Part 15 / Strand 15

Pre-Service Science Teacher Education

Co-editors: *María Martínez Chico & Carla Morais*

Part 15 / Strand 15 Pre-Service Science Teacher Education

Professional knowledge of pre-service science teachers, pre-service teacher preparation, instructional methods in pre-service teacher education, programmes and policy, field experience, relation of theory with practice, and issues related to pre-service teacher education reform.

Sub-themes:

1. Pedagogical Approaches in Pre-service Science Teacher Training
2. Linking Theory and Practice in Pre-service Teacher Education
3. Field Experiences and Practicums in Science Teacher Education
4. Reform and Innovation in Pre-service Science Teacher Programs

Contents

EUROPEAN SCIENCE EDUCATION RESEARCH ASSOCIATION ESERA 2025 Copenhagen

Strand 15: Pre-Service Science Teacher Education

María Martínez Chico[1] and Carla Morais[2]
[1]University of Almeria, Spain
[2]University of Porto, Portugal

Introduction

Pre-service science teacher education plays a central role in preparing future teachers for the demands of science teaching. Beyond disciplinary knowledge, teacher education programmes are expected to promote the development of Pedagogical Content Knowledge (PCK in advance), reflective and inquiry-oriented teaching practices, professional identity and the capacity to respond to emerging educational and societal challenges. Research in this field has therefore focused on how future teachers connect theoretical knowledge with teaching practice while developing the competences required for their profession.

The contributions in this chapter reflect several current directions in pre-service science teacher education across different educational contexts and science disciplines. A central aspect addressed is the development of professional knowledge and competence, including PCK, pedagogical reasoning, topic-specific understandings of science teaching and learning, and the integration of disciplinary, pedagogical and technological knowledge. Across the chapter, these issues are considered and examined in relation to different areas of Science Education, emphazising the importance of understanding how future teachers construct the knowledge needed to design, implement and reflect on science teaching-learning.

A common feature across many contributions is the exploration of innovative approaches to teacher education. Several contributions examine how pre-service teachers learn through mentoring, guided reflection, collaborative work, practicum experiences and other forms of approximation to practice. The chapter reflects a broad view of teacher education in which learning to teach is not reduced to the acquisition of conceptual knowledge, but is also understood as participation in professional communities, identity development, and engagement with the practical, ethical and relational dimensions of teaching. The chapter also includes works that extends this perspective to science teacher educators themselves, thereby drawing attention to teacher education as a professional field in its own right.

Another trend across the different studies included in the chapter is the prominent of innovation in teacher education design. This can be noticed in some contributions that examine digital and technology-supported learning environments, including online learning, AI supported reflection, and digital tools for supporting professional learning and reflective practice. Other studies focus on innovative teaching approaches and organizational formats to support professional learning through a deeper understanding of the nature of scientific models after implementing approaches such as Model-Based Inquiry (MBI).

The chapter also reflects growing attention to broader societal challenges that increasingly shape science teacher education. Sustainability, climate change education, environmental awareness and socially relevant perspectives on science illustrate the role of pre-service teacher education in preparing future teachers to engage learners with contemporary scientific and societal issues.

Methodologically, the contributions illustrate the diversity of research approaches currently used in science teacher education, including qualitative interview studies, implementation and design-based research, questionnaire-based studies, case studies, phenomenographic approaches and

mixed-methods designs. This wide range of methodological approaches reflects the breadth and diversity in the field, including issues of teacher knowledge, identity, reflection, mentoring, innovation, and curricular challenges. Furthermore, all the contributions position initial science teacher training as a dynamic area of educational research, constantly evolving and focused on how to promote the learning of future teachers for the effective and ambitious teaching of science in current contexts marked by the complexity of the content, the often negative perception of science, digital transformation, and pressing social challenges.

EUROPEAN SCIENCE EDUCATION RESEARCH ASSOCIATION ESERA 2025 Copenhagen

Content Knowledge And Its Impact On Pedagogical Content Knowledge: A Case Study Of A Pre-Service Chemistry Teacher In A Residency Program

Luciane Goes[1], Paulo Loureiro[2] and Carmen Fernandez[1]
[1]University of São Paulo, Brazil
[2]University of Georgia, USA

This study explores how variations in content knowledge (CK) are reflected in the integration of pedagogical content knowledge (PCK) in the student teaching of a pre-service chemistry teacher, Marie, participating in a Pedagogical Residency Program (PRP) in Brazil. The PRP is an 18-month teacher education initiative designed to immerse pre-service teachers in school contexts during the final stages of their undergraduate programs, fostering reflection on teaching practice under the guidance of experienced teachers and university supervisors. Data were collected through lesson plans, reports, audiovisual recordings of classroom practice, and interviews using the stimulated recall technique. The analysis was guided by the PCK framework proposed by Park and Oliver, with particular attention to the integration of PCK components. The findings indicate that patterns of PCK component integration varied across teaching topics and were sensitive to the nature of the content. In topics more closely aligned with Marie's disciplinary background, such as the history of chemistry, PCK components were more extensively articulated. In contrast, lessons involving DNA structure and chemistry-art connections revealed more fragmented integration, suggesting that limitations or uncertainties in CK may constrain the coordination of PCK components in situated teaching contexts. These findings highlight the role of CK in shaping PCK and contribute to current discussions on the enacted and topic-specific nature of teachers' professional knowledge in initial teacher education.

Keywords: Pre-service teacher education, Professional development, Educational Policy

Introduction

In Brazil, recent public policies have been seeking to address longstanding challenges in teacher education, such as low professional valorization and the need to better integrate theory and practice during pre-service training. Within this scenario, the Pedagogical Residency Program (PRP) was created as a national policy designed to immerse pre-service teachers in school contexts during the final stages of their undergraduate programs, fostering reflection on teaching practice under the guidance of both school-based mentors and university supervisors.

To understand how such practice-based programs contribute to teacher professional learning, it is necessary to consider the specific types of knowledge involved in teaching. A key construct for understanding teacher professional knowledge in such contexts is the Pedagogical Content Knowledge (PCK). PCK, a concept introduced by Shulman (1986), refers to the unique knowledge teachers possess about how to teach a particular subject, distinguishing teaching expertise from disciplinary expertise. Since its introduction, PCK has been widely recognized as a central element of teaching, as it enables teachers to transform subject matter knowledge into forms that are pedagogically meaningful to learners.

Although the literature has consistently highlighted the importance of content knowledge (CK) for teaching (Magnusson et al., 1999; Neumann, Kind, & Harms, 2019), the relationship between CK and PCK remains theoretically and empirically complex. In this study, CK is not conceptualized as a component of PCK, but rather as a condition of possibility that shapes how PCK components are mobilized and integrated during teaching practice. Previous studies suggest

that insufficient CK may constrain teachers' instructional decisions, limit their responsiveness to students' ideas, and reduce the coherence of their pedagogical approaches (Gess-Newsome & Lederman, 2019). However, much of this research has focused on identifying correlations between CK and PCK or documenting their parallel development, rather than examining how variations in CK shape the integration of PCK components in situated teaching contexts.

In response to this gap, this study examines variations in CK in chemistry and their relationship with the integration of PCK components in the teaching practice of a pre-service chemistry teacher participating in the PRP. By focusing on different science topics, the study explores patterns of integrations of PCK components during instructional planning and classroom enactment. Guided by this perspective, the study addresses the following research question: How do changes in a pre-service chemistry teacher's content knowledge influence the integration of PCK components across different teaching topics within the PRP?

Framing

Pedagogical Content Knowledge

Teachers develop a unique body of professional knowledge throughout their education and teaching experiences, which distinguishes teaching from other professions. This knowledge encompasses not only subject matter knowledge, but also an understanding of how specific content can be taught and learned in particular contexts. Grossman (1990) conceptualizes this body of knowledge as the knowledge base for teaching, highlighting that effective teaching relies on the integration of multiple forms of knowledge developed through formal education and classroom practice.

Within this knowledge base, Pedagogical Content Knowledge (PCK) occupies a central position. Introduced by Shulman (1986), PCK refers to the distinctive knowledge teachers use to transform subject matter into pedagogically meaningful representations for learners. It is this form of knowledge that differentiates teachers from disciplinary specialists, as it encompasses not only what is taught, but how and why specific instructional approaches are used to promote student understanding.

Since its original formulation, the concept of PCK has been refined and expanded in the literature, while remaining a key construct for understanding teaching practice. Among the various models proposed, the pentagonal model developed by Park and Oliver (2008) has been particularly influential in science education research. This model conceptualizes PCK as comprising five interrelated components: Orientations to Teaching Science (OTS), Knowledge of Assessment of Science Learning (KAS), Knowledge of Instructional Strategies for Teaching Science (KIS), Knowledge of Science Curriculum (KSC), and Knowledge of Students' Understanding in Science (KSU). According to Park and Oliver (2008), effective teaching requires not the isolated use of these components, but their dynamic and coherent integration during instructional practice.

An important assumption of the pentagonal model is that improvements in one PCK component should be accompanied by corresponding growth in the others. From this perspective, PCK is not a static body of knowledge, but a dynamic construct that is enacted and reshaped through teaching, reflection, and interaction with students. Teaching, therefore, is understood as an adaptive process in which teachers continuously interpret classroom situations, make instructional decisions, and revise their approaches in response to students' understanding.

While PCK has been widely studied as a form of professional knowledge, its relationship with content knowledge (CK) remains theoretically and empirically complex. Studies have emphasized that a certain level of CK is necessary for effective teaching and for the development

of PCK (Magnusson et al., 1999; Neumann, Kind, & Harms, 2019). Weak content knowledge may constrain teachers' instructional decisions, limit their ability to anticipate student difficulties, and reduce the coherence of their pedagogical strategies (Gess-Newsome & Lederman, 1995). However, much of the existing research has examined CK and PCK either as parallel domains or through correlational approaches, offering limited insight into how CK shapes the organization of PCK during teaching practice.

In this study, CK is not conceptualized as a component of PCK. Rather, CK is understood as a condition of possibility that enables the integration of PCK components in specific instructional contexts. From this perspective, variations in content mastery may influence how teachers mobilize instructional strategies, interpret students' ideas, align their teaching with curricular goals, and design assessment practices. When CK is robust, teachers may be better positioned to integrate multiple PCK components coherently; when it is limited or challenged, such integration may become fragmented or uneven.

Building on classical conceptualizations of PCK (Shulman, 1986; Grossman, 1990; Park & Oliver, 2008), this study addresses an analytical question by focusing on the integration of PCK components rather than on their isolated presence or development. By examining how variations in CK across different teaching topics shape the integrations of PCK components in a pre-service chemistry teacher, the study contributes to ongoing discussions about the role of CK in teacher education and the conditions under which PCK can be effectively enacted during initial teacher preparation.

Methodology

Context And Participants

Data were collected within the Brazilian Pedagogical Residency Program (PRP). The PRP is an 18-month program in which undergraduate students engage in sustained school-based experiences under the supervision of experienced school teachers and a university educator. Participants receive government-funded scholarships and take part in regular planning meetings, classroom observations, and teaching activities.

The study involved six undergraduate chemistry students enrolled in the PRP. From this group, one participant, here referred to as Marie, was selected for in-depth analysis. This purposeful case selection was guided by the analytical goals of the study rather than by representativeness. Marie participated in all phases of the program and planned and implemented three distinct teaching lessons addressing different content domains: Solo Role Play Game (RPG) (history of chemistry), The chemical structure of DNA, and Chemistry and Art: A Playful Exploration of Organic Functions. These science topics differed in terms of disciplinary focus and content complexity, making the case particularly suitable for examining how variations in content knowledge shape the integration of pedagogical content knowledge components.

At the time of data collection, Marie had completed most of her K-12 education in private institutions and was pursuing a teaching degree alongside her chemistry studies. She was also enrolled in a master's degree program in science education, with a particular interest in the history of science. This background provided a rich context for examining how content knowledge developed unevenly across topics and how such variations were reflected in her pedagogical reasoning and instructional decisions.

Data Collection

Multiple data sources were used to capture both planned and enacted aspects of Marie's teaching. These included written reports, lesson plans, audiovisual recordings of weekly PRP meetings,

and recordings of the three lessons taught at the school she was doing her student teaching. These materials provided access to Marie's instructional decisions, reflections, and interactions with students and peers throughout the teaching process.

In addition, a semi-structured interview using the stimulated recall technique was conducted to support reflective analysis of her teaching practices. During the interview, selected excerpts from lesson recordings and planning materials were used to prompt Marie to reflect on her instructional choices, content-related decisions, and perceptions of student understanding (Nilsson, 2014). This approach allowed for deeper insight into the relationship between content knowledge and pedagogical reasoning as articulated by the participant herself.

Data Analysis

Data analysis followed a qualitative interpretative approach consistent with the study's analytical focus on the integration of PCK components. Initially, a thematic analysis was conducted following the procedures outlined by Clarke and Braun (2017). Inductive coding was used to identify salient themes emerging from the data, capturing patterns related to instructional strategies, student understanding, assessment practices, and content-related reasoning.

Subsequently, a deductive analytical phase was conducted in which the codes were organized according to the five components of PCK proposed by Park and Oliver (2008): Orientations to Teaching Science (OTS), Knowledge of Assessment of Science Learning (KAS), Knowledge of Instructional Strategies (KIS), Knowledge of Science Curriculum (KSC), and Knowledge of Students' Understanding in Science (KSU). This process enabled the identification of how each component was mobilized across different teaching topics.

To examine the integration of PCK components, PCK maps were constructed following the methodology proposed by Park and Chen (2012). These maps represent the frequency and intensity of connections between PCK components within each teaching sequence, allowing for comparative analysis across topics. Following this approach, all identified connections between components were initially treated as having equal strength, and interactions involving more than two components were represented through pairwise connections (Park & Chen, 2012). Episode-level maps were then aggregated to produce a single map for each teaching sequence, reflecting overall patterns of PCK integration (Park & Suh, 2019). Variations in the frequency of connections were interpreted as differences in the strength of relationships between components and were visually represented by the thickness of the connecting lines in the maps.

Findings and Results

Marie's Content Knowledge

Instead of providing an exhaustive assessment of Marie's CK, we focused on how her understanding is enacted during her teaching across the three lessons developed within the PRP. This section examines how Marie mobilizes chemical concepts in interaction with students, how she connects ideas across topics, and how moments of confidence and uncertainty emerge in situated instructional contexts.

Across the three teaching sequences, Marie generally draws on chemistry concepts to support explanations and to connect chemistry with historical, biological, and everyday contexts. In the Solo Role Play Game (RPG) lesson, her enactment of CK is marked by the sustained use of historical narratives and conceptual reasoning to frame the development of key chemical ideas. While discussing the theory of phlogiston and Lavoisier's experiments, Marie consistently situates chemical concepts within their historical context, emphasizing the tentative and human character of scientific knowledge. For instance, when explaining the increase in mass observed

during the combustion of iron, she highlights the role of oxygen incorporation, explicitly connecting the experimental observation to the law of conservation of mass*:* "When we burn steel wool, the oxygen from the air is incorporated, and that is why the mass increases" (Marie, RPG lesson). Throughout this lesson, Marie mobilizes CK to respond to students' questions, clarify misconceptions, and sustain the narrative logic of the activity.

In the lesson on the chemical structure of DNA, Marie's enactment of CK reveals both coherent explanations and localized conceptual difficulties. She draws extensively on prior chemistry content, particularly organic chemistry and intermolecular interactions, to support students' understanding of DNA structure. When discussing base pairing, she accurately explains the difference in the number of hydrogen bonds between base pairs: "Guanine with cytosine makes three intermolecular interactions, whereas adenine with thymine makes two" (Marie, DNA Structure lesson). She also makes deliberate connections between the numbering of carbon atoms in organic molecules and the 5′–3′ orientation of the DNA strand, explicitly linking prior chemistry concepts to a biological structure.

At the same time, a conceptual inaccuracy emerges when Marie characterizes RNA as simply "one half" of the DNA molecule, suggesting that the distinction lies primarily in the number of strands rather than in structural differences in the sugar component. This moment illustrates how CK is not uniformly enacted across all aspects of the topic, even within an otherwise coherent explanation. Importantly, this struggle does not interrupt the overall flow of the lesson, but it indicates a point where limitations in CK may shape the way specific ideas are represented to students.

In the Chemistry and Art lesson, Marie mobilizes CK to support interdisciplinary connections between chemistry, artistic practices, and everyday materials. She explains the chemical composition of paints, solvents, binders, and pigments, frequently translating abstract representations into more accessible forms. While discussing the limonene molecule, she explicitly addresses structural representations, noting that "each vertex represents a carbon atom" (Marie, Chemistry and Art lesson). She also draws on organic chemistry concepts to differentiate between functional groups, such as alcohols, aldehydes, carboxylic acids, and ketones, often using the board to support visual explanation.

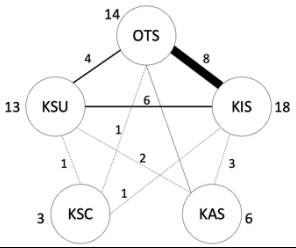
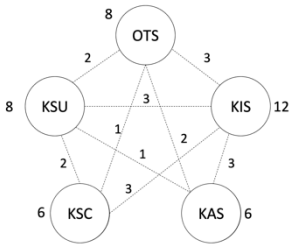
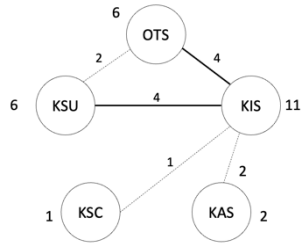
Across these lessons, Marie's CK is enacted in ways that are closely intertwined with instructional goals, student participation, and the unfolding of classroom interactions. Rather than appearing as a fixed background resource, CK emerges as a situated and dynamic element of teaching, occasionally revealing tensions or gaps that become analytically relevant when examined in relation to the integration of PCK components.

Marie's Integration of PCK Components Across Topics

Marie's PCK maps illustrate how different components of PCK were articulated across the three teaching topics developed within the PRP. Table 1 shows the PCK maps for three topics, highlighting the frequency and intensity of component connections. Rather than indicating levels of proficiency, the maps make visible patterns of integration among PCK components, allowing for a comparative analysis of how these configurations vary according to content and instructional context.

Across all three topics, KIS occupied a central position in Marie's PCK maps, functioning as a hub through which other components were connected. This prominence suggests that instructional decision-making played a key role in structuring her teaching practice, regardless of topic. However, the overall degree and configuration of integration differed across the three lessons.

Table 1. PCK Map for the Resident Marie.

Solo RPG (Role Play Game)	The chemical structure of DNA	Chemistry and Art: A Playful Exploration of Organic Functions
		

1-3: ---------- 4-7: ——— >8: ■

OTS: Orientations of Teaching Science; KIS: Knowledge of Instructional Strategies; KAS: Knowledge of Assessment of Science Learning; KSC: Knowledge of Science Curriculum; KSU: Knowledge of Students´ Understanding in Science.

The Solo RPG lesson exhibited the highest number of connections among PCK components, indicating a more articulated integration pattern. In this topic, Marie frequently connected KIS with KSU, OTS, and, to a lesser extent, KSC. Her choice of an RPG-based strategy to address the History of Chemistry illustrates how instructional decisions were informed by epistemological and pedagogical concerns. As she explained in the interview, "I wanted a different way to approach the History of Chemistry, which is rarely addressed by teachers, partly because it is challenging and often reduced to names and dates that reinforce a heroic view of science" (Marie, interview). This strategy created opportunities for student participation and critical engagement, supporting the articulation between KIS and KSU observed in the maps.

The integration between KIS and KSU emerged as a recurrent pattern across all topics. Marie frequently used questions and dialogic interactions to elicit students' prior ideas and adjust her explanations accordingly. For example, in the DNA lesson, she asked: "What do you think of when you hear DNA?" (Marie, DNA class), signaling an attempt to anchor instruction in students' existing conceptions. These interactions contributed to the repeated coupling of instructional strategies with KSU, suggesting a student-oriented approach to teaching.

In contrast, KSC appeared less frequently integrated with other components, particularly in the Chemistry and Art lesson. Although Marie knew about the school's curriculum, such as prior content coverage, references to curriculum mainly informed localized instructional decisions rather than broader planning or assessment considerations. This pattern is consistent with previous studies that report weaker integration of KSC in PCK maps (Park & Chen, 2012). For instance, when planning the Chemistry and Art lesson, Marie noted that students had already studied organic functions and therefore intended to revisit alcohols and ketones based on students' observations of molecular structures: "To ask the students what they see as different and notable in this structure. If they mention the heteroatoms as expected, revisit the two organic functions present alcohol and ketone" (Marie, lesson plan). While this indicates curricular awareness, it was not systematically connected to assessment or to explicit curricular goals within the lesson.

The Chemistry and Art lesson displayed a more limited integration among PCK components overall. Although OTS, KIS, and KSU remained central, fewer connections involved KSC and KAS. Much of the interaction focused on identifying and revisiting previously taught concepts, as illustrated by questions such as "Do you remember the lesson on alcoholism? What

characterized alcohol?" (Marie, Chemistry and Art lesson). These patterns suggest that, in interdisciplinary contexts, Marie's PCK integration was primarily oriented toward activating and diagnosing prior knowledge rather than coordinating multiple components around shared curricular or assessment goals.

