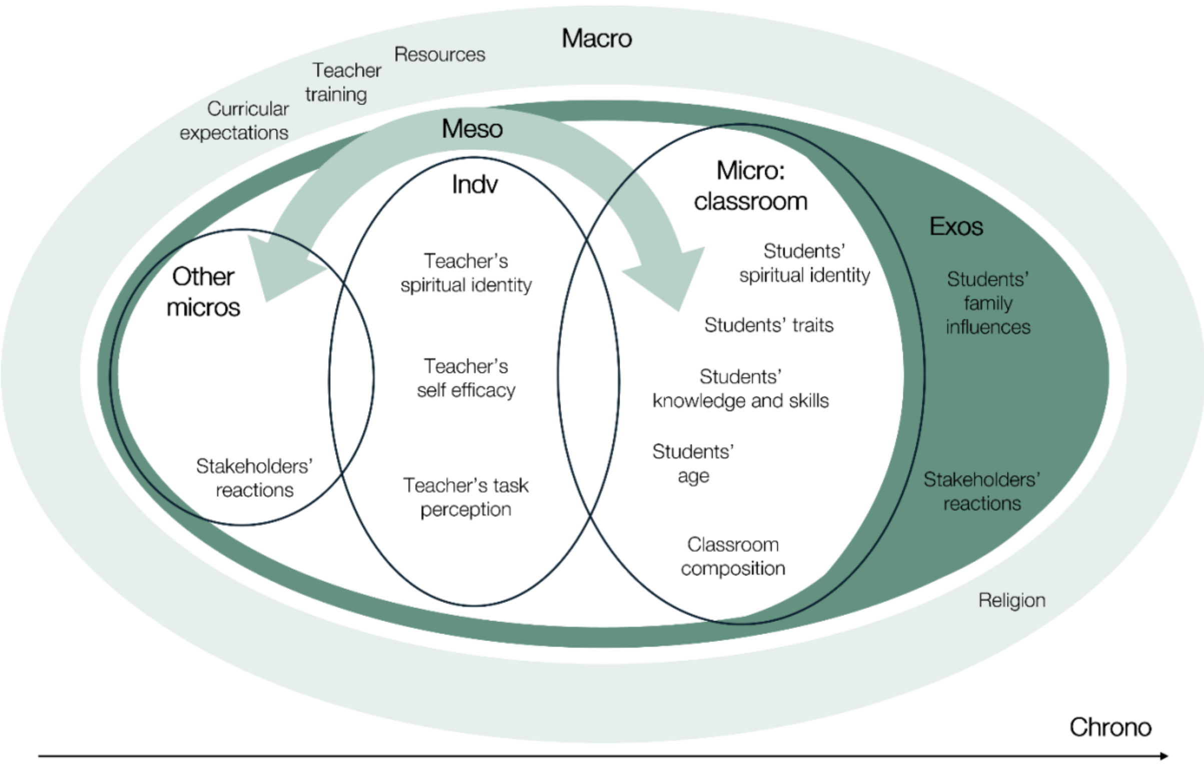
Several studies on teaching SCIs in secondary education have already been conducted. These often focus on potential teaching strategies rather than on the determinants that precede them (e.g. Owens et al., 2017; Reis, 2025). However, identifying the determinants of PAs (and CT from which they arise) when teaching SCIs is a crucial step before questioning which teaching strategies are most appropriate.

Moreover, many of these studies assume that certain topics are inherently controversial. Yet, SCIs may create tension in one classroom but not in the other (Wansink et al., 2024). This implies that topics become SCIs when their dynamic interaction with context determinants results in CT.

Theoretical Background

In a previous systematic literature review (Vanhove et al., Unpublished), we developed a tentative framework of determinants of CT and PAs when teaching SCIs in the Natural Sciences (NS) (Figure 1), based on the systems described in Bronfenbrenner's ecology of human development (1979).

Figure 1: Tentative framework of determinants of classroom tension and protective approaches.