In the DNA structure lesson, Marie mobilized several PCK components, but the resulting integration was less articulated than in the RPG lesson. While KIS and KSU were frequently connected, links involving assessment and curriculum were sparse. The use of visual representations, such as images of the DNA double helix and X-ray diffraction photographs, supported the contextualization of abstract concepts, but these strategies were not consistently connected to assessment practices or curricular choices.

Discussion

The variability observed across Marie's PCK maps highlights the topic-specific and situated nature of PCK integration. Rather than reflecting stable characteristics of the teacher, these configurations appear to be shaped by the nature of the content, the degree of interdisciplinarity involved, and the extent to which CK could be mobilized to support instructional coherence. In topics more closely aligned with Marie's disciplinary background, such as the history of chemistry addressed in the RPG lesson, PCK components were more extensively articulated. In contrast, in topics requiring the integration of chemistry with biology or art, component integration was more fragmented, suggesting that limitations or uncertainties in content knowledge may have constrained the coordination of instructional, curricular, and assessment-related decisions.

The findings of this study contribute to ongoing discussions in PCK research by shifting the analytical focus from the identification of individual components to the examination of their integration in situated teaching contexts. Recent studies have increasingly emphasized PCK as an enacted, dynamic, and topic-specific form of professional knowledge that emerges through instructional decision-making rather than as a stable body of knowledge possessed by teachers (Carlson et al., 2019; Kind & Chan, 2019). In line with this perspective, the variation observed across Marie's PCK maps reinforces the view that PCK integration is sensitive to content characteristics and instructional demands.

While prior research has consistently documented relationships between CK and PCK, often emphasizing their co-development or mutual dependence, the present study advances this discussion by examining how variations in content knowledge are reflected in the integration of PCK components within the teaching practice. Rather than treating PCK as a collection of discrete components or as a stable attribute of the teacher, this analysis explores the configuration and connections between components as they are enacted across different topics.

The comparative analysis of PCK maps across three teaching lessons demonstrates that integration patterns are not uniform, even within the practice of a single pre-service teacher. These variations cannot be fully explained by general teaching competence, but appear to be shaped by topic-specific demands, degrees of interdisciplinarity, and the extent to which CK can be mobilized to support instructional coherence. In this sense, the study moves beyond confirming that CK matters for PCK development, offering instead a fine-grained account of how CK influences the internal organization of PCK during instructional enactment.

Although based on a single case, the study does not seek to generalize about levels of PCK or teaching effectiveness. Instead, its contribution lies in illustrating the analytical potential of PCK maps for examining the situated and topic-dependent integration of pedagogical knowledge in initial teacher education. In doing so, the study opens possibilities for future research that explores

how different configurations of CK and instructional context shape the enactment of PCK across subjects, topics, and stages of teacher development.

Conclusion

This study examined how variations in CK are reflected in the integration of PCK components in the teaching practice of a pre-service chemistry teacher participating in a Pedagogical Residency Program. Rather than aiming to assess levels of CK or pedagogical expertise, the analysis focused on how content understanding was enacted and mobilized across different teaching topics.

The findings indicate that patterns of PCK integration varied across instructional contexts, suggesting that CK may condition how coherently PCK components are articulated during teaching. In topics more closely aligned with the teacher's disciplinary background, such as the history of chemistry addressed in the RPG lesson, PCK components were more extensively integrated. In contrast, in topics involving interdisciplinary demands, such as DNA structure and chemistry and art, the integration of components was more fragmented, highlighting how uncertainties or limitations in CK may constrain the coordination of instructional, curricular, and assessment-related decisions.

Although based on a single case, the findings underscore the importance of examining the enacted integration of knowledge components in practice-based programs such as the Pedagogical Residency Program. Future research could build on this approach by exploring how different configurations of content knowledge, instructional context, and support structures shape the development and enactment of PCK across subjects and stages of teacher education.

Acknowledgement

The authors are grateful for the financial support, Grants #2013/07937-8, #2021/03489-7, #2022/09243-2 and #2024/22915-5, São Paulo Research Foundation (FAPESP) and #312017/2021-9 National Council for Scientific and Technological Development (CNPq).

References

Carlson, J. *et al.* (2019). The Refined Consensus Model of Pedagogical Content Knowledge in Science Education. In: Hume, A., Cooper, R., Borowski, A. (eds) Repositioning Pedagogical Content Knowledge in Teachers' Knowledge for Teaching Science. Springer, Singapore. https://doi.org/10.1007/978-981-13-5898-2_2

Clarke, V., & Braun, V. (2017). Thematic analysis. *The Journal of Positive Psychology, 12*(3), 297-298. https://doi.org/10.1080/17439760.2016.1262613.

Gess-Newsome, J. and Lederman, N.G. (1995), Biology teachers' perceptions of subject matter structure and its relationship to classroom practice. *Journal of Research in Science Teaching*, 32: 301-325. https://doi.org/10.1002/tea.3660320309

Grossman, P. L. (1990). The making of a teacher: teacher and teacher education. New York: Teachers College Press.

Kind, V., & Chan, K. K. H. (2019). Resolving the amalgam: connecting pedagogical content knowledge, content knowledge and pedagogical knowledge. *International Journal of Science Education*, *41*(7), 964–978. https://doi.org/10.1080/09500693.2019.1584931

Magnusson, S., Krajcik, L., & Borko, H. (1999). Nature, sources and development of pedagogical content knowledge. In J. Gess-Newsome & N. G. Lederman (Eds.), *Examining pedagogical content knowledge: the construct and its implications for science education* (pp. 95-132). Dordrecht: Kluwer Academics.

Neumann, K., Kind, V., & Harms, U. (2019). Probing the amalgam: the relationship between science teachers' content, pedagogical and pedagogical content knowledge. *International Journal of Science Education*, 41(7), 847–861. https://doi.org/10.1080/09500693.2018.1497217

Nilsson, P. (2014) When Teaching Makes a Difference: Developing science teachers' pedagogical content knowledge through learning study. *International Journal of Science Education*, 36:11, 1794-1814, DOI: 10.1080/09500693.2013.879621

Park, S., & Chen, Y.-C. (2012). Mapping out the integration of the components of pedagogical content knowledge (PCK): Examples from high school biology classrooms. *Journal of Research in Science Teaching, 49*(7), 922-941. Retrieved from https://onlinelibrary.wiley.com/doi/abs/10.1002/tea.21022. doi:https://doi.org/10.1002/tea.21022

Park, S., & Oliver, J. S. (2008). Revisiting the Conceptualisation of Pedagogical Content Knowledge (PCK): PCK as a Conceptual Tool to Understand Teachers as Professionals. *Research in Science Education, 38*(3), 261-284. Retrieved from https://doi.org/10.1007/s11165-007-9049-6. doi:10.1007/s11165-007-9049-6

Park, S., & Suh, J. K. (2019). The PCK Map Approach to Capturing the Complexity of Enacted PCK (ePCK) and Pedagogical Reasoning in Science Teaching. In A. Hume, R. Cooper, & A. Borowski (Eds.), *Repositioning Pedagogical Content Knowledge in Teachers' Knowledge for Teaching Science* (pp. 187-199). Springer Nature. https://doi.org/10.1007/978-981-13-5898-2_8

Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher, 15*(2), 4-14.

EUROPEAN SCIENCE EDUCATION RESEARCH ASSOCIATION ESERA 2025 Copenhagen

What Do Pre-Service Early Childhood Teachers Learn About The Nature Of Models When Engaging In Model-Based Inquiry?

Marta Gómiz-Aragón and Lourdes Aragón
University of Cádiz, Spain

This study investigates whether pre-service Early Childhood Education teachers at the University of Cádiz (Spain) develop a deeper understanding of the nature of scientific models after implementing a Model-Based Inquiry (MBI) Teaching-Learning Sequence (TLS). The TLS focused on the water cycle, using the ecological garden as a real-world learning context. Students' knowledge of model nature was measured before and after the TLS using the Spanish CoNaMo questionnaire. Statistical analyses revealed significant gains, particularly in the dimensions "beyond exact replicas" and "changing nature of models." These findings highlight the importance of designing TLS that foster authentic epistemic practices and explicitly address students' understanding of model nature to support the development of Pedagogical Content Knowledge (PCK) related to modelling and inquiry.

Keywords: Inquiry-Based Learning, Nature of Science, Pre-service Teacher Education

Introduction

Teaching science involves the challenge of engaging students in scientific practices such as modelling and inquiry. These practices not only support the understanding of complex concepts but also promote a deeper comprehension of the Nature of Science (NOS). However, implementing them effectively in classrooms requires teachers to have a strong Pedagogical Content Knowledge (PCK). Understanding the nature, purpose, and limitations of scientific models is essential in teacher education, as it shapes how future teachers approach science instruction and influences students' learning (Akerson et al., 2010). Science as a cultural product, through its explanatory models, theories, and concepts, has a substantial impact on citizens' lives (Tamayo et al., 2005). Consequently, instructional design should foster a more critical engagement with scientific knowledge.

Addressing NOS in science classes enables students to develop broader perspectives on science, which can in turn influence their own views of the world. According to Lenderman et al. (2023), explicit and reflective instruction, together with teaching approaches such as inquiry, appears to significantly enhance learners' understanding of NOS as a key component for authentic scientific literacy (Vázquez et al., 2001). Within NOS, the nature of models is particularly relevant (Brandão et al., 2011), including, for example, what students understand a model to be and how they consider the evolving nature of scientific models (Treagust et al., 2002).

Integrating these ideas in pre-service teacher education is essential, as it helps future teachers develop the metamodeling skills that form a core component of modelling competence (Nicolaou & Constantinou, 2014). It also provides them with the tools and resources needed to use scientific models appropriately and to recognise their role in scientific knowledge and in future science teaching (Oh & Oh, 2010). According to Bell and Clair (2015), young children can develop scientific skills and understanding aspects of science when guided by teachers with strong scientific preparation. This highlights the need to design instructional interventions that offer explicit and targeted support for learning about the nature of models.

Early Childhood Education is considered a critical stage for fostering the scientific thinking skills that underpin a more sophisticated understanding of the NOS (Bell & Clair, 2015). In this context, the main aim of this study is to analyse the progression in pre-service early childhood teachers' understanding of the nature of models through a training proposal that integrates inquiry and modelling to address the water cycle in a real context, namely the university ecological garden.

Theoretical Framework

PCK emerges from the interaction between disciplinary knowledge and the pedagogical strategies required to teach it. PCK enables pre-service teachers not only to understand the scientific concepts they teach but also to guide students in developing metacognitive and epistemological skills that support deeper engagement with scientific processes (Zohar & Barzilai, 2013). Beyond conceptual mastery, PCK incorporates the ontological status and epistemic value of scientific ideas, together with instructional strategies that promote reflection, scientific thinking, and cognitive self-regulation (Papadouris & Constantinou, 2017).

Epistemic practices are the core processes through which scientific knowledge is generated, validated, and communicated. They can be grouped into three interrelated spheres: empirical investigation, the development of explanations, and critical evaluation—corresponding to inquiry, modelling, and argumentation (Jiménez-Aleixandre & Crujeiras, 2017). Passmore and Svoboda (2012) emphasise that science instruction should engage students in constructing, using, evaluating, and revising models to explain, interpret, and predict phenomena, positioning modelling as a central feature of scientific knowledge (Nersessian, 2002). This work is closely tied to inquiry, which involves asking questions, collecting data, and identifying patterns to support models, and to argumentation, which enables students to justify explanations, assess evidence, and refine conclusions in critical and reflective ways.

Instruction grounded in authentic scientific practices—such as Model-Based Inquiry (MBI)—integrates these three epistemic practices and supports students' understanding of scientific processes and the development of metacognitive skills (Seraphin et al., 2012; National Research Council, 2012). However, engaging in isolated practices is not sufficient for developing the full set of abilities required to work with models critically and reflectively. For this reason, model-based learning is conceptualised in terms of modelling competence, which includes modelling practices—constructing, applying, and revising models—and the metaknowledge needed to reflect on models, their nature, and the processes involved in modelling (Oliva, 2019; Nicolaou & Constantinou, 2014).

Within this framework, metamodeling enables students to understand the nature, purpose, and limitations of scientific models, promoting critical reflection on their use in science and in teaching (Schwarz et al., 2009; Gobert et al., 2011). Knowledge of the nature of models can be organised around four key ideas:

- Models are not exact replicas of phenomena but partial representations of reality (Jansen et al., 2019; Krell & Krüger, 2017; Upmeier zu Belzen & Krüger, 2010).
- Models serve explanatory, interpretive, and predictive functions, helping to make sense of scientific phenomena (Jansen et al., 2019; Krell & Krüger, 2017).
- Multiple models can exist for the same phenomenon, reflecting the diversity of perspectives and approaches in science (Justi & Gilbert, 2002; Upmeier zu Belzen et al., 2019).
- Models are provisional and evolving, subject to revision or modification based on new evidence, alternative theories, or different purposes (Crawford & Cullin, 2004).

PCK, by integrating disciplinary knowledge with pedagogical strategies oriented to epistemic practices such as modelling and inquiry, not only guides the teaching of scientific concepts but also shapes how pre-service teachers foster students' understanding of the nature of models. This perspective underpins the implementation of specific educational interventions, such as MBI Teaching-Learning Sequences (TLSs), which allow researchers to assess how future teachers develop PCK applied to modelling and epistemic reflection.

This study is part of a broader research project evaluating a TLS designed for pre-service teacher education and focused on developing PCK related to modelling and inquiry. Specifically, it examines whether students in the Early Childhood Education degree progress in their understanding of the nature of models after implementing a TLS on the water cycle using the MBI approach. The study is guided by the following research questions:

RQ1. Do students show changes in their understanding of the nature of models after implementing an MBI sequence?

RQ2. Which aspects of the nature of models show these changes?

Methodology

Participants and Educational Context

The study involved 52 students (1 male, 51 female) enrolled in the course Didactics of the Natural Environment, third year of the Early Childhood Education degree at the University of Cádiz, Spain, during the 2024–2025 academic year. A TLS based on the MBI approach was designed and implemented (Gómiz-Aragón & Aragón, 2025), focused on the water cycle, consisting of six 90-minute sessions. The university ecological garden served as a real learning context.

The TLS was structured in five phases to promote the progression of students' initial models of the water cycle toward more complex representations. Table 1 summarises the phases, the main activities, and the aspects of students' understanding of the nature of models (CoNaMo[1] dimensions) addressed in each phase. The four dimensions are: D1 (models beyond exact replicas), D2 (model utility), D3 (multiple model representations), and D4 (evolving nature of models).

Instrument

Data were collected using the CoNaMo questionnaire (Oliva & Blanco-López, 2021), designed and validated to assess knowledge of the nature of scientific models. The questionnaire, originally in Spanish, includes 20 Likert-type items on a 5-point scale (1 = strongly disagree; 5 = strongly agree), distributed across four dimensions (D1–D4), each with 5 items. Scores for each dimension range from 0 to 20 points, and the total score ranges from 0 to 80, providing a quantitative measure of students' understanding of scientific models.

Before administration, the instructor explained the study purpose, and students provided informed consent. The questionnaire was administered in paper format as a pretest at the beginning of the TLS and as a posttest at the end.

[1] From the Spanish *Conocimiento de la Naturaleza de los Modelos*, or 'Knowledge of the Nature of Models'

Table 1. Phases and Activities of the MBI TLS.

Phase	Activities	Nature of models dimensions
1. Defining the TLS objective	A1: Exploration of initial water cycle models through drawings and CoNaMo pretest questionnaire	Identification of prior ideas about model nature, utility, diversity, and evolution (D1, D2, D3, D4)
	A2: Reflection on water, the natural environment, and water footprint	Model utility for understanding and acting on socio-environmental water issues (D2)
2. Initial conceptions	A3: Explicit expression of initial water cycle models	Contrast different representations of the same phenomenon (D3)
	A4: Expression of conceptions about the nature of models	Awareness of what a model is, its purposes, diversity, and evolution (D1, D2, D3, D4)
3. Modelling-based learning	A5: Use of thought experiments and drawings for water cycle modelling	Understanding the need for a model to explain the phenomenon, alternative representations, and reflection on model evolution (D2, D3, D4)
4. Model application through inquiry	A6: Introduction of the garden as a learning context	Model utility for interpreting a real phenomenon in the environment (D2)
	A7: Formulation of the main inquiry question	Definition of the model's purpose to guide the investigation (D2)
	A8: Identification of difficulties and formulation of sub-questions	Need for different models or representations to explain various aspects of the phenomenon (D3)
	A9: Formulation of hypotheses, experiment design and execution, data collection, analysis, and conclusions	Use the model to predict and explain; represent results through drawings or diagrams (D2, D3)
	A10: Answering the main inquiry question	Reflection on model simplification and its utility for addressing the inquiry (D1, D2)
5. Model reconstruction	A11: Final review of the water cycle model through drawings and CoNaMo posttest	Review of final understanding of model nature, utility, diversity, and evolution (D1, D2, D3, D4)
	A12: Group reflective report on the teaching-learning process	Integration of reflection on model function and the learning process (D1, D2, D3, D4)

Data Analysis

To evaluate changes in pre-service teachers' understanding of the nature of models before and after the TLS, a within-group quantitative analysis was conducted. First, the reliability of the data was assessed using ordinal Cronbach's alpha for each dimension and for the overall scale (Table 2).

Table 2. Ordinal Cronbach's alpha for CoNaMo dimensions

CoNaMo dimensions	Pretest	Posttest
D1: Beyond exact replicas	0.700	0.782
D2: Utility	0.543	0.720
D3: Multiplicity	0.765	0.817
D4: Evolving nature	0.877	0.841
Global scale	0.883	0.891

Ordinal Cronbach's alpha values indicate improved internal reliability after the intervention. Pretest reliability ranged from acceptable (0.543) to high (0.877). Post-test reliability increased across dimensions, particularly D2 and D3, with the global scale rising from 0.883 to 0.891, reflecting strengthened reliability and potential improvement in questionnaire comprehension after the TLS.

Next, Wilcoxon signed-rank tests were performed to analyse differences between pre- and post-test scores, and effect sizes were calculated to determine the magnitude of these changes. All analyses were conducted using Jamovi software (version 2.4).

Result

Descriptive analysis of CoNaMo scores (Table 3) showed differences between pre- and posttest. In the pretest, D1 (Beyond exact replicas) had the lowest mean score (M = 2.3), while D4 (Evolving nature) had the highest (M = 3.1). The overall mean score was 2.8. After the intervention, all dimensions improved, with the largest gains in D1 (M = 2.9) and D4 reaching the highest post-test score (M = 3.5). The overall mean increased to 3.2, suggesting enhanced understanding of the nature of models.

Table 3. Descriptive statistics and Wilcoxon signed-rank test results

CoNaMo Dimensions	Pretest M	Pretest DS	Postest M	Postest DS	W	p-value	Effect size (r)
D1: Beyond exact replicas	2.3	0.6	2.9	0.7	230.0	<0.001	0.639
D2: Utility	2.9	0.4	3.2	0.5	220.0	0.002	0.513
D3: Multiplicity	2.9	0.4	3.3	0.6	146.5	<0.001	0.676
D4: Evolving nature	3.1	0.5	3.5	0.5	135.0	<0.001	0.750
Global	2.8	0.3	3.2	0.4	64.0	<0.001	0.891

Inferential analysis using the Wilcoxon signed-rank test confirmed statistically significant improvements across all dimensions. The largest effects were observed in D4 (r = 0.750) and the overall score (r = 0.891). Other dimensions also showed moderate gains: D1 (r = 0.639), D2 (r = 0.513), and D3 (r = 0.676). These results indicate that the intervention contributed to enhancing pre-service teachers' understanding of the nature of scientific models.

Discussion and Conclusions

The instructional intervention, implemented using a MBI approach, had a positive impact on pre-service teachers' understanding of the nature of models, consistent with previous research indicating that improvements are not explained by mere repetition of the instrument (Oliva & Caballero, 2020). Improvements were observed across all dimensions, with the largest gain in D4 (Evolving nature of models), aligning with studies suggesting that this dimension is particularly accessible for students (Jiménez-Tenorio et al., 2016).

This outcome can be attributed to the TLS design, where several activities explicitly highlighted the need to adapt models in response to new evidence, fostering understanding of their provisional nature. According to Engelschalt et al. (2024), recognizing that scientific models are evolving is closely linked to modelling knowledge itself—that is, understanding that models are provisional and develop over time.

In Activity 4, CoNaMo results were shared with the class, using multiple examples to clarify each dimension. This activity promoted dialogic metamodeling, grounded in students' own perceptions. In turn, Activity 5, a thought experiment, introduced new concepts and ideas that helped students develop more complex mental models of the water cycle, represented through detailed drawings. This activity thus exemplified the evolving and provisional nature of models in explaining a natural phenomenon.

In contrast, dimensions such as Multiplicity (D3) and Utility (D2) showed more moderate gains. This may be because the TLS did not include activities specifically designed to compare models with different functions or justify the utility of each representation for explanatory purposes. Future interventions could strengthen these dimensions by incorporating tasks that require selecting models according to their purpose, assessing the adequacy of different representations, and constructing explanations based on multiple types of models.

Overall, the results highlight the importance of explicitly addressing metamodeling, the epistemology of models, and the NOS in teacher education. Research indicates that understanding these aspects rarely develops implicitly through modelling practices; it requires intentional instructional strategies that make their epistemic dimensions visible (Schwarz, 2002). Interventions such as the one described in this study, which include guided reflection, model comparison, analysis of limitations, and discussion of model use, promote more robust learning. This is particularly relevant in pre-service teacher education, where developing PCK involves not only the ability to model but also the capacity to foster metacognitive and epistemic discourse about scientific models in the classroom.

Limitations

This study presents several limitations that should be considered when interpreting the results.

First, the TLS was implemented in the only course in the curriculum specifically dedicated to science education (Didactics of the Natural Environment) and within a limited timeframe, which may have constrained work on certain dimensions of the nature of models. The lack of continuity across other courses in the degree limits the opportunity to consolidate and deepen these learning outcomes.

Second, the study relied exclusively on a quantitative instrument. Although previously validated, it was not triangulated with qualitative sources, which limits a deeper understanding of students' conceptions and prevents clear attribution of observed changes to specific TLS activities. Without additional qualitative evidence, it is not possible to identify precisely which activities had the greatest impact or why some dimensions showed more moderate progression. Nevertheless, the instructor implementing the TLS (second author) was able to identify some key activities that likely supported improvements in certain dimensions. Future studies will examine other student outputs to better determine which activities contribute to the development of a more sophisticated understanding of the nature of models.

Finally, although results indicate gains in overall understanding of the nature of models, it is not possible to determine whether these learnings transfer specifically to the scientific model addressed, in this case, the water cycle model. Evaluating this relationship would require qualitative techniques, such as interviews or analysis of student journals, to explore how students connect what they learned with their own modelling processes in concrete tasks.

Acknowledgement

This study was supported by Grant PID2022-136353NB-I00, funded by MICIU/AEI/10.13039/501100011033 and co-financed by the ERDF/EU.

References

Akerson, V. L., Buzzelli, C. A., & Donnelly, L. A. (2010). On the nature of teaching nature of science: Preservice early childhood teachers' instruction in preschool and elementary settings. *Journal of Research in Science Teaching, 47*(3), 213–233. https://doi.org/10.1002/tea.20323

Brandão, R., Araujo, I., Veit, E. A., & Silveira, F. L. (2011). Validación de un cuestionario para investigar concepciones de profesores sobre ciencia y modelado científico en el contexto de la física. *Revista Electrónica de Investigación en Educación en Ciencias, 6*(1), 43–61.

Crawford, B., & Cullin, M. J. (2004). Supporting prospective teachers' conceptions of modelling in science. *International Journal of Science Education, 26*(11), 1379–1401. http://doi.org/10.1080/09500690410001673775

Engelschalt, P., Bielik, T., Krell, M., Krüger, D., & Upmeier zu Belzen, A. (2024). Investigating pre-service science teachers' metaknowledge about the modelling process and its relation to metaknowledge about models. *International Journal of Science Education, 46*(7), 691–714. https://doi.org/10.1080/09500693.2023.2253368

Fleury Mortimer, E. (1998). Multivoicedness and univocality in classroom discourse: An example from theory of matter. *International Journal of Science Education, 20*(1), 67–82. https://doi.org/10.1080/0950069980200105

Gobert, J. D., O'Dwyer, L., Horwitz, P., Buckley, B. C., Levy, S. T., & Wilensky, U. (2011). Examining the relationship between students' understanding of the nature of models and conceptual learning in biology, physics, and chemistry. *International Journal of Science Education, 33*(5), 653–684. https://doi.org/10.1080/09500691003720671

Gómiz-Aragón, M., & Aragón, L. (2025). Evaluación de la coherencia teórica para el diseño de una SEA de indagación centrada en el modelo del ciclo del agua. In *Libro de Actas electrónicas del XII Congreso Internacional en Investigación en Didáctica de las Ciencias 2025. Enseñanza de las ciencias y pensamiento crítico: desafíos y necesidades de la sociedad democrática* (pp. 2300–2303).

Göhner, M., & Krell, M. (2022). Preservice science teachers' strategies in scientific reasoning: The case of modeling. *Research in Science Education, 52*, 395–414. https://doi.org/10.1007/s11165-020-09945-7

Jansen, S., Knippels, M. C. P. J., & van Joolingen, W. R. (2019). Assessing students' understanding of models of biological processes: A revised framework. *International Journal of Science Education, 41*(8), 981–994. http://doi.org/10.1080/09500693.2019.1582821

Jiménez-Aleixandre, M. P., & Crujeiras, B. (2017). Epistemic practices and scientific practices in science education. In K. S. Taber & B. Akpan (Eds.), *Science education* (pp. 69–88). SensePublishers. https://doi.org/10.1007/978-94-6300-749-8_5

Jiménez-Tenorio, N., Aragón, L., Blanco-López, Á., & Oliva, J. M. (2016). Comprensión acerca de la naturaleza de los modelos por parte de profesorado de ciencias de secundaria en formación inicial

[Understanding the nature of models by science teachers in initial training]. *Campo Abierto, Revista de Educación, 35*(1), 121–132.

Justi, R., & Gilbert, J. K. (2002). Modelling, teachers' views on the nature of modelling, and implications for the education of modellers. *International Journal of Science Education, 24*(4), 369–387. https://doi.org/10.1080/09500690110110142

Krell, M., & Krüger, D. (2017). University students' meta-modelling knowledge. *Research in Science & Technological Education, 35*(3), 261–273. https://doi.org/10.1080/02635143.2016.1274724

Lederman, N. G., Lederman, J. S., & Antink, A. (2013). Nature of science and scientific inquiry as contexts for the learning of science and achievement of scientific literacy. *International Journal of Education in Mathematics, Science and Technology, 1*(3), 138–147.

National Research Council. (2007). *Taking science to school: Learning and teaching science in grades K-8*. The National Academies Press. https://doi.org/10.17226/11625

National Research Council. (2012). *A framework for K–12 science education: Practices, crosscutting concepts, and core ideas*. The National Academies Press. https://doi.org/10.17226/13165

Nersessian, N. J. (2002). The cognitive basis of model-based reasoning in science. In P. Carruthers, S. Stich, & M. Siegal (Eds.), *The cognitive basis of science* (pp. 133–153). Cambridge University Press.

Nicolaou, C. Th., & Constantinou, C. P. (2014). Assessment of the modeling competence: A systematic review and synthesis of empirical research. *Educational Research Review, 13*, 52–73. https://doi.org/10.1016/j.edurev.2014.10.001

Oh, P. S., & Oh, S. J. (2010). What teachers of science need to know about models: An overview. *International Journal of Science Education, 33*(8), 1109–1130. https://doi.org/10.1080/09500693.2010.502191

Oliva, J. M. (2019). Distintas acepciones para la idea de modelización en la enseñanza de las ciencias. *Enseñanza de las Ciencias, 37*(2), 5–24. https://doi.org/10.5565/rev/ensciencias.2648

Oliva, J. M., & Blanco-López, Á. (2021). Development of a questionnaire for assessing Spanish-speaking students' understanding of the nature of models and their uses in science. *Journal of Research in Science Teaching, 58*(6), 852–878. https://doi.org/10.1002/tea.21681

Oliva, J. M., & Caballero, Á. (2020). El aprendizaje de los modelos atómicos y su contribución al desarrollo de prácticas de metamodelización en ciencias [The learning of atomic models and their contribution to the development of metamodeling practices in science]. In *1er Congreso Internacional sobre Educación Científica y Problemas Relevantes para la Ciudadanía* (pp. 152–155).

Papadouris, N., & Constantinou, C. P. (2017). Integrating the epistemic and ontological aspects of content knowledge in science teaching and learning. *International Journal of Science Education, 39*(6), 663–682. https://doi.org/10.1080/09500693.2017.1299950

Passmore, C. M., & Svoboda, J. (2012). Exploring opportunities for argumentation in modelling classrooms. *International Journal of Science Education, 34*(10), 1535–1554. https://doi.org/10.1080/09500693.2011.577842

Schwarz, C. V. (2002). Is there a connection? The role of meta-modeling knowledge in learning with models. *Proceedings of the International Conference of Learning Sciences*.

Schwarz, C. V., Reiser, B. J., Davis, E. A., Kenyon, L., Achér, A., Fortus, D., Shwartz, Y., Hug, B., & Krajcik, J. (2009). Developing a learning progression for scientific modeling: Making scientific modeling accessible and meaningful for learners. *Journal of Research in Science Teaching, 46*(6), 632–654. https://doi.org/10.1002/tea.20311

Seraphin, K. D., Philippoff, J., Kaupp, L., & Vallin, L. M. (2012). Metacognition as a means to increase the effectiveness of inquiry-based science education. *Science Education International, 23*(4), 366–382.

Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher, 15*(2), 4–14. https://doi.org/10.3102/0013189X015002004

Tamayo, A., Eugenio, O., & Orrego, C. M. (2005). Aportes de la naturaleza de la ciencia y del contenido pedagógico del conocimiento para el campo conceptual de la educación en ciencias. *Revista Educación y Pedagogía, 17*(43), 13–25.

Treagust, D. F., Chittleborough, G., & Mamiala, T. L. (2002). Students' understanding of the role of scientific models in learning science. *International Journal of Science Education, 24*(4), 357–368. https://doi.org/10.1080/09500690110066485

Upmeier zu Belzen, A., & Krüger, D. (2010). Modellkompetenz im Biologieunterricht. *Zeitschrift für Didaktik der Naturwissenschaften, 16*, 41–57.

Upmeier zu Belzen, A., van Driel, J., & Krüger, D. (2019). Introducing a framework for modeling competence. In A. Upmeier zu Belzen, J. van Driel, & D. Krüger (Eds.), *Towards a competence-*

based view on models and modeling in science education (pp. 3–19). Springer. https://doi.org/10.1007/978-3-030-30255-9_1

Vázquez, Á., Acevedo, J. A., Manassero, M. A., & Acevedo, P. (2001). Cuatro paradigmas básicos sobre la naturaleza de la ciencia. *Argumentos de Razón Técnica, 4*, 135–176. http://hdl.handle.net/11441/21704

Zohar, A., & Barzilai, S. (2013). A review of research on metacognition in science education: Current and future directions. *Studies in Science Education, 49*(2), 121–169. https://doi.org/10.1080/03057267.2013.847261

EUROPEAN SCIENCE EDUCATION RESEARCH ASSOCIATION ESERA 2025 Copenhagen

Prospective Physics Teachers' Perceptions Of An Objective Structured Teaching Examination (OSTE)

Christoph Vogelsang[1], Lea Lohrsträter[1], Philipp Wotschel[1] and Thomas Janzen[2]
[1]PLAZ- Professional School of Education, Paderborn University, Germany
[2]Center for Practical Teacher Training, Bielefeld, Germany

Assessments or examination procedures should be adequately aligned with the intended learning objectives and planned learning activities, ensuring that the assessment or examination is a valid and reliable measure of the desired learning outcomes. However, academic teacher education programmes often use assessment formats that do not align well with teachers' actual professional practice. Performance-based assessments provide an alternative approach, for example in the form of role-play-based simulations with trained actors representing typical professional activities in environments of reduced complexity. We have developed such a performance-based assessment format for physics teacher education, following the concept of Objective Structured Teaching Examinations (OSTE), as used in medical education. The developed OSTE prototype consists of seven short simulation-based assessments, reflecting four areas of teachers' professional competence (Instruction, Assessment, Pedagogy and Innovation) that form a 90-minute examination course. To investigate prospective physics teachers' perceptions of such an assessment format in terms of its suitability as a summative examination procedure, we piloted the OSTE prototype with N = 54 physics prospective teachers from five German universities using short questionnaires. The results show that participants perceived the OSTE as authentic and relevant. However, they also highlight the need for adequately designed new learning opportunities to prepare for such examinations, which should be integrated into teacher education programmes.

Keywords: teacher education, assessment, examination, simulation, core practice

Background

Prospective teachers often find it difficult to apply the knowledge acquired during their university studies in the classroom and often feel that their studies do not adequately prepare them for future professional practice (Tynjälä & Heikkinen, 2011). This gap between theory and practice in academic teacher education has been the subject of much research. However, the influence of the assessment or examination procedures used in teacher education on this gap is rarely considered.

The Role Of Assessments For Learning

Assessments serve various purposes. Assessment results are used for certification, which has implications for candidates' further study and careers (summative assessment). Furthermore, feedback on assessments can inform students about their performance and thus support them in achieving future learning goals (formative assessment). Hence, according to the model of Constructive Alignment, assessments – including formal examinations – learning objectives and learning activities need to be aligned in such a way that they form a coherent learning process (Biggs & Tang, 2011). Therefore, in teacher education, assessments must be designed in such a way that prospective teachers acquire the necessary skills to become good teachers.

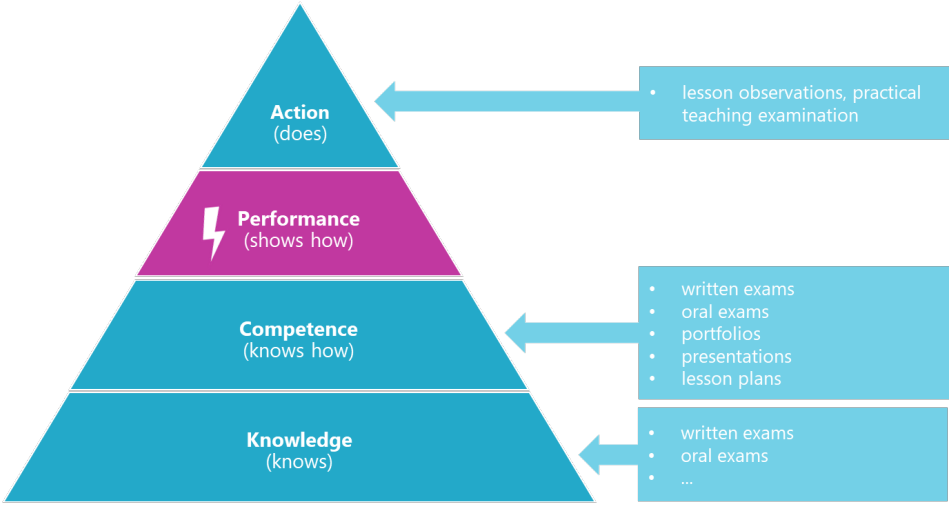
Research in higher education indicates that students' perceptions of assessment procedures or formats have a variety of effects on how they learn and on their course choices (Struyven et al., 2005). Various aspects of assessments have been found to be particularly important. For example, the fairness of an assessment is critical, meaning the perception of fair evaluation and the

opportunity for the candidates to demonstrate their actual capabilities (Sambell, 1997). Fairness of an assessment is related to its perceived transparency, referring to clear expectations and evaluation criteria (Drew, 2001). A key factor, particularly in teacher education, is how authentic an assessment is perceived to be. The authenticity of an assessment relates to how relevant it is perceived to be for the intended learning objective, and its alignment with the professional activities of teachers. Additionally, it refers to whether the content and procedure of an assessment are considered to be authentic (Gulikers et al., 2008). Students tend to choose more in-depth learning strategies to meet the intended learning goals if they perceive an assessment to be more authentic (Villaroel et al., 2021). However, the typical assessments formats used in teacher education programmes rarely reflect later professional activities.

Assessment-Gap In Teacher Education

For a more detailed analysis of assessment formats, we use Miller's (1990) framework for clinical assessment (Figure 1). Although it was originally developed for medical education, it can also be adapted for teacher education.

Figure 1. Typical assessment formats used in teacher education.



The framework differentiates between four levels of assessment depending on which learner dispositions or abilities are focused on. Assessments at the first level (level of knowledge) focus on prospective teachers' declarative knowledge (e.g. content knowledge). Typical formats for assessing this knowledge are written or oral exams. At the second level (level of competence), assessments focus on the procedural knowledge that prospective teachers need to know in order to perform typical professional tasks (Verloop et al., 2001). Alongside written and oral exams, typical formats include portfolios, term papers and, particularly in teacher education, written lesson plans. Assessments at the third level (level of performance) focus on prospective teachers' performance. The focus of this level is on performance, in the sense that prospective teachers can demonstrate their ability to carry out specific professional tasks in a standardised, lower-complexity setting. In contrast, assessments at the fourth level (level of action) focus on prospective teachers' actions under the full complexity of the field. There is a kind of 'assessment gap' between the testing of knowledge on the one hand and professional action in the full complexity of the classroom on the other. While typical formats such as classroom observations are frequently used in teacher education programmes at the fourth level, formats at the third level are scarce. This points to an assessment gap that mirrors the broader theory–practice divide in teacher education.

Addressing The Gap: Performance-Based Assessments

Assessment formats are needed that represent typical professional activities in settings of reduced complexity (approximations of practice, Grossman, 2021). Such assessment formats have long been established in medical education. In these assessments, typical professional tasks (e.g. conducting a clinical interview) are simulated under standardised conditions, often in role-play-based simulations with trained actors. To assess medical educators' teaching and communication skills, several such simulated tasks are also combined in so-called Objective Structured Teaching Examinations (OSTE) (Fakhouri & Nunes, 2019). An OSTE typically consists of a series of 10-15-minute simulation-based assessments that are completed as a coherent examination course. Comparable performance-based assessment formats have rarely been used in teacher education, particularly in science teacher education. However, simulation-based learning approaches are sometimes used for training purposes (e.g. Dotger et al., 2010) or in research projects (e.g. Kulgemeyer & Riese, 2018). Previous findings suggest that prospective teachers positively evaluate such simulations, and especially role-playing formats, as realistic practice and perceive them as authentic and motivating (cf. de Coninck et al. 2019). However, there is seldom evidence of their suitability as an assessment format in teacher education. Therefore, we analysed prospective teachers' perceptions of performance-based examination procedures based on the exemplary case of a specific OSTE developed for Physics Teacher Education.

An OSTE Prototype For Physics Teacher Education

We developed a prototype of an OSTE with the aim of assessing performative aspects of the professional competence of prospective physics teachers (Blömeke et al., 2015). It consists of seven 10–20-minute stations designed aligned with the four areas of competence (Instruction, Assessment, Pedagogy and Innovation) defined in the German National Standards for Teacher Education (KMK, 2022). Following the core practices approach (Grossman, 2021), each station assesses a single isolated core practice. Some stations have a more pedagogical focus, and others focus more on practices specific to physics teachers and were developed based on previous work (e.g., Feser, 2019; Kulgemeyer & Riese, 2018). In terms of content, the stations focus on mechanics. The task and the corresponding response format of the stations vary: the OSTE includes simulated conversations with trained actors as well as simulated video calls on a laptop and stations that must be completed entirely in writing. An overview of all simulated scenarios is described in Table 1.

Participants complete each station in turn, though this order varied from person to person. A complete examination course takes approximately 90 minutes, including short breaks, to fit into the standard schedule of typical courses in German teacher education. All stations follow the same procedure:

1) The participant familiarises with the context of the station by using the material provided (e.g. vignette with background information, standardised auxiliary materials).
2) The participant prepares for the task in a short preparation time.
3) The participant carries out the task.
4) The participant moves on to the next station.

Performance at each station is assessed using standardised coding rubrics by trained raters. In our pilot study, different forms of data were collected depending on the response format, which provided the basis for the performance evaluation. The simulated conversations with actors were videotaped and transcribed afterwards. In the simulated video calls, participants spoke their

answers into a headset microphone. These were audio-recorded and also transcribed. The written answers were processed in the same way as traditional forms of assessment.

Table 1. OSTE-Overview

	Scenario/Task	Response
Instruction		
Station 1: Lesson planning	Participants are asked to fill in the blank in a given lesson plan for a physics lesson by devising a suitable experiment on Newton's Third Law.	written
Station 2: Analysing physics lessons	During a field placement, a fellow prospective teacher asked for feedback on his teaching. Participants therefore have to reflect on and provide feedback on short sequences of videotaped instruction.	simulated video call
Station 3: Explaining a physical phenomenon	Participants are asked to explain to a student why motorcycle accidents are more likely to happen on bends after rain.	simulated conversation (one actor)
Assessment		
Station 4: Student counseling	Participants have to conduct an individual counselling/consultative meeting with a student who is repeatedly disruptive in class	simulated conversation (one actor)
Station 5: Evaluating students' answers in a test	Participants are given two answers to a physics test on acoustics written by students and must evaluate them using provided criteria.	written
Pedagogy		
Station 6: Mediating a conflict between two students	Two students have gotten into a conflict during a break. Participants have to mediate in order to resolve or defuse the conflict.	simulated conversation (two actors)
Innovation		
Station 7: Collaborative lesson development	Participants are asked to discuss the suitability of a lesson analysis tool with a colleague for potential use in professional development.	simulated video call

Objectives

Using the OSTE prototype as an example, we investigated prospective teachers' perspectives on such a performance-based assessment format, which was adapted from medical education. The following research question was investigated.

How do prospective teachers perceive an OSTE prototype for physics teacher education in terms of its suitability as a possible examination procedure?