Within the framework, all determinants can lead to CT, although some may result in different types of CT than others. We classify the different types of CT as follows. First, sensitivity arises when (in)directly life-related topics interact with identities, personal experiences or person characteristics. Second, social controversy appears when the application of scientific insights provokes societal, cultural or ethical questions, requiring multiperspectivity and a good understanding of the Nature of Science to manage this type of tension. Last, denial is a tension that arises from the rejection of scientifically established theories by certain groups or individuals in society. Understanding the different types of CT and their preceding determinants can guide future research in developing strategies specific to each type of tension.

This framework is tentative and currently based solely on literature. We now need empirical data to refine it and tailor it to the contexts of Flanders and Brussels. Therefore, a qualitative study is necessary as it allows for a profound exploration of teachers' experiences, perspectives, and emotions (Patton, 2014).

Research Questions

Classroom Tension may not originate from single determinants alone. It depends on how determinants co-occur and interact. Therefore, in this study, we will investigate associations be-tween determinants, thereby adding information to the framework that is currently missing. We will address two main research questions (RQs):

RQ1) What are the associations among determinants of Classroom Tension and Protective Approaches?

RQ2) How do these associations between determinants vary across different types of CT (i.e. social controversy, denial, sensitivity)?

Research Design and Methods

Participant search

We interviewed 20 Flemish and Brussels-based teachers of biology (11) and physics (9). The participant search was conducted via the website we created, which was distributed via the supervisors' networks, social media and professional development activities.

Performing the interviews

The interviews started with questions about SCIs (e.g. "Which sensitive or controversial issues have you experienced in your subject?"), followed by a collaborative exploration of the underlying determinants. Connections between determinants were explored through the use of diagrams, drawing on the principles of graphic elicitation (e.g. Bravington & King, 2019). This approach is similar to semi-structured interviews since broad themes are predetermined but the conversation can meander to discover new themes and discuss in more detail what is important to the participant. However, in this approach, the diagrams are co-constructed with the teachers. Having a visual map of topics and determinants mentioned earlier in the interview allows for a non-linear conversation where earlier themes can be expanded upon later in the interview. Moreover, since it is an agreed upon visualization at the end of the conversation, it also reduces the reliance on the researchers' interpretations.

Analysis

All data are analysed using NVivo (Lumivero, 2023), based on both inductive and deductive codes. The deductive codes are derived from the tentative framework of determinants of CT when teaching SCIs, as shown in Figure 1 (Vanhove et al., Unpublished). This is the work that has been done so far. Next, an Epistemic Network Analysis (ENA) (Shaffer et al., 2016) will be conducted to identify the main associations between determinants, both within specific types of CT and overall (superimposed networks). Networks of specific types of CT will be compared by subtracting the networks. Subsequently, we will return to NVivo to examine in greater detail what teachers said about these key associations. Finally, the tentative framework will be adjusted to these outcomes.

Preliminary Findings

The interviews have been completed, and the data are currently being analysed. ENA still needs to be performed. However, during the interviews, some notable associations emerged at first glance. For example, multiple teachers reported that there is an association between students' prior knowledge and the student-teacher relationship:

"*And because of the excessive focus on Chernobyl, pupils get the idea that nuclear energy, for example, is very dangerous. Whereas objective data say it is the safest thing you can do. ... And then you really have to have a relationship of trust with those students. So that they feel, "what you're saying is right". ... The danger is that students will tune out, that they won't believe you. That they won't believe the data, but instead what they see in the media. And that [creates] tension."* (FYS4)

Students' prior knowledge seems to recur in other associations; for example, this biology teacher experiences CT because students' prior knowledge contradicts the content she has to teach. In this case, the prior knowledge is mainly influenced by religion; both the religious background of the student at home, as well as religious classes of colleagues.