In particular, we focused on prospective teachers' views of authenticity, cognitive involvement and perceived academic preparation for the OSTE.

Method

We tested the OSTE with eight groups of pre-service teachers at five German universities in 2024. The sample consists of N = 54 prospective physics teachers (gender: 64.8% male, 35.2% female). At the time of the pilot study, they were, on average, in their sixth semester (M = 6.2, SD = 4.1).

44.4% of the participants already had experience teaching mechanics in schools at the time of the test (e.g. through their mandatory field experiences or working as substitute teachers).

After finishing each station, participants completed a short questionnaire with five-point Likert items about their perceptions of the station in terms of authenticity (3 items, example: *"I think the situation described is authentic."*) and cognitive involvement (3 items, example: *"I have immersed myself in the situation."*). The internal consistency of both scales was sufficient for all stations (authenticity: $0.73 < \alpha < 0.88$, cognitive involvement: $0.80 < \alpha < 0.87$). The participants were also asked how well their studies had prepared them for each station (1 item, *"I feel that my studies have prepared me well for the station."*). At the end of the whole OSTE, they completed a questionnaire covering demographic information and an overall rating of the OSTE prototype using six-point Likert items (see Table 3). We were able to conduct follow-up interviews with four participants to gain deeper insights into their perspectives and to enrich the quantitative data.

Results

Evaluation Of The Individual Stations/Scenarios

Table 2 shows the descriptive results regarding perceived authenticity, cognitive involvement and preparedness.

Table 2. Descriptive results – individual stations (range: 0 to 4, theoretical mean: 2).

Station	Authenticity		Cognitive Involvement		Preparedness	
	M	SD	M	SD	M	SD
Station 1: Lesson planning	2.73	0.91	3.13	0.74	2.45	1.01
Station 2: Analysing physics lessons	2.84	0.83	2.98	0.81	2.31	1.06
Station 3: Explaining a physical phenomenon	3.18	0.79	3.36	0.67	2.23	1.02
Station 4: Student counselling	3.35	0.61	3.42	0.59	0.90	1.04
Station 5: Evaluating students' answers in a test	3.35	0.61	3.40	0.58	1.75	1.04
Station 6: Mediating a conflict between two students	3.47	0.61	3.31	0.61	0.87	1.07
Station 7: Collaborative lesson development	2.93	0.93	3.01	0.76	1.71	1.27

Regarding the evaluation of the individual stations, Station 5 (Evaluating students' answers in a test) and the simulated conversation in Station 6 (Mediating a conflict between two students) in particular generated a high level of cognitive involvement and were perceived as highly authentic. The stations with simulated video calls and Station 1 (Lesson planning) were perceived as slightly less authentic, but cognitive involvement was still comparably high. In terms of trends, stations involving actors were perceived as more authentic. In comparison, stations closer to the lower assessment levels in Miller's (1990) framework were perceived as less authentic. On average, however, perceptions of each station were above the theoretical mean. Participants were highly cognitively involved in each station. Box plots of data for authenticity and cognitive involvement are also shown in Figures 2 and 3 to illustrate the differences among participants more concisely. Overall, students felt that their studies had done little to prepare them for the tasks set at the examination stations. They felt most prepared for tasks relating to instruction, which are found in stations 1 to 3. For more pedagogical core practices reflected in Station 4 (Student counseling) or Station 6 (Mediating a conflict between two students) most of them felt not prepared at all.

Figure 2. Perceived authenticity of the individual stations – Boxplots.

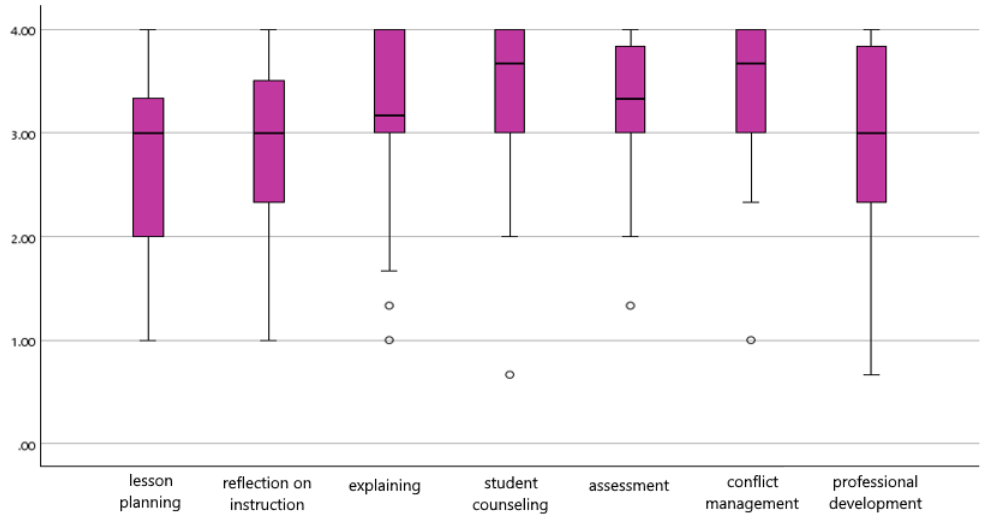
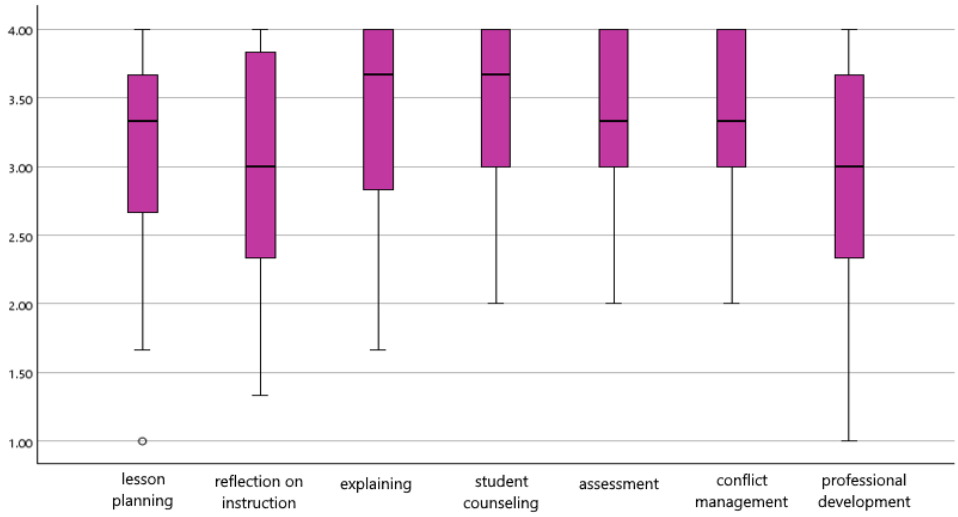


Figure 3. Perceived cognitive involvement in the individual stations – Boxplots.



Evaluation of the whole OSTE prototype

Table 3 shows the descriptive results regarding the overall assessment of the OSTE prototype.

Table 3. Descriptive results – overall evaluation (theoretical mean: 3.5).

Items	M	SD
"Such an examination course assesses what is relevant for my future career as a teacher"	5.35	0.71
"You can prepare well for such an examination course"	3.57	1.04
"In such an examination course it is easy to compare the performance of different students"	3.81	1.11
"An examination course like this reflects authentic practices of the teaching profession"	5.41	0.71
"You can plan your preparation well for such an examination course"	3.81	1.09
"An examination course like this assesses what is relevant throughout teacher education"	5.20	1.02

The results are positive in terms of their suitability as a possible examination format but also point to the challenges of the still unfamiliar format. Specifically, participants felt that the OSTE

prototype reflects authentic professional core practices of physics teachers and assesses what is relevant to their future profession. On the other hand, the participants were less positive about the possibility of preparing well for such an examination format and the comparability of students' performance in the OSTE prototype.

These quantitative results are also reflected in the interviews. For example, one participant pointed out that the OSTE prototype covers relevant professional skills.

> "Also zum einen, dass man Fachwissen halt zum Beispiel einem Schüler nahbringen kann. Das ist ja eine Kompetenz, die eigentlich sehr wichtig ist, aber die so bis jetzt in keiner Prüfung bei mir eigentlich drankam würde ich sagen. [Well, for one thing, you can teach a student content knowledge. That's a competency that's actually very important, but I would say that it hasn't really come up in any of my exams so far.]"

The time pressure aspect of the OSTE prototype was also considered to be an appropriate representation of the professional demands placed on teachers.

> "Ich habe erst gedacht, dass es so ein bisschen auch negativ [...] ist, dadurch, dass man ja so schnell 'switchen' muss zwischen diesen einzelnen Stationen, dann habe ich aber gedacht, wenn man später in dem Beruf ist wird es nicht anders sein. [At first, I thought it was a bit negative [...] because you have to switch between these different stations so quickly, but then I realised that it won't be any different when you're working in the profession later on.]"

However, the interviews also suggest that prospective teachers feel less prepared for performance-based assessments compared to traditional assessment formats.

> "So als Prüfungsformat finde ich das besser, aber ich persönlich fände die mündliche Prüfung für mich schöner, weil ich mich da halt besser drauf vorbereiten könnte, weil ich eher weiß, was da drankommt. [I think that's a better examination format, but personally I would prefer the oral exam because I could prepare for it better, as I have a better idea of what to expect.]"

Discussion

Overall, the OSTE prototype is perceived by participants as very relevant and authentic to teachers' professional practice, similar to the findings for simulation-based learning scenarios reported, for example, by de Coninck et al. (2019) and Wildgans-Lang et al. (2022). Based on the results, it can be assumed that the OSTE would be accepted as an examination procedure by prospective physics teachers, if they are adequately prepared for this innovative assessment format during the course of their studies. Adapting teaching approaches and learning environments is clearly necessary if performance-based assessments such as the OSTE are to be integrated into teacher education programmes, following the concept of Constructive Alignment (Biggs & Tang, 2011). This would not only help pre-service teachers to prepare for the assessment but also make the assessment format more transparent. The successful pilot tests at five different universities also suggest that the results are likely to be generalisable across different specific curricula.

However, it is difficult to determine the extent to which students consider the procedure to be fair. In our pilot study, we could not test the OSTE as a summative assessment, as this would necessitate modifications to the formal examination procedures at each university. The students therefore did not experience the OSTE prototype as a high-stakes assessment, but they knew that it was an initial trial designed to gather their perspectives on the format. The evaluation would probably have differed in some respects if their performance had actually been graded, which

would have had a greater impact on their future studies. Therefore, further trials under high-stakes pressure conditions are necessary. Despite its high transformative potential, the implementation of an OSTE as a summative examination procedure requires more resources than traditional examination formats (e.g. trained actors, sufficient rooms). Careful con-sideration should therefore be given to the stage of teacher education at which such an OSTE can be integrated most effectively. This also remains an open question for future research.

Acknowledgement

This project has received funding from the German Federal Ministry of Research, Technology and Space (BMFTR) – Project PERFORM-LA, Grant number NFGWIHO02.

References

Biggs, J., & Tang, C. (2011). *Teaching for Quality Learning at University*. McGraw Hill.

Blömeke, S., Gustafsson, J.-E. & Shavelson, R. J. (2015). Beyond Dichotomies: Competence viewed as continuum. *Zeitschrift für Psychologie, 223*(1), 3–13. https://doi.org/10.1027/2151-2604/a000194

Coninck, K. de, Valcke, M., Ophalvens, I., & Vanderlinde, R. (2019). Bridging the theory-practice gap in teacher education: The design and construction of simulation-based learning environments. In K. Hellmann, J. Kreutz, M. Schwichow & K. Zaki (Eds.), *Kohärenz in der Lehrerbildung [Coherence in Teacher Education]* (pp. 263–280). Springer Fachmedien. https://doi.org/10.1007/978-3-658-23940-4_17

Dotger, S., Dotger, B. H., & Tillotson, J. (2010). Examining how preservice science teachers navigate simulated parent–teacher conversations on evolution and intelligent design. *Science Education, 94*(3), 552-570. https://doi.org/10.1002/sce.20375

Drew, S. (2001). Perceptions of what helps learn and develop in education. *Teaching in Higher Education, 6*(3), 309-331. https://doi.org/10.1080/13562510120061197

Fakhouri, S. A., & Nunes, M. D. P. T. (2019). Objective structured teaching examination (OSTE): an underused tool developed to assess clinical teaching skills. A narrative review of the literature. *Sao Paulo Medical Journal, 137*, 193-200. https://doi.org/10.1590/1516-3180.2018.0308161118

Feser, M. S. (2019). *Physiklehrkräfte korrigieren Schülertexte [Physics teachers correct student texts]*. Logos.

Grossman, P. (Ed.). (2021). *Teaching core practices in teacher education*. Harvard Education Press.

Gulikers, J. T., Kester, L., Kirschner, P.A., & Bastiaens, T.J. (2008). The effect of practical experience on perceptions of assessment authenticity, study approach, and learning outcomes. *Learning and Instruction, 18*(2), 172-186. https://doi.org/10.1016/j.learninstruc.2007.02.012

KMK (2022). *Standards für die Lehrerbildung: Bildungswissenschaften [Standards for Teacher Education: Educational Sciences]. Beschluss der Kultusministerkonferenz vom 16.12.2004 i. d. F. vom 07.10.2022.* https://www.kmk.org/fileadmin/veroeffentlichungen_beschluesse/2004/2004_12_16-Standards-Lehrerbildung.pdf

Kulgemeyer, C., & Riese, J. (2018). From professional knowledge to professional performance: The impact of CK and PCK on teaching quality in explaining situations. *Journal of Research in Science Teaching, 55*(10), 1393-1418. https://doi.org/10.1002/tea.21457

Sambell, K., McDowell, L., & Brown, S. (1997). 'But is it fair?': an exploratory study of student perceptions of the consequential validity of assessment. *Studies in Educational Evaluation, 23*(4): 349–371. https://doi.org/10.1016/S0191-491X(97)86215-3

Struyven, K., Dochy, F., & Janssens, S. (2005). Students' perceptions about evaluation and assessment in higher education: A review. *Assessment & Evaluation in Higher Education, 30*(4), 325-341. https://doi.org/10.1080/02602930500099102

Tynjälä, P. & Heikkinen, H. L. (2011). Beginning teachers' transition from pre-service education to working life. *Zeitschrift für Erziehungswissenschaft, 14*(1), 11–33. https://doi.org/10.1007/s11618-011-0175-6

Verloop, N., van Driel, J., & Meijer, P. (2001). Teacher knowledge and the knowledge base of teaching. *International Journal of Educational Research, 35*(5), 441-461. https://doi.org/10.1016/S0883-0355(02)00003-4

Villarroel, V., Boud, D., Bloxham, S., Bruna, D., & Bruna, C. (2020). „sing principles of authentic assessment to redesign written examinations and tests. *Innovations in Education and Teaching International, 57*(1), 38-49. https://doi.org/10.1080/14703297.2018.1564882

Wildgans-Lang, A., Scheuerer, S., Obersteiner, A., Fischer, F. & Reiss, K. (2022). Learning to Diagnose Primary Students'Mathematical Competence Levels and Misconceptions in Document-Based Simulations. In F. Fischer & A. Opitz (Eds.), *Learning to Diagnose with Simulations* (pp. 17-31). Springer International Publishing. https://doi.org/10.1007/978-3-030-89147-3_3

EUROPEAN SCIENCE EDUCATION RESEARCH ASSOCIATION ESERA 2025 Copenhagen

Dealing With Students' Misconceptions In A Virtual Reality Classroom In Pre-Service Teacher Training

Inga Kallweit, Nina Sofie Werthschulte and Insa Melle
TU Dortmund University, Germany

Pre-service teacher training at universities faces the challenge of combining theoretical knowledge and practical experience. In order to bridge this gap, enormous efforts are made to create training situations that are as close to reality as possible, for example by inviting classes to universities or conducting role plays. Modern technologies, such as virtual reality (VR) classrooms, offer innovative opportunities to simulate immersive training situations while saving on personnel and time resources. In addition, VR-based training scenarios can be reproducible and analysable. Pre-service teachers can gain experience in dealing with virtual students in a protected environment and afterwards analyse their own actions and reactions. The study presented here aims to use a VR classroom to train future chemistry teachers. The focus is on dealing with student misconceptions. While the pre-service teachers in the VR classroom can react as they would in a real classroom, a coach manipulates the virtual students and thus the teaching situation. The purpose of this study is to determine whether this VR-based training helps pre-service chemistry teachers recognize and respond to common misconceptions about combustion.

Keywords: Pre-Service Teacher Education, Virtual Reality

Introduction

Balancing theory and practice in pre-service teacher training remains a significant challenge in higher education. In response, several German states, require pre-service teachers to complete an internship semester. In the run-up to this practical experience in school, the university seminars aim to prepare pre-service teachers for teaching situations as realistically as possible.

Placing prospective teachers in an immersive environment and training them in that environment through the use of VR offers new opportunities. Although research on the application of VR in teacher education is still in its early stages, initial findings suggest that VR classrooms can have a positive impact on aspects of teacher preparation such as presence in the classroom (e.g., Wiepke, 2022). The aim of the study presented here is to utilize the potential of a VR classroom for the training of future chemistry teachers. One focus is on dealing with students' misconceptions in a virtual discussion.

Theoretical Framework

VR In Pre-Service Teacher Training

Research into the potential applications of VR environments for pre-service teacher training is not yet very advanced. At the same time, immersive VR media are increasingly being integrated into educational contexts and studies to analyse their potential benefits (Wiepke & Heinemann, 2024). Initial studies indicate positive effects on the behaviour of pre-service teachers, but also highlight the great need for further development and research. The advantages of using a VR classroom as a teaching simulation include the immersive experience and reproducibility (Wiepke, 2022). In addition, VR classrooms provide the opportunity to experience and practice teaching in a safe environment (Lugrin et al., 2016). Therefore, there is potential in exposing pre-service teachers to a virtual teaching situation, that allows them to analyse their own behaviour and repeatedly engage in the same or a similar teaching situation.

The complexity of a teaching situation can be a major challenge, especially for those just starting out in the profession. Classroom management is therefore an important aspect of pre-service teacher training (Evertson & Weinstein, 2013). For this reason, previous research on VR classrooms has focused on classroom management training. To this end, Lugrin et al. (2016) developed a VR classroom that is used in university seminars. In this setting, pre-service teachers are deliberately placed in stressful situations in order to promote and analyse classroom management skills. The results of the study indicate that the system is suitable for university education, that acceptance by pre-service teachers is high and their assessment is positive (Lugrin et al., 2016).

Students' Misconceptions

The fact that students often use every day beliefs, which are not always scientifically based preconceptions in the chemistry classrooms has been empirically investigated many times (e.g., Horton, 2007; Schmidt et al., 2007). It has also been shown that teachers and pre-service teachers know little about misconceptions or how to deal with them (e.g., Gabel, 1999; Uhren et al., 2013).

For this reason, there are established concepts for the training and further education of (future) chemistry teachers that address the diagnosis and handling of students' misconceptions in chemistry lessons (e.g., Marohn, 2008). Rohrbacher-Lochner and Marohn (2018) developed and evaluated a seminar for pre-service chemistry teachers, in which the pre-service teachers received theoretical input on student misconceptions, planned a lesson on this basis and carried it out with invited classes at the university (Rohrbacher-Lochner & Marohn, 2018). But running real classes at universities requires extensive planning and is very time consuming. At this point, the use of a VR classroom in university education can be resource-saving. In addition, it offers the advantages of reproducibility and comparability of teaching situations. The study presented here focuses on the handling of student misconceptions in a virtual classroom discussion with the topic of 'combustion'.

Method

The study takes place as part of an obligatory course for all chemistry teacher students in the master's program. In the subsequent semester, these pre-service teachers will participate in an internship semester. During the seminar sessions at university, various topics are dealt with in preparation for the practice, such as lesson planning and teaching methods. One seminar session explicitly addresses students' misconceptions, their diagnosis, and possible forms of response. At the end of the semester, the pre-service teachers participate in the VR classroom individually. They are placed in a given teaching situation on the topic of 'combustion' and their task is to lead a class discussion to analyse the experiment 'combustion of iron wool'. In this experiment, the iron wool is weighed before and after combustion. The chemical reaction of the combustion causes the iron wool to react with the oxygen in the air and is heavier after the reaction. The explanation for the increase in weight requires knowledge of chemical reactions. Concerning this, there are a number of examined misconceptions (e. g., Horton, 2007).

In this study, the VR classroom developed by the University of Potsdam is used (e.g., Wiepke, 2022; Huang et al., 2021). It is designed for two users: a pre-service teacher, who is trained and a coach supervising the training session. Using a VR head-mounted display and controllers, the pre-service teacher enters a virtual classroom with 30 virtual students (Figures 1 and 2). The virtual students are controlled by the coach via a web interface, which shows the seating arrangement of the virtual classroom so that each individual virtual student can be controlled. In order to simulate the classroom discussion, possible student responses were anticipated in advance and recorded in a path diagram. Empirically proven misconceptions on the topic of

'combustion' were included in these statements. The coach assigns the pre-service teacher's statements and reactions to one of three categories: From *"Notices and responds to students' misconceptions in a way that promotes a meaningful class discussion"* to *"Does not react to students' misconceptions and does not promote a meaningful class discussion"*. By following the paths in the diagram, the coach selects a suitable student answer.

Figure 1. Pre-Service Chemistry Teacher with VR Head-Mounted Display.

Figure 2. Virtual Students in the VR Classroom (Participant's Perspective).

Research Questions

One focus of this study is to explore the potential of the VR classroom in terms of how pre-service chemistry teachers deal with students' misconceptions:

Q1) How do pre-service teachers respond to students' misconceptions in a classroom discussion in the VR classroom?

Q2) How do pre-service teachers evaluate the teaching situation in the VR classroom?

To address the research questions, a qualitative study was conducted. Therefore, video recordings were made of the pre-service chemistry teachers during their training in the VR classroom as well as screen recordings of the virtual students including the web interface. In addition, the pre-service teachers answered a questionnaire directly after the training. This questionnaire consists of five questions, three of which are answered on a three- or four-point Likert scale and two of which are open-ended. The questions that use a Likert scale could also be answered with *"not able to assess"*. The focus of the questionnaire is on the subjective impression after training in the VR classroom. One week later, individual interviews were conducted. The interview guideline focuses on the experiences in the VR classroom, self-perception and their own assessment of how they dealt with students' misconceptions. Furthermore, excerpts from the

video recordings were used to reflect on the conversation. The interview transcripts were used to answer research questions Q1) and Q2).

First Results

Eight pre-service teachers participated in the first trial in February 2025. They only reacted visibly to the misconceptions in 23% of cases, which is very low. Interestingly, prospective teachers usually responded immediately with an explanation, rather than, for example, asking follow-up questions or involving other students in the conversation. There seems to be room for improvement, particularly since classroom discussions based on misconceptions provide great learning opportunities (Sommer et al., 2022).

The evaluation of the questionnaire, which was completed directly after the training, shows that the pre-service teachers described the experience in the VR classroom as consistently positive. In one of the open-ended questions, five pre-service teachers mentioned that they needed a short time to get used to the VR classroom, but then quickly found their way around. Half of the pre-service teachers reported that they had identified all the misconceptions, while the other half assumed that they had not recognized all the misconceptions (Likert scale: *recognized all misconceptions, recognized not all misconceptions, recognized none misconceptions*). This is particularly remarkable because the pre-service teachers only responded to the misconceptions mentioned in a quarter of the cases. When asked how confident they felt in spontaneously reacting to student statements, half of the pre-service teachers responded with *not confident*, three with *confident* and one was not able to assess (Likert scale: *very confident, confident, not confident, not confident at all*). Seven of the eight pre-service teachers rated the usefulness of VR for pre-service teachers as at least high (Likert scale: *very high, high, medium, low*). These results were confirmed by the guided interviews conducted one week after the training. Five of the pre-service teachers once again emphasized the benefits for their own development and the environment's intuitive handling of. However, they would like to have more opportunities to interact with the virtual class, e.g., working together on a blackboard. The interviews also revealed that the pre-service teachers were unsure how to deal with the misconceptions mentioned during the conversation, which is consistent with the results described above.

Discussion and Outlook

Overall, these first results presented are only preliminary. Nevertheless, these results suggest that the pre-service teachers' attitude towards the training in the VR classroom is positive and that the training is considered helpful for professional development (Q2). In addition, the first trial resulted in extensions to the path diagram to enable the coach to react more flexibly to the students' impulses and foster a more fluent classroom conversation. However, it became clear that pre-service teachers rarely visibly respond to the aforementioned misconceptions and still have limited conversation prompts (Q1). Clearly, there is still great potential for developing their conversation skills here, which will be addressed in subsequent seminars together with the per-service teachers.

The next iteration of the study will investigate whether the training leads to improved identification of misconceptions and better dialogue management in class discussions. For this reason, the training will be carried out twice in the following study. In order to achieve improvements in dialogue management, the first training session will be analysed in more detail together with the pre-service teachers and after that, they go through a second training in the VR classroom. In addition, we plan to develop a second VR classroom that deals with the subject of electrochemistry.

References

Evertson, C. M., & Weinstein, C. S. (2013). *Handbook of Classroom Management: Research, Practice, and Contemporary Issues*. Routledge.

Gabel, D. (1999). Improving teaching and learning through chemistry education research: a look to the future. *Journal of chemical education, 76*(4), 548-554.

Horton, C. (2007). Student Alternative Conceptions in Chemistry (Student Misconceptions and Preconceptions in Chemistry). *California Journal of Science Education, VII*(2).

Huang, Y., Richter, E., Kleickmann, T., Wiepke, A., & Richter, D. (2021). Classroom complexity affects student teachers' behaviour in a VR classroom. *Computers & Education, 163*, 104100. https://doi.org/10.1016/j.compedu.2020.104100

Lugrin, J.-L., Latoschik, M. E., Habel, M., Roth, D., Seufert, C., & Grafe, S. (2016). Breaking Bad Behaviours: A New Tool for Learning Classroom Management Using Virtual Reality. *Front. ICT, 26*(3). https://doi.org/10.3389/fict.2016.00026

Marohn, A. (2008). "Choice2learn" – eine Konzeption zur Exploration und Veränderung von Lernervorstellungen im naturwissenschaftlichen Unterricht [„Choice2learn" – A concept for exploring and changing learner perceptions in science lessons]. *Zeitschrift für Didaktik der Naturwissenschaften, 14*, 57-83. https://doi.org/10.25656/01:31632

Rohrbach-Lochner, F., & Marohn, A. (2018). How research-based learning can increase teacher students' knowledge and abilities – a design-based research project in the context of pupils' (mis) conceptions in science. *RISTAL*, *1,* 35-50. https://doi.org/10.23770/rt1810

Schmidt, H.-J., Marohn, A., & Harrison, A. G. (2007). Factors That Prevent Learning in Electrochemistry. *Journal of Research in Science Teaching, 44*(2), 258-283.

Sommer, K., Wambach-Laicher, J., & Pfeifer, P. (Eds.) (2022). *Chemiedidaktik in Übersichten [Chemistry Education in Overviews]*. Aulis.

Uhren, S., Ralle, B., & Di-Fuccia, D.-S. (2013). Zum Umgang von Lehrkräften mit alternativen Schülervorstellungen [How teachers deal with alternative student perceptions]. *Chimica et cetera artes rerum naturae didacticae, 38*(105), 51-67.

Wiepke, A. (2022). Präsenzgefühl und Selbstwirksamkeitserwartung im VR-Klassenzimmer [Sense of presence and self-efficacy in the VR classroom]. *MedienPädagogik: Zeitschrift Für Theorie Und Praxis Der Medienbildung, 48,* 40-51. https://doi.org/10.21240/mpaed/48/2022.06.06.X

Wiepke, A., & Heinemann, B. (2024). A systematic literature review on user factors to support the sense of presence in virtual reality learning environments. *Computers & Education: X Reality, 4,* 100064. https://doi.org/10.1016/j.cexr.2024.100064

EUROPEAN SCIENCE EDUCATION RESEARCH ASSOCIATION ESERA 2025 Copenhagen

Primary Pre-Service Teachers' Professional Identity Development For Teaching Climate Change

Chara Bitsaki[1,2], Lucy Avraamidou[2] and Dimitris Stavrou[1]
[1]Department of Primary Education, University of Crete, Greece
[2]Faculty of Science and Engineering, University of Groningen, Netherlands

Given the complexity of the climate crisis, preparing pre-service teachers to teach Climate Change as a multifaceted topic is essential. However, pre-service teachers are unprepared to integrate this multifacetedness into their teaching. This study investigates how pre-service teachers develop their professional identities during a 12-week seminar on Climate Change Education at a southern European university. The participants in the study were 29 primary pre-service teachers who had participated in activities related to Climate Change content and Climate Change competencies (Normative Competence, Anticipatory Competence, System Thinking, Strategic Competence, and Interpersonal Competence). Simultaneously, the pre-service teachers, divided into seven groups, designed step-by-step teaching materials on Climate Change that included Climate Change competencies. Data were collected through autobiographical texts, teaching materials, reflection journals, and final interviews, and qualitative analysis methods were utilised. The findings indicate that Climate Change Teacher Education should support pre-service teachers by fostering self-awareness and equipping them with teaching strategies to build students' Climate Change Competencies. Participants recognised their competence in teaching Climate Change and explored widely used teaching strategies. Moreover, this process enhanced their self-recognition as competent Climate Change teachers, reinforcing their confidence in integrating Climate Change into their future teaching practices. These findings contribute to the growing discourse on Climate Change Teacher Education, emphasising the benefits of identity-focused approaches that empower pre-service teachers to engage students meaningfully in sustainability and climate action.

Keywords: Science Teacher Identity, Teacher Education, Climate Change

Introduction

Climate Change is a 21st-century challenge that affects the natural environment, society, the economy, and health (IPCC, 2023). Therefore, the climate crisis is not only an ecological threat but also a moral and educational challenge that demands action across all sectors of society. Climate change is a complex system shaped by interacting natural processes and human activities, making it difficult to define, predict, and address with single solutions (Lehtonen et al., 2018; Miani et al., 2025a; Peters & Tarpey, 2019). It is often described as a "super-wicked problem" because interventions can meet resistance or produce unintended consequences. Scientifically, climate change involves non-linear interactions, feedback loops, and uncertainty across interconnected Earth subsystems, which demand an interdisciplinary understanding (Miani et al., 2025a). Socially, it functions as a polarised socioscientific issue, involving ethical dilemmas, justice concerns, and emotional dimensions. These features challenge education, where fragmented curricula and content transmission often fail to support holistic systems thinking and transformative competencies (Eilam, 2022; Sezen-Barrie et al., 2025). Engaging multiple perspectives supports systemic reasoning about drivers and solutions (Cantell et al., 2019; Höhle & Bengtsson, 2023), while future thinking helps learners connect present decisions to uncertain but plausible trajectories (Miani et al., 2025b).

Consequently, addressing the climate crisis requires interdisciplinary and systemic approaches, as well as cooperation among diverse stakeholders (Lehtonen et al., 2018; Miani et al.,2025a).

This makes it vital for Climate Change Education to develop key skills that improve climate literacy and prepare students to be future citizens capable of addressing climate challenges (USGCRP, 2024). These key skills, known as sustainability or climate change competencies, are a) Normative Competence, b) Anticipatory Competence, c) Systems Thinking, d) Strategic Competence, and e) Interpersonal Competence (Wiek et al., 2011), with Scientific Inquiry playing a key role in building and applying these skills (Taurinen et al., 2024).

Building students' key competencies for climate literacy requires teachers who can effectively incorporate them into their teaching. However, teachers encounter various challenges in implementing Climate Change Education. These challenges arise from fragmented knowledge of content and a lack of confidence in managing the inherent uncertainty of climate science (Waldron et al., 2019). Consequently, it becomes difficult to address the complexity of the phenomenon in the classroom and to link scientific content with its societal, ethical, and emotional dimensions (Drewes et al., 2018; Shea et al., 2016). Additionally, several studies indicate that teachers often feel unprepared (Ennes et al., 2021; Waldron et al., 2019) and do not see themselves as competent climate change educators (Ratinen, 2013). This limited professional self-recognition is associated with hesitation in fostering values and agency within their teaching role (Hestness et al., 2014; Timm & Barth, 2021) and is influenced by teachers' personal experiences, attitudes, values, and beliefs regarding climate change (Bascopé et al., 2025; Leite, 2024; McNeal et al., 2017).

Addressing these challenges requires teacher education to move beyond emphasising content knowledge and pedagogical strategies and adopt more comprehensive approaches. Effective Climate Change Teacher Education should not only strengthen teachers' understanding of scientific concepts and ability to design inquiry-based, interdisciplinary learning environments, but also connect this knowledge to the broader social, economic, and ethical dimensions of the climate crisis (Brandt et al., 2019; Cantell et al., 2019). Furthermore, teacher education must offer opportunities for teachers to reflect on their own experiences, values, and beliefs, recognising that positionality fundamentally shapes professional practices and agency. When such elements are integrated, teacher education becomes a transformative space for developing an identity through which teachers see themselves as competent and responsible educators, capable of linking scientific understanding with moral purpose and social engagement (Menon, 2020).

Nevertheless, few studies focus on Climate Change Teacher Education (Rousell & Cutter–Mackenzie–Knowles, 2020), and even fewer invest in teachers' beliefs, values, and attitudes as part of their professional growth. While research highlights the importance of pre-service teacher education beyond scientific content alone (Ennes et al., 2021; Hestness et al., 2014; Waldron et al., 2019; Zangori et al., 2017), there are very few empirical studies that examine teacher training and professional development related to climate change content alongside teachers' beliefs, values and attitudes, and their interaction with environmental, societal, and economic factors (e.g. Brandt et al., 2019; Kriewaldt & Jun Lee, 2023; Waldron et al., 2019).

To address these issues, we propose using the lens of Teacher Identity (Avraamidou, 2014a) in teacher education through the concept of Climate Change Teacher Identity. Climate Change Teacher Identity (CCTI) is crucial for preparing teachers to address the scientific, interdisciplinary, and socio-political demands of Climate Change Education. Teaching climate change requires more than content knowledge and pedagogical techniques: teachers must integrate knowledge, skills, attitudes, and values to help students develop sustainability competencies and navigate complex, uncertain futures (Felix & Clayton, 2025; Howell & Allen, 2019). Building on science teacher identity research (Avraamidou, 2014a), CCTI extends science teacher identity by foregrounding urgency, ethics, emotions, and civic responsibility, positioning

teachers as facilitators of systems thinking, futures thinking, and value-based inquiry (Eilam, 2022; Miani et al., 2025a). Despite growing work on Climate Change Teacher Education, coherent identity-based frameworks, especially in primary education, remain limited.

We conceptualise CCTI through Carlone and Johnson's (2007) three dimensions: competence, performance, and recognition, while recognising that emotions, values, and context shape all three (Avraamidou, 2019; Nation & Feldman, 2022). Competence involves an evidence-based understanding of climate systems and their interactions with the environment, society, the economy, politics, and ethics. Performance refers to how teachers enact this competence through language, representations, and pedagogical tools, including engaging uncertainty and controversy. Recognition concerns seeing oneself, and being seen by others, as a legitimate climate change educator, supported through reflective questions about past, present, and future teacher selves.

Based on the above, this study focuses on the development of the Climate Change Teacher Identity of primary education pre-service teachers as a lens on how pre-service teachers learn and develop during a university seminar on Climate Change Education. The research question that guides this investigation is "How do the dimensions of Primary pre-service teachers' Climate Change Teacher Identity depict during the design of teaching materials on climate change complexity?"

Methods

Research Design And Participants

To address the research question mentioned above, we examined the development of primary pre-service teachers' Climate Change Teacher Identity. All 29 participants took part in a 12-week university seminar on Climate Change Education at the Department of Primary Education in the University of Crete, organised into 7 groups of 4 to 5 students each. In this study, the first author held a double role of a trainer and researcher.

The sessions of this seminar included the following activities:

Reflection on learning experiences in formal and informal environments and values about Climate Change (Session 1): The pre-service teachers had to recall and reflect on their past learning experiences, attitudes, and values related to Climate Change, and share those experiences with their group. Based on their reflections, the participants developed an autobiographical text in which they expressed the aforementioned past experiences in more detail.

Introduction to the scientific content (Session 2): In this session, the pre-service teachers became familiar with Climate Change content by exploring its impacts using real data, hands-on and video experiments, and models and simulations.

Engagement with activities for Climate Change Competencies (Sessions 4-10): The pre-service teachers participated in activities related to the complexity of Climate Change through physics experiments, discussed inclusivity in proposed solutions for Climate Change through a role-playing game, and envisioned themselves in IPCC future scenarios. For these sessions, they wrote three reflection journals and a text in which they imagined themselves as future Climate Change teachers. During this session, they became more familiar with innovative teaching methods proposed by the literature.

Teaching Material Development and Implementation (Sessions 2-12): During these sessions, the pre-service teachers designed, developed, and implemented teaching materials based on climate change competencies, utilising tools such as CoRes (Hume & Berry, 2010) and continuous feedback from the trainer and researcher in this study. The teaching material developed by the

participants was rich, including hands-on experiments, group activities that enhance students' decision-making skills and agency (role-playing games and actions), and artefacts. The implementation took place in the university's science centre.

Data Collection

Data were gathered from autobiographical texts, teaching materials, reflection journals, and a final semi-structured interview. The autobiographical texts offer insights into pre-service teachers' personal experiences, attitudes, and values towards climate change, providing space to express their Self-View as future climate change educators. The reflection journals served both as sources for pre-service teachers' Competence and Self-View. The teaching materials on the other side provided insights into pre-service teachers' Competence and Performance, serving as a means for participants to embody their knowledge and skills related to climate change, as well as their perceptions of a climate change educator's role. Finally, the final interviews served as a form of data triangulation.

Data Analysis

Given the exploratory nature of the study and the small number of participants, we employed qualitative content analysis methods (Mayring, 2014). To answer our research question, we conducted a top-down and bottom-up analysis of autobiographical texts, reflection journals, and teaching materials, focusing on pre-service teachers' Climate Change Teacher Identity. For that, we utilised Carlone & Johnson's framework (2007) to develop a category system for the Climate Change Teacher Identity dimensions. More specifically, Competence was examined through pre-service teachers' knowledge and understanding of Climate Change Complexity (e.g. systems thinking, uncertainty, multiplicity, etc.). Performance was examined in terms of the extent and manner in which PSTs expressed climate change complexity through their designed teaching materials (e.g., representations, tasks, inquiries, decision-making structures). As far as Recognition that regards how the pre-service teachers see themselves and are seen by others, we decided to focus on the first part since the majority of them have not enrolled in practicals yet, and as a result, they haven't yet any reflections on how their students or other teachers are seeing them. Based on that, we focused on pre-service teachers' self-view, which was examined through pre-service teachers' perceptions of themselves and their roles as climate change educators, including how they described their responsibilities, doubts, and ethical/value orientations. Table 1 presents the categories and subcategories derived from this analysis.

Table 1. Categories and Subcategories for Climate Change Teacher Identity

Categories	Subcategories
Competence	Resistance in the nature of complex systems Challenges in managing multiple perspectives Managing Social Aspects Systemic Approaches
Performance	Implement Feedback loop Implement Interactions between subsystems Implement Linear approaches Implement Social/Financial/Ethical implications
Self-View	Activist Optimist Sceptic Inspiring

Results

Across the dataset, participants showed the development of Climate Change Teacher Identity across all three identity dimensions. Below, we present findings organised by Competence, Performance, and Self-View, then highlight interactions among these dimensions.

Competence

Preservice teachers showed developing competence by clearly identifying aspects of climate change complexity and reflecting on the difficulty of communicating those ideas to children. One participant from Group 7 highlighted the challenge of explaining the disproportionate impacts of a seemingly small temperature rise and also recognised personal involvement in the issue:

"I believe the most difficult aspect to negotiate with primary school students will be helping them realise that just a 2-degree increase in temperature can be so destructive and understanding how we, ourselves, contribute to that rise."

This excerpt reflects competence in two ways: (1) recognising that climate change impacts are non-linear and counterintuitive, and (2) linking the scientific phenomenon to human systems and agency.

Another pre-service teacher from Group 1 pointed to the complexity introduced by political-economic structures in sustainability-related practices (in this case, recycling), indicating awareness that climate-related issues cannot be reduced to individual behaviour alone:

"What I think would be the most difficult to explain to students is how recycling works in each region, and why these changes depend on factors like quantity, cost, etc. Because they don't fully understand the political and economic issues that complicate the situation."

Here, competence includes understanding variability across contexts and recognising socio-economic aspects as part of the system.

Pre-service teachers also engaged with uncertainty and epistemic questions about predictability. One excerpt shows a participant from Group 3 negotiating what counts as a scientifically acceptable explanation, resisting embracing the nature of complexity: "Here, even though it's not stated that something supernatural intervenes in the system, chance seems to me as such. So, it doesn't align with my own understanding of science."

While another pre-service teacher from Group 5 reframed unpredictability as a matter of limited means rather than chance in interplay with deterministic laws:

"Perhaps if the conclusion were that we simply can't yet predict its evolution because we don't have the necessary means, it would be easier for me to accept."

This shows increasing skill in distinguishing epistemic uncertainty (limits of measurement and modelling) from non-scientific explanations, which is essential for teaching complexity responsibly. However, it also reveals a strong resistance to embracing the inherent complexity of nonlinear systems and to interpreting their evolution solely through deterministic laws.

Performance

Performance was apparent in how pre-service teachers designed learning sequences and chose phenomena that could act as "entry points" into complex system reasoning. The dataset included teaching materials on ocean acidification, glacier melting, and their implications for biodiversity. Finally, one teaching material approached sustainable mobility as a solution to climate change through hydrogen-powered cars.

In these materials, the pre-service teachers attempted to represent causal chains and feedback relationships (e.g., emissions → ocean chemistry changes → ecological consequences), integrate observable phenomena and modelling and hands-on experimentation, and build decision-making tasks that connect scientific understanding with choices and values.