"*My biggest problem is with my [colleagues of religion. I have] two colleagues who are Muslim. ... She says, 'Yes, I want to include it, but I want creationism to be given an equally prominent role.' ... I'm willing to try, but we cannot even consider it; my Protestant colleague doesn't… even want to have an internal philosophical dialogue about it with scientists and religious representatives. ... I think that's a great pity. ... children hear completely different information from another teacher. ... and what they see at home doesn't correspond with what they see at school ... So I'm on my own to put them on a different track, and it's not about convincing them either. It's about just being aware and at least looking at what other information is available. But that's very difficult. Really."* (BIO6)

Our aim is to complete a first iteration of the ENA by the start of the summer school, so that different networks (i.e. a general network and a network for each type of CT) can be presented, and feedback can be implemented directly after the summer school. The eventual result will be an updated overview of the determinants of CT and PAs, and their associations, as reported by teachers in Flanders and Brussels. Once this framework has been established, intervention studies can focus on (missing) strategies to handle CT during the teaching of SCIs.

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Developing of educational competence among university teachers in Lithuania: Regulations vs. reality.

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Keywords: science education, tertiary education, educational competence, university teachers, narrative inquiry, institutional documents

Focus of the Study

This study focuses on exploring how university teachers with up to ten years of professional experience narratively construct and make sense of their educational competence within the context of tertiary education. Situated within the field of science education in higher education, the research adopts a narrative inquiry approach, using narrative interviews as the primary source of data. Educational competence is examined through teachers' personal and professional stories, with particular attention to how pedagogical, teaching, and didactic dimensions of competence are articulated, experienced, and developed over time. By analysing narrative data, the study seeks to understand how early- and mid-career university teachers interpret their professional development, negotiate institutional expectations, and attribute meaning to their experiences of teaching and learning. The focus on narrative accounts allows the research to foreground teachers' voices and to examine educational competence as a dynamic, experience-based construct rather than a fixed set of predefined skills.

Review of Literature / Theoretical Background / Theoretical Framework

Research on educational competence in higher education reveals persistent conceptual ambiguity between the notions of competence and competency, which are often used interchangeably in both policy documents and academic literature. While competence is commonly defined as a set of knowledge, skills, abilities, attitudes, and behaviours required for specific professional tasks, competency is increasingly understood as a broader personal capacity enabling effective, high-quality, and context-sensitive performance (Schur et al., 2022). Recent studies tend to conceptualise educational competency as a multidimensional construct encompassing pedagogical, teaching, and didactic dimensions, highlighting its dynamic and developmental nature rather than treating it as a fixed set of measurable skills (Glaesser, 2018;). Within higher education, educational competence has been closely linked to teaching quality, professional development, and institutional expectations, particularly in the context of globalisation, digitalisation, and quality assurance reforms (Crawford et al., 2020; Nascimbeni et al., 2024).

Despite the growing body of normative frameworks and policy-oriented research emphasising the importance of developing educational competence, empirical studies focusing on university teachers' lived experiences remain very limited (in fact, they do not exist in our country). Existing research frequently prioritises institutional perspectives and formal evaluation mechanisms, while teachers' own interpretations of how educational competence is developed, negotiated, and enacted over time receive comparatively little attention (Jatkauskienė & LaBoterf, 2012; Gasiūnaitė & Juknytė-Petreikienė, 2017). Moreover, studies indicate discrepancies between formally articulated competence standards and actual professional development practices, suggesting that educational competence is often shaped informally through personal reflection and experience rather than structured institutional support (Bubnys, 2012; Matulaitienė & Kaminskienė, 2020). This gap in the literature points to the need for qualitative, experience-oriented approaches that can capture how early- and mid-career university teachers narratively construct and make sense of their educational competence within contemporary higher education contexts.

Research Questions

How do university teachers with up to ten years of professional experience narratively construct and make sense of their educational competence development during the early stage of their academic careers?

How do these teachers describe the relationship between their lived experiences of developing educational competence and the formal institutional requirements and expectations placed on university teachers?

What needs, strategies, and resources do early-career university teachers identify in their narratives as shaping how they pursue educational competence development (e.g., formal training, informal learning, peer support, self-directed practices)?