However, pre-service teachers varied in the degree of sophistication in their teaching materials. While a common pattern was the use of concrete contexts (oceans, glaciers) to support students' reasoning and understanding of climate science, some materials approached these concepts by emphasising only one-way interactions (e.g., the impact of increasing CO2 concentration in the oceans and its effect on ocean biodiversity, without addressing the feedback loop influencing the atmosphere). On the other hand, Groups 1, 2, 6, and 7, which demonstrated greater competence in embracing complexity and managing multiple perspectives in their teaching, succeeded in designing materials that familiarised students with the various drivers of the climate system, as well as the societal aspects that interact with it.

An exception to these two categories is Group 4, which consisted of pre-service teachers facing multiple challenges in scientific content. This group spent time during the seminar familiarising themselves with the scientific content but paid less attention to integrating complexity into it.

Self-View

Self-View appeared in pre-service teachers' reflections on the teacher's role, especially their responsibility to support meaningful action, cultivate values, and serve as role models.

One pre-service teacher described an intention to emphasise practical actions so students can immediately see positive impacts and develop daily environmental awareness:

"Finally, I would like to place greater emphasis on simple and practical actions that students can undertake, so that they can immediately recognise the positive impact of their choices and develop environmental awareness in their daily lives."

This reflects self-recognition through an action-oriented teaching stance, in which the teacher's identity is linked to empowering students.

Another pre-service teacher articulated a deeper tension on how to foster enduring values rather than short-term compliance, and how the teacher's own behaviour and role modelling become part of climate change teaching:

"How can I convey to my students an attitude and a way of life that they will follow throughout their lifetime and not just in the short term? How will they fully embrace the principles and values of a climate-literate citizen? I believe that attitudes and values are matters cultivated daily, not merely through a single educational scenario. What kind of role model do you, as a teacher, provide for your students?"

This excerpt illustrates recognition as a stance of reflective, ethically aware identity. Pre-service teachers are not only asking "Can I teach this content?" but also "Who must I be, and how must I live, to teach this credibly?"

This collection of excerpts represented all groups except again Groups 3 and 5, who appear to be sceptics of certain proposed solutions related to climate change, as well as of the effectiveness of the teacher's role in the current economic status quo.

An example of this scepticism is represented in the excerpt below: "The discussion about green growth doesn't satisfy me, because I see that this plan is also being carried out without a central strategy, and probably not in order to improve our everyday lives."

Interactions Among Climate Change Identity Dimensions

Across the seven cases, the data suggested that competence, performance, and self-view were not isolated. Instead, pre-service teachers' materials and reflections showed interactions consistent with identity scholarship (e.g., Beijaard et al., 2004; Keiler, 2018).

Competence And Performance

Pre-service teachers who clearly expressed complexity and uncertainty tended to design tasks that incorporated system relationships, contextual constraints, or systems thinking rather than simple cause-and-effect narratives.

Performance And Recognition

As pre-service teachers developed and improved teaching materials, recognition was evidenced through responsibility statements (e.g., emphasising daily actions, role modelling, values). Designing for practice prompted reflection on what it means to be a climate change teacher.

Recognition And Competence

Recognition concerns (e.g., wanting to promote values responsibly) sometimes led pre-service teachers to seek more thorough explanations and more careful framing of the concepts of the climate system and the societal drivers within it.

These interactions support the argument that Climate Change Teacher Identity is co-constructed through iterative engagement with content, pedagogy, and professional positioning.

Discussion

This study provides empirical insights into how pre-service teachers learn and develop as they formulate their professional identities by reflecting on their prior experiences, values, and attitudes toward climate change as they learn to teach it. By adapting Carlone and Johnson's (2007) framework, we conceptualised identity not simply as confidence or attitude but as a dynamic interplay of (a) competence in complexity-focused reasoning, (b) performance through designed teaching practices, and (c) self-view through self-positioning and legitimacy.

The findings align with the broader literature, which shows that teachers experience fragmented knowledge and uncertainty as obstacles, struggle to transform climate science into teachable material, and integrate the value-oriented nature of climate change teaching. Yet the results also point to noticeable shifts when the pre-service teachers begin to treat complexity as an opportunity to expand their teaching rather than a reason to avoid the topic. They selected phenomena that enable complexity representations and engaged in reflective recognition of the challenges and obstacles to negotiating these representations with their students.

Our findings highlight the critical role of Climate Change Teacher Education in shaping teachers' positionality and equipping them with the necessary teaching strategies to address complex topics like Climate Change (Nation & Feldman, 2022; Tolppanen & Kärkkäinen, 2022). By fostering self-awareness, pre-service teachers became more confident in teaching Climate Change content, utilising their strengths to integrate diverse pedagogical approaches. This process also enhanced their self-recognition as competent climate change educators prepared to respond to the challenges of the climate crisis. A central implication is that teacher education can support climate change teaching not only by "adding more content" but by designing learning experiences where pre-service teachers engage explicitly with complexity and uncertainty, iteratively translate this into teaching materials, and reflect on positionality, ethics, and the teacher's role.

Implications For Climate Change Teacher Education

Considering that attitudes, values, and personal experiences shape the teaching climate for climate change, it is crucial to examine how teachers' professional identities develop and are reshaped over time (Nation & Feldman, 2022; Tolppanen & Kärkkäinen, 2021). The Climate Change Teacher Identity framework proposed above highlights that competence, performance, and self-view are co-constructed through teachers' biographies and the learning environments

they encounter. Therefore, Climate Change Teacher Education should go beyond disseminating content knowledge and pedagogical strategies to create conditions in which pre-service teachers can reconstruct themselves as climate change educators. Evidence from climate change-focused professional development suggests that identity shifts are strongly supported when teachers are given sustained opportunities to reflect on their positioning, values, and experiences alongside learning about climate change content and pedagogy (e.g., Nation & Feldman, 2022; Tolppanen & Kärkkäinen, 2021; Zen et al., 2024).

Accordingly, climate change teacher education should foreground structured identity work integrated with practice: sustained self-awareness and self-reflection on teaching trajectories through autobiographies, reflective journals, and prompts that engage questions such as "Who am I as a teacher?", "How did I become this kind of teacher?", and "Who do I want to become as a teacher?" (Avraamidou, 2019), so that pre-service teachers can trace changes in their competence, performances, and self-view over time.

These identity-oriented activities should be integrated into opportunities for learning, designing, and experimenting with teaching methods that are common in Climate Change Education. Such methods include investigating local phenomena, engaging in systems-thinking tasks, exploring futures-thinking activities, and participating in value-focused discussions. This allows pre-service teachers to see themselves as climate change educators and to renegotiate their identity claims through tangible classroom practices (Felix & Clayton, 2025; Nation & Feldman, 2022; Sezen-Barrie et al., 2025). Overall, Climate Change Teacher Education should be intentionally designed as a space where pre-service teachers both learn how to teach about climate change and develop into climate change teachers. This can be achieved through combining autobiographical exploration, ongoing reflection, and multimodal self-representations with rich pedagogical experiences. These experiences broaden competencies, enable new ways of performance, and foster recognition as climate change educators.

References

Avraamidou, L. (2014). Studying science teacher identity: Current insights and future research directions. Studies in Science Education, 50(2), 145-179. https://doi.org/10.1080/03057267.2014.937171

Avraamidou, L. (2019). Science identity as a landscape of becoming: rethinking recognition and emotions through an intersectionality lens. Cultural Studies of Science Education, 15(2), 323–345. https://doi.org/10.1007/s11422-019-09954-7

Bascopé, M., Becerra, R., Salazar, D., Arenas, A., Morales, R., Merino, C., ... & Ampuero, P. (2025). Teacher continuous professional development in climate change education: Analysing teachers' perspectives. The Journal of Environmental Education, 1-22. https://doi.org/10.1080/00958964.2025.2471971

Beijaard, D., Meijer, P. C., & Verloop, N. (2004). Reconsidering research on teachers' professional identity. Teaching and Teacher Education, 20(2), 107–128. https://doi.org/10.1016/j.tate.2003.07.001

Brandt, J.-O., Bürgener, L., Barth, M., & Redman, A. (2019). Becoming a competent teacher in education for sustainable development. International Journal of Sustainability in Higher Education, 20(4), 630–653. https://doi.org/10.1108/ijshe-10-2018-0183

Cantell, H., Tolppanen, S., Aarnio-Linnanvuori, E., & Lehtonen, A. (2019). Bicycle model on climate change education: Presenting and evaluating a model. Environmental Education Research, 25(5), 717–731. https://doi.org/10.1080/13504622.2019.1570487

Carlone, H. B., & Johnson, A. (2007). Understanding the science experiences of successful women of colour: Science identity as an analytic lens. Journal of Research in Science Teaching, 44(8), 1187–1218. https://doi.org/10.1002/tea.20237

Drewes, A., Henderson, J., & Mouza, C. (2018). Professional development design considerations in climate change education: teacher enactment and student learning. International Journal of Science Education, 40(1), 67–89. https://doi.org/10.1080/09500693.2017.1397798

Eilam, E. (2022). Climate change education: The problem with walking away from disciplines. Studies in Science Education, 58(2), 231-264. https://doi.org/10.1080/03057267.2021.2011589

Ennes, M., Lawson, D. F., Stevenson, K. T., Peterson, M. N., & Jones, M. G. (2021). It's about time: perceived barriers to in-service teacher climate change professional development. Environmental Education Research, 27(5), 762–778. https://doi.org/10.1080/13504622.2021.1909708

Felix, S. M., & Clayton, S. (2025). Describing teachers' environmental identity as part of education for sustainable development. Environmental Education Research, 1-18. https://doi.org/10.1080/13504622.2025.2482740

Hestness, E., McDonald, R. C., Breslyn, W., McGinnis, J. R., & Mouza, C. (2014). Science teacher professional development in climate change education informed by the Next Generation Science Standards. Journal of Geoscience Education, 62(3), 319-329. https://doi.org/10.5408/13-049.1

Höhle, J. V., & Bengtsson, S. L. (2023). A didactic toolkit for climate change educators: Lessons from constructive journalism for emotionally sensitive and democratic content design. Environmental Education Research, 29(11), 1659–1677. https://doi.org/10.1080/13504622.2023.2182746

Howell, R. A., & Allen, S. (2019). Significant life experiences, motivations and values of climate change educators. Environmental Education Research, 25(6), 813–831. https://doi.org/10.1080/13504622.2016.1158242

Hume, A., & Berry, A. (2010). Constructing CoRes—a Strategy for Building PCK in Pre-service Science Teacher Education. Research in Science Education, 41(3), 341–355. https://doi.org/10.1007/s11165-010-9168-3

Keiler, L. S. (2018). Teachers' roles and identities in student-centred classrooms. International Journal of STEM Education, 5(1). https://doi.org/10.1186/s40594-018-0131-6

Kriewaldt, J., & Lee, S. J. (2022). Towards powerful knowledge: An Australian case study of prospective teachers' knowledge and dispositions for sustainability education. International Research in Geographical and Environmental Education, 32(1), 35–52. https://doi.org/10.1080/10382046.2022.2146836

Lehtonen, A., Salonen, A. O., & Cantell, H. (2018). Climate Change Education: A New Approach for a World of Wicked Problems. Sustainability, Human Well-Being, and the Future of Education, 339–374. https://doi.org/10.1007/978-3-319-78580-6_11

Leite, S. (2024). Towards a transformative climate change education: Questions and pedagogies. Environmental Education Research, 30(12), 2376-2393. https://doi.org/10.1080/13504622.2024.2365983

McNeal, P., Petcovic, H., & Reeves, P. (2017). What is motivating middle-school science teachers to teach climate change? International Journal of Science Education, 39(8), 1069-1088. https://doi.org/10.1080/09500693.2017.1315466

Menon, D. (2020). Influence of the sources of science teaching self-efficacy in preservice elementary teachers' identity development. Journal of Science Teacher Education, 31(4), 460-481. https://doi.org/10.1080/1046560x.2020.1718863

Miani, L., Bitsaki, C., Metaxas, I., Stavrou, D., & Levrini, O. (2025). Embracing Complexity and Uncertainties to Deal with Climate Change Challenges: An Interdisciplinary Module for Preservice Teacher Education: Miani et al. Science & Education, 1-36. https://doi.org/10.1007/s11191-025-00658-9

Miani, L., De Zuani Cassina, F., & Levrini, O. (2025b). Raising awareness on the complexity of decision-making through climate change education. Research in Science Education. Advance online publication. https://doi.org/10.1007/s11165-025-10266-w

Mayring, P. (2014). Qualitative Content Analysis: Theoretical Background and Procedures. Approaches to Qualitative Research in Mathematics Education, 365–380. https://doi.org/10.1007/978-94-017-9181-6_13

Nation, M. T., & Feldman, A. (2022). Climate change and political controversy in the science classroom: How teachers' beliefs influence instruction. Science & education, 31(6), 1567-1583. https://doi.org/10.1007/s11191-022-00330-6

Peters, B. G., & Tarpey, M. (2019). Are wicked problems really so wicked? Perceptions of policy problems. Policy and Society, 38(2), 218–236. https://doi.org/10.1080/14494035.2019.1626595

Intergovernmental Panel on Climate Change. (2023a). Summary for policymakers. In H. Lee & J. Romero (Eds.), Climate change 2023: Synthesis report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (pp. 1–34). IPCC. https://doi.org/10.59327/IPCC/AR6-9789291691647.001

Ratinen, I. J. (2013). Primary Student-Teachers' Conceptual Understanding of the Greenhouse Effect: A mixed method study. International Journal of Science Education, 35(6), 929–955. https://doi.org/10.1080/09500693.2011.587845

Rousell, D., & Cutter-Mackenzie-Knowles, A. (2020). A systematic review of climate change education: Giving children and young people a ‘voice’ and a ‘hand’ in redressing climate change. Children’s Geographies, 18(2), 191–208. https://doi.org/10.1080/14733285.2019.1614532

Sezen-Barrie, A., Windschitl, M., & Nxumalo, F. (2025). Transformative climate and environmental education for a just future. Science Education, 109(3), 715-721. https://doi.org/10.1002/sce.21963

Shea, N. A., Mouza, C., & Drewes, A. (2016). Climate change professional development: Design, implementation, and initial outcomes on teacher learning, practice, and student beliefs. Journal of Science Teacher Education, 27(3), 235–258. https://doi.org/10.1007/s10972-016-9456-5

Stouthart, T., Bayram, D., & van der Veen, J. (2023). Capturing Pedagogical Design Capacity of STEM Teacher Candidates: Education for Sustainable Development through Socioscientific Issues. Sustainability, 15(14), 11055. https://doi.org/10.3390/su151411055

Timm, J.-M., & Barth, M. (2021). Making education for sustainable development happen in elementary schools: The role of teachers. Environmental Education Research, 27(1), 50–66. https://doi.org/10.1080/13504622.2020.1813256

Taurinen, J., Vilhunen, E., Vesterinen, V.-M., Veijonaho, S., Äijälä, M., & Ruuskanen, T. (2024). Exploring young people’s perceived climate change competence. Environmental Education Research, 1–15. https://doi.org/10.1080/13504622.2024.2441202

Tolppanen, S., & Kärkkäinen, S. (2021). Limits of caring: pre-service teachers’ reasons for not taking high-impact actions to mitigate climate change. Environmental Education Research, 28(7), 986–1002. https://doi.org/10.1080/13504622.2021.2007224

US Global Change Research Program. (2024). Climate Literacy: Essential Principles for Understanding and Addressing Climate Change. U.S. Global Change Research Program. https://doi.org/10.7930/clg2024

Waldron, F., Ruane, B., Oberman, R., & Morris, S. (2016). Geographical process or global injustice? Contrasting educational perspectives on climate change. Environmental Education Research, 25(6), 895–911. https://doi.org/10.1080/13504622.2016.1255876

Wiek, A., Withycombe, L., & Redman, C. L. (2011). Key competencies in sustainability: a reference framework for academic program development. Sustainability Science, 6(2), 203–218. https://doi.org/10.1007/s11625-011-0132-6

Zangori, L., Peel, A., Kinslow, A., Friedrichsen, P., & Sadler, T. D. (2017). Student development of model-based reasoning about carbon cycling and climate change in a socio-scientific issues unit. Journal of Research in Science Teaching, 54(10), 1249–1273. https://doi.org/10.1002/tea.21404

Zen, S., Ropo, E., & Sovia, S. (2024). Teacher Identity and Climate Change Education: Implications for Curriculum Integration in Indonesia. Journal of Teacher Education for Sustainability, 26(2), 74-104. https://doi.org/10.2478/jtes-2024-0017

EUROPEAN SCIENCE EDUCATION RESEARCH ASSOCIATION ESERA 2025 Copenhagen

Exploring Pre-Service Primary Teachers' Pedagogical Content Knowledge Of Interdisciplinarity In Science And Mathematics

Sílvia Ferreira[1,2], Helena Simões[1], Catarina Delgado[1,3] and Fátima Mendes[1,3]

[1] Instituto Politécnico de Setúbal, Escola Superior de Educação, Portugal
[2] UIDEF, Instituto de Educação, Universidade de Lisboa, Portugal
[3] CIEQV, Centro de Investigação em Qualidade de Vida, Portugal

This study examines the interdisciplinary pedagogical content knowledge (IPCK) of pre-service primary teachers enrolled in a two-year master's program in Primary Education (1st to 6th grades), with a specialization in Mathematics and Sciences. The main objective was to investigate changes in their IPCK regarding interdisciplinarity between science and mathematics following participation in a lesson study. Data were collected through an open-ended questionnaire administered in two phases, before and after the lesson study. The questionnaire aimed to capture the specificity of pre-service teachers' understanding of interdisciplinarity by exploring their conceptualizations and the examples of activities they proposed to promote the integration of science and mathematics.

The results indicate that, before the lesson study, pre-service teachers held a limited view of interdisciplinarity, characterized by uneven connections between the two areas. There was a significant emphasis on interdisciplinarity through knowledge to be explored, with less attention given to the processes. Mathematics was mainly integrated through data processing within sciences activities. Furthermore, only a few participants viewed interdisciplinarity as a meaningful integration, where both disciplines collaborate to support one another, thereby enabling unique learning experiences. After the lesson study, the findings suggest that most pre-service primary teachers changed their IPCK towards a more comprehensive perspective on interdisciplinarity in science and mathematics.

Keywords: Interdisciplinarity in science and mathematics; Pre-service primary teachers; Lesson study; Pedagogical content knowledge

Introduction

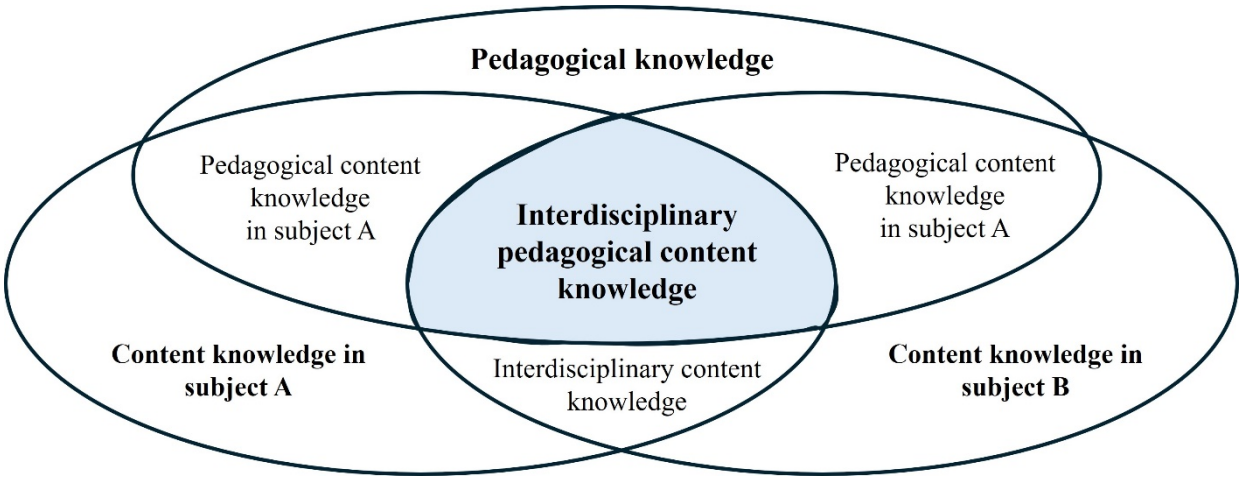
Future teachers should be able to make connections between different disciplines. An interdisciplinary approach encourages deeper understanding overtime, inter-relating different topics or subjects (OECD, 2019). That implies careful planning in how and when the topics of each subject will be explored, to promote connections between them.