What challenges, tensions, and "internal struggles" emerge in teachers' narratives as they attempt to develop educational competence within the first decade of academic work, and how are these tensions negotiated over time?

What facilitating and constraining factors are narrated as influencing educational competence development (e.g., institutional culture, workload, evaluation practices, disciplinary norms), and how do these factors interact within teachers' stories?

Research Design and Methods

The study adopts a qualitative research design grounded in narrative inquiry, drawing on pragmatist and interpretive traditions that conceptualise experience as a dynamic, meaning-making process articulated through narrative (Dewey; Clandinin & Connelly, 2000; Polkinghorne, 1988). Narrative interviews are employed as the primary method of data generation, incorporating elements of in-depth interviewing to encourage participants to construct extended accounts of their professional development. The study focuses on university teachers with up to ten years of professional experience, whose narratives provide insight into early-career processes of educational competence development. Narrative interviews are designed to elicit holistic professional stories while allowing flexibility for probing significant events, turning points, tensions, and reflections related to pedagogical, teaching, and didactic dimensions of educational competence. Data analysis follows a narrative analytical approach informed by Riessman's distinction between thematic, structural, and dialogic/performance-oriented analysis, as well as by

Lieblich et al.'s model of holistic and categorical readings of narrative content and form (Riessman, 2007; Lieblich et al., 1998). This methodological framework enables the reconstruction of individual professional trajectories and the examination of how personal experiences of educational competence development are narrated in relation to broader institutional and social contexts.

Preliminary Findings

Although empirical data collection is ongoing, the analytical framework developed in this study allows for the identification of preliminary interpretive directions regarding educational competence development in early academic careers. Drawing on narrative inquiry, educational com-etence is approached not as a stable set of skills but as a process that is retrospectively orgnized and given meaning through teachers' professional stories (Polkinghorne, 1988; Riessman, 2007). Preliminary analytical considerations suggest that educational competence is likely to be narrated through key experiential episodes, such as initial teaching encounters, moments of perceived failure or success, and encounters with formal evaluation or institutional expectations. These episodes appear to function as narrative turning points through which teachers reinterpret their professional identities and learning trajectories.

From a narrative perspective, early-career teachers' accounts are expected to reveal tensions between personal understandings of "good teaching" and formally articulated competence requirements. Such tensions may be narrated as internal struggles, ambivalence, or strategic adaptation, reflecting the dynamic interplay between individual experience and institutional norms. Preliminary analytical orientations also indicate that educational competence development is likely to be described as largely informal and self-directed, shaped by reflection on practice, peer interactions, and situated problem-solving rather than by structured institutional support. These emerging interpretive patterns highlight the potential of narrative interviews to uncover how educational competence is negotiated over time, revealing both enabling and con-straining conditions within the first decade of academic work.

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Effects of attitudes and emotions on the development of interest in sustainability-oriented learning environments in chemistry education

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Focus of the Study

Climate change, biodiversity loss, and pollution present current and urgent future challenges (IPCC, 2023). Education for Sustainable Development (ESD) could be an opportunity to encouraging environmental action and support engagement. ESD is an interdisciplinary responsibility shared by all teachers and institutions, such as schools (MSB NRW, 2019; UNESCO, 2020). In chemistry education, discussing sustainability-related issues and raising awareness of resource use could promote ESD (Kiesling et al., 2022; MSB NRW, 2019). At the same time, it is well known that young people are showing an increasing interest in topics related to sustainable development, such as climate protection (Kress, 2021), and that they experience a range of emotions in response to these issues. Adolescents feel sad, anxious, angry, and powerless, but also hopeful in the context of climate change (Hickman et al., 2021; Ojala, 2017). At this point, there is limited understanding of how adolescents' interest and emotions interact when addressing sustainability-related topics. This research project therefore aims to address the discrepancy between the growing interest in sustainability-related topics and the potential negative emotions associated with the debate in chemistry education.

Theoretical Background

ESD aims to empower learners to take responsibility for themselves and work towards changing various areas of social interactions in order to promote sustainable development (MSB NRW, 2019). The ESD competencies to be promoted include enabling learners to act responsibly for a socially just, economically viable, and environmentally sustainable future; assessing consequences and interactions; and reflecting on their own actions and limitations. Global frameworks such as the PISA 2025 Framework demonstrate alignment with these competencies (OECD, 2023). This framework defines environmental science competencies, such as making informed decisions based on creative and systems thinking, as well as considering diverse evidence, and demonstrate respect for different perspectives when looking for solutions to socio-ecological crises. In chemistry education, ESD could be implemented by learning based on socio-scientific issues (SSIs), consideration of green chemistry principles (e.g. prevention and use of renewable feedstocks) in practical work, or ESD-driven school development, and incorporating sustainability issues as topics or contexts (Burmeister et al., 2012; Kiesling et al., 2022; MSB NRW, 2019).

Ocean acidification is a sustainability-related topic that can be explained in terms of chemical processes. It can also be used as context or as SSI. Contexts can be used to convey content in real-life situations that are relevant to life (Gilbert, 2006). A context-oriented learning environment is characterised by learner-centred and learner-active design. According to the need-to-know principle, competence acquisition takes place in a context-oriented manner (Taconis et al., 2016). Another approach to address sustainability-related topics are the SSIs which focus on decision-making competence (Sadler, 2004). Studies about SSI-based learning demonstrate positive effects on chemistry interest (Calik & Wiyarsi, 2021). The use of contexts in chemistry education can have a positive effect on affective variables (e.g. interest and motivation) (Ben-nett et al., 2007; Fechner, 2009).

As described above, young people's engagement with sustainability debates is characterised by emotions, attitudes and growing interest. Emotions can be defined as an affective response directed towards a specific object and accompanied by temporary changes in experience and be-haviour (Eder & Brosch, 2017). In psychological research, attitudes are commonly defined as an overarching evaluative judgment of a psychological object, reflected along dimensions such as good–bad, beneficial–harmful, pleasant–unpleasant, or likable–dislikable (Osborne et al., 2003). The four-phase model of interest development is the most significant theoretical framework for interest development in this research (Hidi & Renninger, 2006). Within the model it is described how individual interest develops from situational interest to individual interest. The initial phase delineates *triggered situational interest*, a psychological condition that is influenced by affective processes such as positive or negative emotions. The second phase is characterized by *maintained situational interest*, which is defined as a recurrent interaction with the object. The third phase is defined as *emerging individual interest*, which refers to the development of predisposition, which shaped by repeated exposure to the object. The final phase delineates *well-developed individual interest*, characterised by the predisposition to repeatedly interact with the object of interest over longer periods of time. In addition, Schiefele (1999) ascribes an emotional valence to interest. This means that persons feel emotions like stimulation when interacting with objects. In comparison, attitudes are interrelated with interest, as repeated situational experiences of interest reflect stable attitudes over time (Su, 2020).

Research on emotions within science education has increased substantially in recent years. A current study, presented at the ESERA Conference 2025, conducted a systematic literature re-view to examine which emotions are addressed in science education research, how emotions are conceptualized, and how they are evaluated (Le & Sahin-Topalcengiz, 2025). The review revealed that a wide range of emotions is considered. Complementary empirical research from related educational contexts has examined students' climate-related anxiety, identifying differences by gender, and school type (Höhnle et al., 2024). The study indicates higher anxiety levels among female students, and slight variations across school tracks. Moreover, evidence from a review suggests that both positive and negative emotions can, under certain conditions, promote sustainable behaviour (Brosch, 2021).

The first step of this research project involved conducting a systematic review. The aim of the systematic review was to provide an overview of the findings from previous research into the effects of using sustainability- and chemistry-related learning environments on affective and emotional variables, or their combination. The results demonstrate that emotions are rarely measured as constructs directly related to subject matter or content, and that combinations of emotions and interest, as well as attitudes as stable dispositions in relation to interest, are previously neglected. Consequently, a discrepancy remains between the increasing interest in sustainability-related topics fostered through context-based learning and the potentially negative emotional responses associated with sustainability debates.