However, the implementation of interdisciplinarity in schools faces problems of different kinds (e.g. Johnson & Czerniak, 2023). The interdisciplinary work between science and mathematics will always involve the mobilization of disciplinary knowledge from, at least, these two disciplines and depends upon teachers' pedagogical content knowledge (PCK) of each discipline (Ríordáin et al., 2015) and their possible intersections, denominated interdisciplinary pedagogical content knowledge (IPCK) (An, 2017) (Figure 1). According to An (2017),

> interdisciplinary pedagogical content knowledge (IPCK) is the specific capacity for teachers to accomplish the following: (1) work with interdisciplinary considerations that include an understanding of the representation of concepts using themes across curriculum boundaries; (2) apply pedagogical methods and interdisciplinary themed activities in addressing content areas from multiple subjects simultaneously; (3) identify knowledge connections within and between particular subjects, and develop lessons based on such

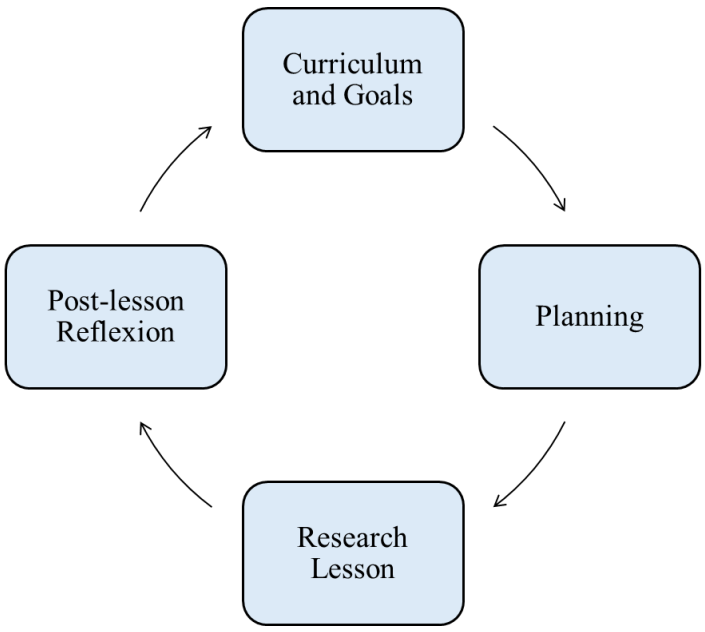
connections; and (4) employ knowledge of how interdisciplinary explorations can be developed as a part of an instructional process wherein students link existing knowledge across curricula, while presenting that new knowledge through contexts from multiple subjects. (p. 239)

Figure 1. Graphic representation of interdisciplinary pedagogical content knowledge (IPCK) (An, 2017, p. 239).



A way to support teachers practice professional development regarding interdisciplinarity is through lesson study (Lewis, 2009; Murata, 2011; Tomkelski et al., 2022). The central framework of lesson study comprises four key moments: i) characterization of the context and definition of a goal for the development of the research lesson; ii) planning, that is, collaboratively designing a lesson on a specific curriculum topic through multiple sessions with a group of teachers; iii) research lesson, that corresponds to the implementation of the planned lesson in a classroom setting.; and iv) post-lesson reflection, when the group of teachers meets to discuss and reflect on the students' actions in the research lesson, based on observations recorded (Lewis, 2009; Murata, 2011; Tomkelski et al., 2022). Figure 2 presents the lesson study cycle constituted by four phases.

Figure 2. Lesson study cycle of the investigation (Adapted from Lewis, 2009; Murata, 2011; Tomkelski et al., 2022).



Lesson study provides opportunities for pre-service teachers to strengthen their understanding of content, pedagogy, and student learning, namely skills and knowledge in science and

mathematics education (e.g., Kraft et al., 2024; Martins et al., 2023). For instance, Martins et al. (2023) involved mathematics pre-service teachers in a lesson study and concluded that this process allowed them to refine their teaching strategies, leading to improved practice and a better understanding of how to promote students' mathematics reasoning. Kraft et al. (2024) in an extensive review of the literature on lesson studies in science teacher preparation programs concludes that lesson study is a transformative process, enriching pedagogical content knowledge.

This study explores the interdisciplinary pedagogical content knowledge (IPCK) of Portuguese pre-service primary teachers enrolled in a two-year master's program in Primary Education in Sciences and Mathematics. The main aim was to investigate changes in pre-service primary teachers' PCK concerning interdisciplinarity in science and mathematics following their participation in a lesson study. The research is part of a broader project that aims to understand the dynamics of implementing interdisciplinary activities in science and mathematics. It involves pre-service primary teachers from two Portuguese higher education institutions, the Polytechnic Institutes of Setúbal and Lisbon, within the framework of lesson study.

Method

The participants were the whole class of the teaching master programme 2024/25, 11 pre-service primary teachers (8 females and 3 males, aged 22 to 35 years) enrolled in the courses "Didactics of Sciences", "Didactics of Mathematics" and "Teaching Practice in Primary Education". These are annual compulsory subjects in the second-year curriculum of the master's program in Primary Education (1st to 6th grades) with a specialization in Mathematics and Sciences, of the School of Education of Setúbal, Portugal. Prior to this program, the pre-service teachers had completed a three-year degree in Basic Education. The Didactics courses in both areas involved the exploration of different strategies for teaching science and mathematics and were used to support the planification of the research lesson, that was implemented during a seven-week internship in a 5th grade class (Teaching Practice).

During the first semester, the pre-service teachers completed a questionnaire to assess their pedagogical content knowledge of interdisciplinarity in science and mathematics, both before and after the implementation of the lesson study, after informed consent from all participants. The questionnaire was less structured, word-based and open-ended to capture the specificity of the situation analysed in this study (Cohen et al., 2007). This research instrument included four open-ended questions, as follows:

(1) Identify a curricular topic that integrates mathematics and sciences and can be approached interdisciplinarily in primary education (Key Stage 2).

(2) Indicate mathematics and sciences content that can be approached interdisciplinarily in the study of the topic you identified. You may use a diagram to illustrate the relationships between the content (Note: Students were allowed to consult official curriculum documents.).

(3) Provide examples of one or two interdisciplinary activities you would use to explore the topic, incorporating the previously mentioned content from both subjects. Specify the teaching strategies or methodological approach you would adopt in the classroom.

(4) If you have already planned or observed an interdisciplinary activity during previous internships or even during your school years as a student, describe the activity in question, highlighting its relevance.

The analysis of these questions involved content analysis, with the definition of categories and subcategories for analysis for each question, which were formed inductively based on data,

through an iterative process. Tables 1 and 2, which are presented in the results, show the categories and subcategories of questions 1 and 3 of the questionnaire, respectively, which were selected to present in this paper based on their relevance to the study.

For question 1, the following categories of analysis were defined: predominance of the subject area; and nature of the content. Question 2 included two categories: diversity of content; and nature of the content. In order to analyse the scope of responses to question 3, several categories of analysis were defined, namely: predominance of the subject area; curricular alignment; consistency between content and activity; type of activity; organization of work with students; teaching resources; and planned outputs. In the case of question 4, four categories of analysis were created: predominance of the subject area in the planned activity; predominance of the subject area in the activity experienced; relevance of the activity; and justification of the relevance of the activity.

Taking into account all the responses to the questionnaire, we also sought to analyse the concept of interdisciplinarity among students, considering two subcategories: comprehensive view and limited view (Table 3). The comprehensive view is related to the level of complete integration between the two disciplines, with the establishment of relationships between science and mathematics. In the limited view one of the disciplines, Mathematics or Science, predominates, but the other is also present, although in a supporting role.

The categorization of responses to each question was carried out by four researchers, authors of the paper, familiar with the theoretical framework of the study. In a joint meeting, the researchers discussed the main doubts in the categorization of data, and the entire analysis was reviewed. Disagreements were resolved through discussion until consensus was reached.

The lesson study process was structured within a single cycle with four main phases (Figure 2). In the first and second phases, during weeks one to four of the seven-week internship, the pre-service teachers worked collaboratively in groups to define the goals and plan a research lesson centred on an interdisciplinary activity in mathematics and sciences. This work was supported by the four higher education teachers, the researchers, in Didactics sessions. In the third phase, during weeks five to seven of the internship, while the other pre-service teacher from each internship pair taught the research lesson while the other pre-service teacher and one higher education teacher observed the lesson and collected data. The fourth phase, conducted after the internship, involved a group discussion about the planned and implemented lesson and a written reflection (one part produced collaboratively by the internship pair and another part developed individually).

Results and Discussion

Table 1 presents the results for question 1: Identify a curricular topic that integrates mathematics and sciences and can be approached interdisciplinarily in primary education (Key Stage 2), based on the responses of the 11 pre-service teachers (PST), who participated in both the initial and final applications of the questionnaire. The initial questionnaire, applied before the lesson study, shows that PST tended to select topics primarily focused on sciences. In these cases, the science topic served as the context for integrating mathematics, as illustrated by examples such as: “The Terrestrial Materials present in the region (determine the predominant type of terrestrial material in the region)” (PST 1) and “Biodiversity” (PST 3). After the lesson study, the responses reflected a greater emphasis on ensuring that, within the context of science activities, mathematical content is equally explored. The following example shows that situation: “Types of soil, soil properties, and powers of base 10” (PST 7). The absence of change in the category “nature of the contents” suggests that, despite improvements in disciplinary integration, pre-service teachers’ conceptions

of interdisciplinarity remain predominantly knowledge-oriented, possibly reflecting limitations associated with curricular structure and their still limited teaching experience.

Table 2 presents the results for question 3: Provide examples of one or two interdisciplinary activities you would use to explore the topic, incorporating the previously mentioned content from both subjects. Specify the teaching strategies or methodological approach you would adopt in the classroom for three selected categories. The initial questionnaire responses indicate a predominance of focus on the mathematics area. This may reflect the pre-service teachers' effort to make this subject explicit in the activity proposal, despite the curriculum topic focusing on science (as seen in question 1). After the lesson study, there was an increasing concern with integrating both subject areas in the interdisciplinary activity proposals.

Table 1. Pre-service teachers' responses to the question 1 of the initial and final applications of the questionnaire, before and after lesson study.

Categories	Subcategories	Number of PST (n=11)	
		InitialQ	FinalQ
Predominance of the subject area	Science	6	3
	Mathematics	1	0
	Both areas	4	8
Nature of the contents	Focus on knowledge	8	8
	Focus on process	0	0
	Knowledge and process	3	3

Table 2. Pre-service teachers' responses to the question 3 of the initial and final applications of the questionnaire, before and after lesson study.

Categories	Subcategories	Number of PST (n=11)	
		InitialQ	FinalQ
Predominance of the subject area	Science	4	2
	Mathematics	6	2
	Integration of both areas	1	7
Curricular alignment	Total	5	9
	Partial	6	2
	Without	0	0
Coherence between content and activity	Total	4	6
	Partial due to lack of explicitness	0	5
	Excluded due to lack of suitability	7	0
	Without	0	0

The results for the categories "curricular alignment" and "coherence between content and activity" (Table 2) reveal that there was an increased knowledge of the curriculum in the areas of mathematics and sciences, gained through direct involvement in the lesson study, which required an additional effort in a more detailed planning process – including curriculum analysis, task design, and reflection on learning. It is also important to note that this was the pre-service teachers' first teaching practice (internship) in primary education, specifically with 5th and 6th graders, which likely influenced their initial focus and subsequent development of their IPCK.

The results presented in Table 2 reveal a clear qualitative development in pre-service teachers' ability to design interdisciplinary activities. In particular, the disappearance of responses classified as "excluded due to lack of suitability" in the final questionnaire suggests a strengthened capacity to align interdisciplinary intentions with pedagogically coherent activities, an aspect associated with the collaborative planning, implementation, and reflection, characteristics of the lesson study process. At the same time, the increase in activities classified as "partial due to lack of explicitness" should not be interpreted as a regression, but rather as evidence of a growing awareness of the complexity involved in interdisciplinary planning. This pattern indicates that pre-service teachers proposed complex and ambitious integrations of mathematics and sciences, in some cases for the first time, although some proposals still required clearer articulation of the relationships between content and activity.

To illustrate the analysis, the following excerpt presents the activity proposed by one of the pre-service teachers in response to Question 3 of the final questionnaire. This activity demonstrates integration of both subject areas, total curricular alignment, and total coherence between content and the proposed activity:

> Analysis of Bottled Water Labels and Mineral Comparison
>
> Pupils, working in pairs, receive labels from different [and real] brands of bottled water and analyse the chemical information provided.
>
> In Natural Sciences, they discuss the importance of each mineral for human health and debate which type of water is most suitable for different needs (e.g. low-sodium water for people with high blood pressure).
>
> In Mathematics, pupils compare the decimal values shown on the labels, organize them in tables, and represent them on a number line.
>
> The methodological approach focuses on collaborative work and the use of concrete materials, promoting the integration of both subjects.
>
> (*PST 6, Final Questionnaire*)

Analysing the questionnaire responses as a whole, two conceptions of interdisciplinarity were identified: a comprehensive view and a limited view (Table 3). The initial questionnaire, applied before the lesson study, shows that most pre-service teachers (PST) proposed activities that considered an integrative topic, but mathematics supports science. Few PST view interdisciplinarity as a meaningful integration of mathematics and science, when the disciplines interact to support each other, allowing unique learning (An, 2017; Huntley, 1998). In the final questionnaire, evidence of IPCK development was observed. Most PST showed increased attention to balancing the presence of both subject areas, although integration was not always fully achieved, often occurring sequentially. Typically, the topic was selected from the science curriculum, with both areas explored within the activity.

Table 3. Pre-service teachers' conceptions of interdisciplinarity in the initial and final applications of the questionnaire, before and after lesson study.

Categories	Subcategories	Number of PST (n=11)	
		InitialQ	FinalQ
Conceptions of Interdisciplinarity	Comprehensive view (integration)	4	7
	Limited view (partial integration)	7	4

Conclusions

The findings indicate that the majority of pre-service primary teachers developed their interdisciplinary pedagogical content knowledge (IPCK) toward a more comprehensive perspective on interdisciplinarity in science and mathematics. This development was reflected in their increased ability to identify meaningful connections within and between both subjects, to design lessons grounded in these connections, and to deepen their understanding of the curriculum and how it can be coherently managed across subject areas. An initially limited conception of interdisciplinarity evolved into a more integrative perspective that encompasses the PCK of each discipline as well as their potential intersections (An, 2017).

Within the context of the project, the pre-service primary teachers participated in a lesson study, a formative process that emphasizes collaborative work in planning, observing, and reflecting on implemented lessons, with a focus on deepening their IPCK (Lewis, 2009; Murata, 2011). During this process, the pre-service teachers not only designed and implemented interdisciplinary tasks but also engaged in systematic reflection on their teaching experiences, identifying areas for improvement and refinement in their interdisciplinary practices. Across the different stages of the lesson study, reflection on the implemented lesson emerged as a particularly valued component of the training process, highlighting its central role in supporting the development of IPCK.

These findings should be interpreted in light of the study's limitations, namely the small number of participants, the focus on a single lesson study cycle, and the use of self-reported questionnaire data. Nevertheless, the results offer relevant insights into the potential of lesson study to support the development of IPCK in initial teacher education.

Acknowledgement

This study was supported by the School of Education of Lisbon, through the InterMatCN Project - Interdisciplinary Lesson Studies in Mathematics and Natural Sciences in initial teacher training (Project IPL/ESELX/PICA_1_2024_InterMatCN).

References

An, S. (2017). Preservice teachers' knowledge of interdisciplinary pedagogy: The case of elementary mathematics–science integrated lessons. *ZDM Mathematics Education, 49*(2), 237–248. https://doi.org/10.100711858-016-0821-9

Cohen, L., Manion, L., & Morrison, K. (2007). *Research methods in education* (6th ed.). Routledge.

Huntley, M. (1998). Design and implementation of a framework for defining integrated Mathematics and Science Education. *School Science and Mathematics, 98*(6), 320-327. https://doi.org/10.1111/j.1949-8594.1998.tb17427.x

Johnson, C. C., & Czerniak, C. M. (2023). Interdisciplinary Approaches an Integrated STEM in Science Teaching. In N. G. Lederman, D. L. Zeidler, & J. S. Lederman (Eds.), *Handbook of Research on Science Education: Volume III* (pp. 559–585). Taylor and Francis. https://doi.org/10.4324/9780367855758

Kraft, T., & Hernández Rodríguez, O. (2024). Lesson study in science teacher preparation programs: a literature review. *International Journal for Lesson and Learning Studies, 13*(2), 116-129. https://doi.org/10.1108/IJLLS-12-2023-0181

Lewis, C. (2009). What Is the Nature of Knowledge Development in Lesson Study? *Educational Action Research, 17*(1), 95–110. doi:10.1080/09650790802667477

Martins, M., Ponte, J.P., & Mata-Pereira, J. (2023). Learning to promote students' mathematical reasoning: Lesson study contributions in initial teacher education. *Eurasia Journal of Mathematics, Science and Technology Education*. https://doi.org/10.29333/ejmste/13127

Murata, A. (2011). Introduction: Conceptual overview of lesson study. In L. C. Hart, A. Alston & A. Murata (Eds.), *Lesson study research and practice in mathematics education* (pp.1-12). Springer.

OECD (2019). *Knowledge for 2030*. OECD. https://www.oecd.org/content/dam/oecd/en/about/projects/edu/education-2040/concept-notes/Knowledge_for_2030_concept_note.pdf

Ríordáin, M., Johnston., J., & Walshe. G. (2015). Making mathematics and science integration happen: key aspects of practice. *International Journal of Mathematical Education in Science and Technology, 47*(2), 233–255. https://doi.org/10.1080/0020739X.2015.1078001

Tomkelski, M. L., Baptista, M., & Richit, A. (2023). Physics Teachers' Learning on the Use of Multiple Representations in Lesson Study about Ohm's Law. *European Journal of Science and Mathematics Education, 11*(3), 427-444. https://doi.org/10.30935/scimath/12906

EUROPEAN SCIENCE EDUCATION RESEARCH ASSOCIATION ESERA 2025 Copenhagen

Linking Pre-Lesson Content Representations And Post-Lesson Reflections: AI-Based Insights Into Context-Specific PCK Development

Lukas Mientus[1] and Andreas Borowski[2]
[1]Otto von Guericke University Magdeburg, Germany
[2]University of Potsdam, Germany

Understanding pedagogical reasoning across the teaching cycle remains a central challenge in science education research, as lesson planning and retrospective reflection are typically examined using separate instruments and analytic frameworks. This contribution adopts a methodological perspective by linking Content Representations (CoRes) and written reflections as relational artefacts of pedagogical reasoning. Drawing on data from pre-service physics teachers during a teaching internship, embedding-based semantic similarity analyses are used to relate structured planning units from CoRes to segments of unstructured reflective texts. Instead of aggregating similarity scores or applying predefined coding schemes, the analyses retain the full relational structure and explore it using complementary representations, including similarity heatmaps and Principal Component Analysis. Exemplary case analyses illustrate how analytic design choices, such as reflection segmentation or modes of visualization, shape what becomes visible when planning and reflection are analysed in direct relation to one another. The contribution is exploratory and methodological: it demonstrates how relations between planning-related knowledge and retrospective reasoning can be made visible without evaluating teaching or inferring development or change in pedagogical content knowledge.

Keywords: Pedagogical Content Knowledge (PCK); Pedagogical reasoning; Content Representations (CoRes); Written reflection; Embedding-based text analysis

Introduction

Understanding pedagogical reasoning across the teaching cycle remains a central challenge in science education research, particularly because lesson planning and retrospective reflection are typically examined using separate instruments and analytic frameworks. Consequently, empirical research has rarely addressed how knowledge articulated during planning relates to how teachers' reason about their practice after teaching.

Within research on Pedagogical Content Knowledge (PCK), teachers' professional knowledge is understood as person-, topic-, and context-specific. Instruments such as Content Representations (CoRes) make planning-related PCK explicit, whereas written reflections provide access to retrospective pedagogical reasoning. Despite their widespread use, these instruments are rarely analysed in direct relation to one another, limiting insights into how articulated planning-related knowledge is taken up, recontextualized, or omitted in reflective discourse.

Recent advances in natural language processing enable new methodological approaches for exploring such relations. In particular, embedding-based semantic similarity analyses allow heterogeneous text-based artefacts to be related without relying on predefined coding schemes. This makes it possible to examine planning and reflection as relational data while refraining from evaluative or developmental claims.

Against this background, the present study explores how relations between CoRes and written reflections can be made visible by analysing them in direct relation to one another. Using AI-based semantic similarity analyses and focusing on exemplary cases, the study illustrates how different analytic representations foreground different aspects of planning–reflection relations.

The contribution is methodological and PCK-oriented: it demonstrates how planning and reflection can be linked analytically without evaluating teaching or inferring changes in PCK. By doing so, the study positions planning and reflection not as separate data sources, but as relational artefacts of pedagogical reasoning across the teaching cycle.

Theoretical Background

Pedagogical Content Knowledge And Pedagogical Reasoning

Pedagogical Content Knowledge (PCK) is widely regarded as a central component of science teachers' professional knowledge (Shulman, 1986, 1987; Van Driel et al., 1998; Van Driel & Berry, 2012; Loughran et al., 2006; Carlson et al., 2019). The Refined Consensus Model of PCK (RCM) provides a shared theoretical framework that distinguishes between different knowledge bases and emphasizes context-specific, enacted forms of PCK emerging in concrete teaching situations (Carlson et al., 2019).