Research Questions

Thus, based on existing literature and the conducted systematic review, the following research questions can be formulated:

(1) How do attitudes in sustainability-oriented learning environments influence the development of subject- and topic-related interest in chemistry, from situational to individual inter-est?

(2) How do emotions in sustainability-oriented learning environments influence the development of subject- and topic-related interest in chemistry, from situational to individual inter-est?

Research Design and Methods

The research questions will be addressed through an intervention study. The intervention includes a sustainability-oriented learning environment. Over the course of approximately eight lessons, students will approach sustainability-related topics and relevant chemical processes in a problem-oriented and experimental manner.

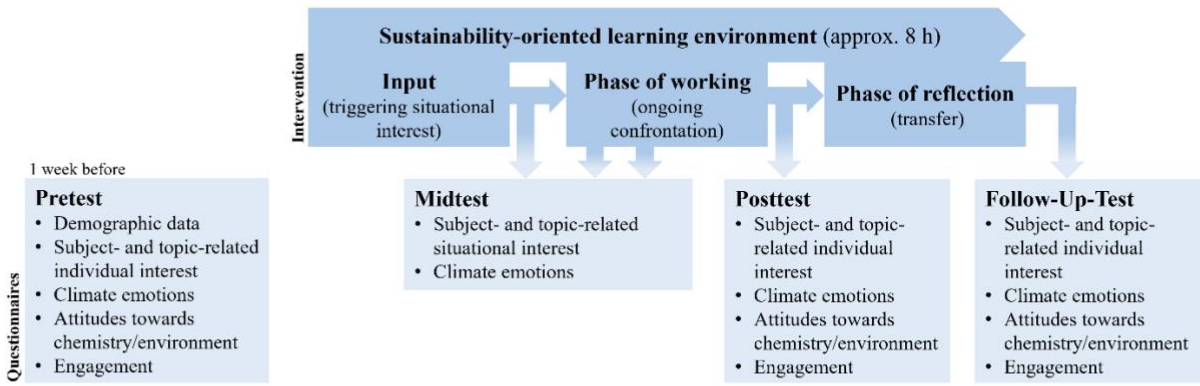

Figure 1: Study design

Thus, pre- and post-intervention questionnaires will be used to collect data on subject- and topic-related individual interest and attitudes, climate emotions and engagement. Situational interest and climate emotions will be recorded during the intervention. A follow-up survey on subject- and topic-related individual interest and attitudes, climate emotions and engagement will be used to draw conclusions about the long-term effects. Figure 1 describes the variables to be measured and their timepoints in detail.

Preliminary Findings

The planned study, including the intervention and instruments, will be prepared in detail before and will be carried out after ESERA Summer School. Advice on designing the learning environment and instruments as well as on analysing the main study, would be welcome.

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An integrated SSI-SEL intervention to foster social-emotional competence and socioscientific orientation in Chinese high school students

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Keywords: Science Education, Secondary Education, Social-Emotional Learning, Socioscientific Issues, Mixed-Methods Research

Focus of the Study

This study addressed a critical interdisciplinary gap at the convergence of science education, civic engagement, and student wellbeing. The COVID-19 pandemic highlighted global adolescent mental health challenges (Vindegaard & Benros, 2020) and exposed complex socioscientific dilemmas, underscoring the limitations of traditional, content-centric science education (Feinstein & Waddington, 2020). In response, this research empirically investigated an integrated pedagogical model designed to systematically unite Social-Emotional Learning (SEL) with Socioscientific Issues-Based Learning (SSI-L). SEL focuses on developing competencies to understand emotions, show empathy, and make responsible decisions (CASEL, 2015), while SSI-L uses controversial societal issues to promote critical thinking and civic literacy (Zeidler, 2014). Despite their potential synergy, these paradigms have largely evolved in isolation. This study was conducted in a Mainland Chinese public high school context, where significant academic pressure and psychological distance from conventional SSIs pose unique barriers to engagement. The primary objective was to determine the differential efficacy of an integrated SSI-SEL intervention compared to standalone SSI-L, standalone SEL, and a control condition in fostering Grade 10 students' holistic Social-Emotional Competence (SEC) and Socioscientific Orientation (SO).

Theoretical Framework

The study was built upon a synthesized theoretical foundation bridging educational psychology and science education. Social-Emotional Competence (SEC) was anchored in the CASEL framework (2020) and conceptualized as a tripartite construct within its five domains (Self-Awareness, Self-Management, Social Awareness, Relationship Skills, Responsible Decision-Making), comprising *Knowledge, Attitudes*, and *Skills*. This model is grounded in Social Cognitive Theory (Bandura, 1986), which posits reciprocal interactions between personal factors, behavior, and the environment, suggesting knowledge and attitudes mediate skill application.

The targeted outcome, Socioscientific Orientation (SO), was operationalized through four key dimensions synthesized from Herman et al. (2021) and Lee et al. (2013): *Ecological Worldview* (interconnectedness), *Social and Moral Compassion* (empathy, ethical sensitivity), *Socioscientific Accountability* (responsibility, willingness to act), and *Scientific Evidence Views*.

The rationale for integration is supported by documented reciprocal relationships. SSI contexts are inherently emotive and morally charged, creating authentic arenas for practicing and refining SEC (Sadler & Zeidler, 2005). Conversely, core SEL skills like emotion regulation and perspective-taking are prerequisites for deep, ethical engagement with SSIs (Gao et al., 2019).

This study posited that explicitly teaching the CASEL framework within the contextual richness of SSI-L would produce a synergistic effect, leading to greater concurrent growth in both SEC and SO than either approach alone.

Research Questions

1. **Program Efficacy:** To what extent do the integrated SSI-SEL, standalone SSI-L, and standalone SEL interventions impact students' SEC and SO, both immediately post-intervention and at a two-month follow-up, compared to a control group?

2. **Construct Interrelationship:** What is the nature of the relationship between SEC and SO at both macro (composite) and micro (sub-dimension) levels, and do these relationships differ across intervention groups?

3. **Internal Construct Dynamics:** What are the intercorrelations among the sub-dimensions of SEC and SO within each experimental condition?

Research Design and Methods

The study employed a convergent mixed-methods design (Creswell & Plano Clark, 2017) embedded within a quasi-experimental framework. Participants consisted of approximately 200 Grade 10 students drawn from four intact classes in a Chinese public high school. These classes were assigned to one of four distinct conditions: an integrated SSI-SEL group (Experimental Group 1), an SSI-Only group (Experimental Group 2), an SEL-Only group (Experimental Group 3), and a blank control group that received no formal intervention.

The intervention lasted one academic semester. The SSI conditions engaged with two project-based SSI units: "Stray Animal Governance and Protection" and "The Environmental Paradox of Electric Vehicles and Self-Driving Technology." The SSI-Only group followed a standard SSI instructional model. The SEL-Only group received a structured SEL curriculum based on the Strong Teens program (Carrizales-Engelmann et al., 2016) and the RULER Mood Meter (Brackett et al., 2019), detached from SSI contexts. The Integrated SSI-SEL group received the synergistic model, systematically overlaying SSI project work with explicit SEL instruction and reflective tools.

Data Collection:

Quantitative data were collected at pre-test (T1), immediate post-test (T2), and delayed post-test (T3) using: (a) a researcher- developed Social-Emotional Knowledge Test, (b) the Social-Emotional Attitudes and Skills Questionnaire (SEAS-Q), and (c) the adapted Socioscientific Orientation Questionnaire (SOQ). Qualitative data included guided student reflections, classroom observations, and post-intervention interviews with students and teachers.

Data Analysis:

Quantitative analysis involved: (1) Confirmatory Factor Analysis (CFA) to validate instruments; (2) Repeated-Measures MANOVA to examine within- and between-group changes in SEC/SO across time; (3) Structural Equation Modeling (SEM) and correlation matrices to explore RQs 2 and 3. Qualitative data underwent hybrid thematic analysis (Fereday & Muir-Cochrane, 2006) using NVivo, with findings integrated to contextualize quantitative results.

Preliminary Findings

CFA confirmed the validity of the SEAS-Q and SOQ measurement models (CFI/TLI > .90, RMSEA < .08). Repeated-measures MANOVA revealed significant differential impacts. The Integrated SSI-SEL group demonstrated the most substantial and sustained gains, showing significant improvement in both SEC composite scores (*F*(2, 94) = 15.32, *p* < .001, ηp^2 = .25) and SO composite scores (*F*(2, 94) = 12.87, *p* < .001, ηp^2 = .22). Key growth areas included *Social Awareness* (SEC, *d* = 0.62) and *Social and Moral Compassion* (SO, *d* = 0.67). Gains in the *Responsible Decision-Making* domain of SEC were also notable (*d* = 0.58). The SEL-Only group improved significantly in SEC (*F*(2, 92) = 10.45, *p* < .001, ηp^2 = .19), with the largest effect in *Self-Awareness* (*d* = 0.55), but showed no significant change in SO. The SSI-Only group improved in SO (*F*(2, 96) = 8.91, *p* < .001, ηp^2 = .16), especially in *Socioscientific Accountability* (*d* = 0.49), but showed minimal SEC change. The Control Group showed no significant change in either SEC or SO over time.

Between-group comparisons at T2 confirmed the integrated model's superiority. The Integrated group outperformed the SSI-Only group in SEC composite scores (*p* < .01, *d* = 0.52) and the SEL-Only group in SO composite scores (*p* < .01, *d* = 0.56). Crucially, the Integrated group's gains in the *Social and Moral Compassion* dimension of SO were significantly larger than all other groups (*p* < .001), suggesting the intervention successfully bridged socio-emotional and ethical development. The delayed post-test (T3) indicated that gains in the Integrated and SEL-Only groups were largely maintained, while some attenuation was observed in the SSI-Only group's SO scores, hinting at the role of SEL in supporting retention.

SEM path analysis revealed a significant positive relationship between overall SEC and SO (β = .68, *p* < .001). Multi-group analysis showed this relationship was strongest in the Integrated SSI-SEL group. Micro-level correlations indicated that *Social Awareness and Relationship Skills* were particularly strong predictors of *Social and Moral Compassion* (SO) in the integrated condition, whereas in the SSI-Only group, SO showed weaker correlations with the intrapersonal SEC domains (*Self-Awareness, Self-Management*).

Qualitative findings richly complemented these results. Students in the Integrated group consistently employed more nuanced emotional vocabulary from the Mood Meter and demonstrated deeper stakeholder analysis. One reflection typified this synthesis: “Mapping the shop owner’s anxiety about a fur ban on the Mood Meter helped me move from judging his position to understanding his fear, which changed how I weighed the ethics of the policy.” Teacher interviews noted that the integrated model’s explicit SEL protocols, such as structured emotional check-ins before debates, fostered a more respectful and productive classroom climate during heated SSI discussions. In contrast, reflections from the SSI-Only group were more focused on factual argumentation and cost-benefit analysis, while those from the SEL-Only group, though rich in personal emotional insight, lacked connection to a compelling real-world civic context.

These preliminary findings robustly support the central hypothesis that explicit integration yields synergistic benefits, fostering the co-development of the emotional literacy and ethical civic orientation necessary for navigating complex socioscientific landscapes. The study underscores the potential of integrated SSI-SEL pedagogy as a holistic educational approach in science education, particularly in contexts like China where fostering both socio-emotional resilience and scientific civic literacy is increasingly vital.

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