Within the RCM, pedagogical reasoning is conceptualized as a cyclical process linking planning, teaching, and reflection (Alonzo et al., 2019). Planning and reflection are commonly associated with macro-level pedagogical reasoning, referring to articulated reasoning processes before and after teaching, whereas micro-level reasoning captures in-the-moment, often tacit decision-making during instruction. While macro-level pedagogical reasoning can be accessed through written artefacts such as lesson plans or reflections, micro-level reasoning remains empirically difficult to capture (Mientus et al., 2022).

In teacher education, practical phases are considered particularly relevant for PCK-related pedagogical reasoning, as they require pre-service teachers to articulate knowledge in planning and to retrospectively interpret their teaching experiences in reflection (Brouwer & Korthagen, 2005; Korthagen & Kessels, 1999). Accordingly, analysing artefacts of planning and reflection is a common approach to studying macro-level pedagogical reasoning. However, these artefacts are typically examined in isolation, leaving largely unaddressed how knowledge articulated during planning relates to retrospective reasoning after teaching.

Content Representations As Structured Planning Artifacts

Content Representations (CoRes) are a well-established instrument for capturing context-specific planning-related PCK in science education (Loughran et al., 2004, 2006). They are typically structured as tables in which teachers identify central "Big Ideas" of a topic and elaborate on them using guiding questions addressing different aspects of teaching (Sannert et al., 2025). Following the RCM, CoRes can be interpreted as structured articulations of different PCK facets, such as content knowledge (CK), pedagogical knowledge (PK), knowledge of students (KS), curricular knowledge (CuK), assessment knowledge (AK), and the learning context (Context) (Carlson et al., 2019; Mientus & Borowski, 2024); in the present study, these facets serve only as descriptive reference points rather than analytic coding categories. The PCK articulated in a CoRe is inherently person-, topic-, and context-specific (Chan & Hume, 2019).

In teacher education, CoRes are commonly used to support lesson planning and to externalize planning-related professional knowledge. Analytically, CoRes provide structured access to macro-level pedagogical reasoning before teaching, but do not capture how articulated planning-related knowledge is taken up or reconsidered after instruction.

Written Reflections As Retrospective Reasoning Artefacts

Written reflections are widely used to access retrospective pedagogical reasoning after teaching (Korthagen & Kessels, 1999; Poldner et al., 2014). They are typically unstructured free-text documents combining descriptive, evaluative, and affective elements. Reflective texts are

commonly analysed to study macro-level pedagogical reasoning, using qualitative, quantitative, or automated text-analytic approaches (Buckingham Shum et al., 2017; Ullmann, 2019; Wulff et al., 2022). However, reflective texts are often analysed in isolation, leaving open how retrospective reasoning relates to knowledge articulated during planning.

Linking CoRes and written reflections therefore offers a promising way to examine pedagogical reasoning across the teaching cycle, while posing methodological challenges due to the heterogeneous structure of the two artefacts. Together, CoRes and written reflections provide complementary access to macro-level pedagogical reasoning before and after teaching. Analysing them in relation to one another addresses a largely unexplored perspective in PCK-oriented research.

Methodological Approach

Research Context And Data Corpus

The study is situated in the context of pre-service physics teacher education during the teaching internship (Praxissemester) at the University of Potsdam. Practical phases in teacher education are considered a key setting for PCK-related pedagogical reasoning, as they require pre-service teachers to articulate professional knowledge in planning and to retrospectively interpret their teaching experiences. In this context, students are required to prepare, conduct, and reflect on their own lessons, thereby producing written artefacts associated with different phases of pedagogical reasoning.

Since the winter semester 2019/20, written self-reflections of pre-service physics teachers have been systematically collected as part of the ReFeed project (Mientus et al., 2021). Building on this data infrastructure, an additional preparatory component was introduced in the winter semester 2022/23: prior to teaching, students were asked to create Content Representations (CoRes) using a specially developed online environment. This resulted in paired datasets consisting of a CoRe as a planning artefact and a corresponding written reflection as a post-lesson artefact.

For the present study, data from six pre-service physics teachers were considered. Each participant produced three CoRe–reflection pairs related to self-taught lessons. After excluding incomplete cases, a total of 18 paired artefacts were available in the broader project. The present contribution draws on selected pairs for illustrative analysis. The aim is not statistical generalization, but the exploration of planning–reflection relations in person- and context-specific cases.

Instruments: Cores And Written Reflections

The Content Representation (CoRe) serves as the instrument for capturing planning-related professional knowledge prior to teaching. Following established practice (Loughran et al., 2006), CoRes are structured as tables in which central "Big Ideas" of a topic are elaborated using guiding questions. In the present implementation, these guiding questions were aligned with PCK facets specified in the Refined Consensus Model. Each table field can thus be treated as an articulation of context-specific professional knowledge related to content, pedagogy, students, curriculum, assessment, or learning context.

Written reflections constitute the complementary instrument for capturing retrospective pedagogical reasoning after teaching. Students produced free-text reflections on their lessons without a strict template, resulting in texts that vary in length, structure, and emphasis. The reflections combine descriptive accounts of classroom events with evaluative and affective elements and are consistent with common reflective practices in teacher education.

From a methodological perspective, the two instruments differ substantially in their degree of structure. CoRes provide segmented, planning-oriented representations of professional knowledge, whereas written reflections consist of continuous, unstructured text. Analysing relations between these artefacts therefore requires an approach that can relate heterogeneous text formats without reducing them to predefined categories.

Units Of Analysis And Segmentation

For the CoRes, each table field corresponding to a response to a guiding question is treated as an independent unit of analysis. This follows the internal logic of the instrument, as each field represents a coherent aspect of planning-related professional knowledge.

For written reflections, the default unit of analysis is the sentence. Sentence-level segmentation enables fine-grained mapping between planning units and reflective statements and supports detailed inspection of planning–reflection relations (Ullmann et al., 2019; Wulff et al., 2022). As reflective arguments may extend across multiple sentences, paragraph-level segmentation is additionally explored for illustrative purposes. Segmentation is treated as an analytic design choice, and its implications for interpreting semantic relations are explicitly addressed in the analysis.

Semantic Linking Of Planning And Reflection

To relate CoRes and written reflections, an embedding-based semantic similarity approach is employed. CoRe units and reflection segments are mapped into a shared semantic space using sentence embeddings derived from large language models. Semantic similarity between planning units and reflection segments is calculated using cosine similarity.

For each CoRe–reflection pair, all planning units are compared with all reflection segments, resulting in a similarity matrix that represents the relational structure between planning and reflection. Rather than aggregating similarity scores, the full similarity structure is retained for analysis and visualization. Heatmaps are used to illustrate local and sequential similarity patterns, while Principal Component Analysis (PCA) is applied to visualize the relative positioning of planning and reflection units in the shared semantic space. These representations serve an illustrative and exploratory purpose.

Analytic Focus And Scope

The analytic focus of the study is explicitly exploratory and methodological; the analyses neither evaluate teaching nor infer changes in PCK. Instead, they demonstrate how relations between planning and reflection can be made visible by analysing CoRes and written reflections in direct relation to one another. Accordingly, the study emphasizes exemplary case analyses rather than aggregate patterns. Selected CoRe–reflection pairs are used to illustrate how different analytic representations foreground different aspects of planning–reflection relations, such as the effects of segmentation choices or differences in global semantic overlap. The analyses are descriptive and intended to support methodological reflection on relational approaches to studying pedagogical reasoning in PCK-oriented research.

Analytic Strategy: Exemplary Case Analyses

The analyses presented in this study follow an exemplary and contrastive logic. Rather than aiming for systematic comparison or representativeness, selected CoRe–reflection pairs are used to illustrate how different analytic representations make different aspects of planning–reflection relations visible. The cases were chosen to highlight methodological contrasts, not to evaluate individual teachers or to establish typologies.

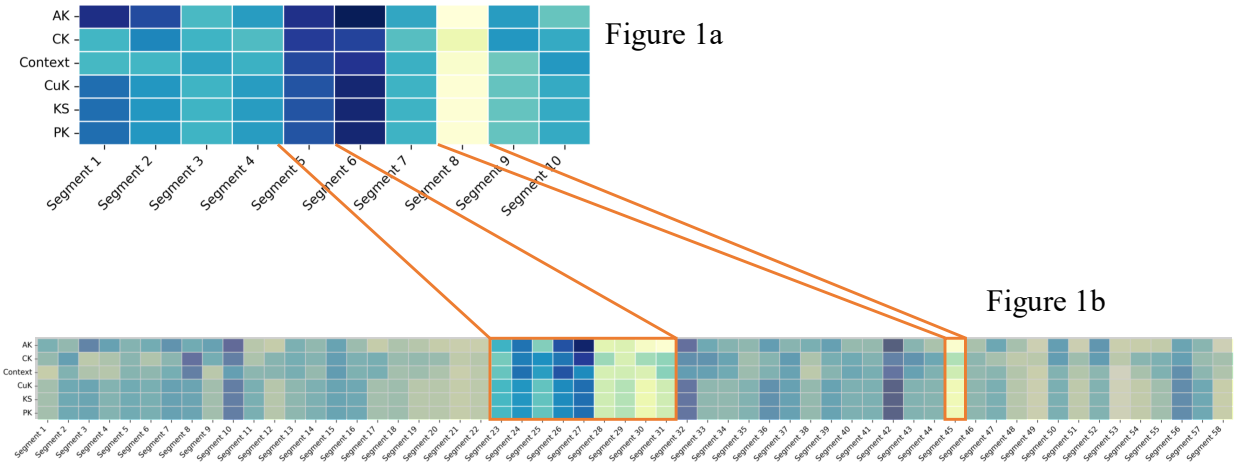
Two complementary analytic representations are employed. First, similarity heatmaps are used to examine local and sequential relations between planning units and reflection segments. These visualizations foreground how specific elements of articulated planning-related knowledge are semantically related to individual segments of the written reflection. Second, Principal Component Analysis (PCA) is used to visualize the global semantic configuration of planning and reflection units within a shared embedding space. This representation shifts the analytic focus from sequential relations to overall patterns of semantic overlap.

The two examples presented below are not intended as comparative cases in a strict sense. Instead, they serve as illustrative contrasts that demonstrate how analytic design choices shape what becomes visible when planning and reflection are analysed relationally.

Example 1: Effects Of Reflection Segmentation On Interpreting Planning–Reflection Relations

Figure 1 illustrates how analytic decisions regarding the segmentation of written reflections influence the interpretation of semantic relations between planning and reflection. Both heatmaps shown in Figure 1a and Figure 1b are based on the same CoRe–reflection pair. The only difference lies in the unit of analysis used for the written reflection: paragraph-level segmentation in Figure 1a and sentence-level segmentation in Figure 1b.

Figure 1. Effects of reflection segmentation on semantic relations between planning and reflection: similarity heatmaps based on paragraph-level (a) and sentence-level (b) segmentation of the same CoRe–reflection pair.



In Figure 1a, the written reflection is segmented into ten paragraphs. The vertical axis represents planning-related units from the CoRe, grouped by PCK-related facets, while the horizontal axis follows the reflection text paragraph by paragraph. At this level of aggregation, the heatmap suggests a relatively homogeneous pattern of semantic alignment. Several planning-related facets appear to co-occur across the same reflective segments, and only one paragraph shows minimal semantic proximity to the planning artefact.

When the same reflection is segmented at the sentence level (Figure 1b), a more differentiated pattern emerges. The reflection is now represented by 58 segments, revealing substantial variation in semantic similarity within paragraphs that previously appeared homogeneous. Sentences focusing on instructional actions and contextual constraints show higher semantic proximity to planning-related units, whereas affective or self-referential statements display markedly lower similarity.

This example demonstrates that segmentation is not a neutral preprocessing step, but a methodological lens that shapes how planning–reflection relations are interpreted. Paragraph-level segmentation foregrounds broader thematic alignment, whereas sentence-level

segmentation makes fine-grained variation within reflective discourse visible. Neither approach is treated as inherently superior; rather, the example illustrates how analytic choices affect what kinds of relations can be observed.

Example 2: Visualizing Semantic Overlap Between Planning And Reflection Using PCA

Figure 2 provides a complementary perspective by visualizing planning and reflection units in a shared semantic space using PCA. Whereas the heatmaps foreground local and sequential relations, the PCA shifts the analytic focus toward global patterns of semantic overlap and distance. Figures 2a and 2b show two illustrative CoRe–reflection pairs. The PCA represents a two-dimensional projection of high-dimensional embedding vectors; the axes themselves have no substantive interpretation and serve only to indicate relative semantic proximity.

In both figures, individual CoRe units are plotted as points and grouped by PCK-related facets, with ovals approximating the semantic regions spanned by each facet. Reflection sentences are plotted in the same space. The visualization highlights the degree to which reflective statements are located within or outside the semantic regions approximated by the planning artefact.

Figure 2. PCA-based visualization of the shared semantic space of CoRe planning units (grouped by PCK facets) and written reflection sentences for two illustrative planning–reflection pairs.

Figure 2a

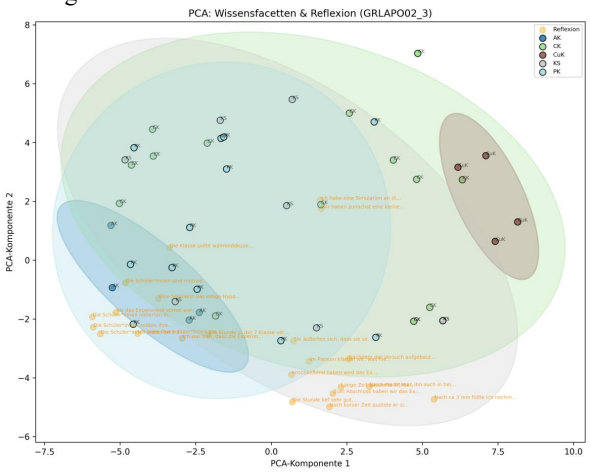
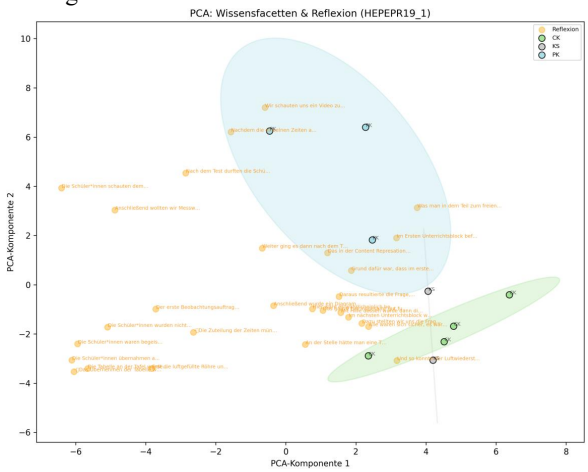


Figure 2b



In Figure 2a, reflection sentences are largely located within the regions spanned by the CoRe units. Descriptively, this configuration indicates a high degree of semantic overlap between planning-related knowledge and retrospective reflection. In Figure 2b, by contrast, several reflection sentences fall outside these regions, suggesting a lower degree of semantic overlap. These observations are reported descriptively and are not interpreted as indicators of teaching quality, completeness of planning, or professional development.

Across both cases, the PCA visualizations also illustrate that the apparent size and shape of planning-related semantic regions depend on properties of the underlying text material, such as length and elaboration. Consequently, PCA-based representations should be understood as heuristic tools for exploring global patterns of semantic overlap rather than as stable characteristics of individuals or artefacts.

Methodological Contribution Of The Exemplary Analyses

Taken together, the exemplary analyses illustrate how linking CoRes and written reflections enables a relational view of pedagogical reasoning that remains inaccessible when planning and reflection are analysed separately. The heatmaps foreground local and sequential relations, while the PCA visualizations provide a global perspective on semantic overlap. Importantly, the

examples show that different analytic representations do not reveal the same aspects of the data but selectively foreground different relations. The purpose of these analyses is not to derive generalizable findings, but to demonstrate the analytic potential and limitations of relational, embedding-based approaches for studying planning–reflection relations in PCK-oriented research.

Discussion

This contribution adopts a methodological perspective on pedagogical reasoning by treating lesson planning and retrospective reflection as relational artefacts situated at different points of the teaching cycle. Linking Content Representations and written reflections makes visible patterns of semantic alignment and non-alignment that remain inaccessible when each artefact is analysed in isolation. In this sense, the study extends instrument-specific approaches by foregrounding relations rather than isolated representations of professional knowledge.

The exemplary analyses resonate with theoretical conceptualizations of pedagogical reasoning as a cyclical process connecting planning, teaching, and reflection. Descriptively, instructional and contextual considerations articulated during planning tend to show higher semantic proximity to reflective statements than affective or self-referential passages. These observations suggest that different modes of retrospective reasoning relate differently to articulated planning-related knowledge. However, in line with the analytic scope outlined above, such patterns are not interpreted as indicators of learning, transformation, or quality of teaching; nor do the analyses provide access to micro-level reasoning processes or changes in PCK.

A central insight of the study is that analytic representations actively shape what becomes visible. Sequential similarity heatmaps foreground local relations along the progression of reflective texts, whereas spatial projections such as PCA highlight global patterns of semantic overlap. These representations are complementary rather than competing and underscore that relational analyses are not neutral windows onto pedagogical reasoning, but methodological lenses that emphasize different aspects of planning–reflection relations.

Limitations

The present study is subject to several limitations. First, the analyses are based on a small number of illustrative cases and are not intended to support generalization across individuals or contexts. The exemplary cases serve to demonstrate analytic possibilities rather than to establish stable empirical patterns.

Second, the observed relations are sensitive to methodological design choices. In particular, segmentation of reflective texts substantially affects the granularity and interpretation of semantic similarity, and PCA-based visualizations depend on properties of the underlying text material such as length, elaboration, and linguistic variation. These dependencies should be understood as characteristics of the analytic approach rather than as sources of measurement error.

Finally, the identified relations describe semantic proximity between planning and reflection, not learning outcomes, instructional effectiveness, or professional development. Developmental or evaluative interpretations would require additional data, triangulation with other methods, and longitudinal designs that are beyond the scope of this contribution.

Implications And Outlook

Despite these limitations, the study points to several implications for future research in science education. Methodologically, it illustrates how planning and reflection can be analysed as relational data without reducing either artefact to predefined categories or evaluative metrics.

This opens up exploratory research designs that focus on pedagogical reasoning across the teaching cycle rather than on isolated knowledge components.

Future work may systematically investigate how analytic decisions, such as segmentation strategies or modes of visualization, influence the interpretation of planning–reflection relations. Longitudinal designs could explore whether characteristic patterns of semantic alignment emerge over time and how they relate to instructional experience. Combining embedding-based analyses with qualitative interpretation may further clarify how different forms of retrospective reasoning connect to articulated planning-related knowledge.

At the same time, the approach should be understood as an analytic tool for making relations visible and inspectable, not as a validated measurement instrument. Its contribution lies in supporting methodological and theoretical reflection on how pedagogical reasoning can be studied relationally within PCK-oriented research, rather than in providing definitive interpretations of teachers' professional knowledge or its development.

References

Alonzo, A. C., Berry, A., & Nilsson, P. (2019). Unpacking the complexity of science teachers' PCK in action: Enacted and personal PCK. In A. Hume, R. Cooper, & A. Borowski (Eds.), *Repositioning pedagogical content knowledge in teachers' knowledge for teaching science* (pp. 273-288). Springer Singapore. https://doi.org/10.1007/978-981-13-5898-2

Brouwer, N. & Korthagen, F. (2005). Can teacher education make a difference? *American Educational Research Journal*, 42, 153-224.

Buckingham Shum, S., Sándor, Á., Goldsmith, R., Bass, R., & McWilliams, M. (2017). Towards reflective writing analytics: Rationale, methodology and preliminary results. *Journal of Learning Analytics*, 4(1), 58–84. https://doi.org/10.18608/jla.2017.41.5

Carlson, J., Daehler, K.R., Alonzo, A., Barendsen, E., Berry, A., Borowski, A., ... & Wilson, C. (2019). The Refined Consensus Model of Pedagogical Content Knowledge in Science Education. In A. Hume, R, Cooper & A. Borowski (Eds.) *Repositioning Pedagogical Content Knowledge in Teachers' Knowledge for Teaching Science*. Springer. https://doi.org/10.1007/978-981-13-5898-2

Chan, K.K.; Hume, A. (2019). Repositioning Pedagogical Content Knowledge in Teachers' Professional Knowledge; Springer.

Korthagen, F. A. J., & Kessels, J. P. A. M. (1999). Linking theory and practice: Changing the pedagogy of teacher education. *Educational Researcher*, 28(4), 4–17. https://doi.org/10.3102/0013189x028004004

Kunter, M., Baumert, J., Blum, W., Klusmann, U., Krauss, S., & Neubrand M. [Hrsg.] (2011). Professionelle Kompetenz von Lehrkräften. *Ergebnisse des Forschungsprogramms COACTIV*. Waxmann. ISBN 978-3-8309-2433-3.

Loughran, J., Mulhall, P. and Berry, A. (2004), In search of pedagogical content knowledge in science: Developing ways of articulating and documenting professional practice. *Journal of Research in Science Teaching*, 41: 370-391. https://doi.org/10.1002/tea.20007

Loughran, J., Berry, A. & Mulhall, P. (2006). *Understanding and developing science teachers' pedagogical content knowledge*. Rotterdam. Sense Publishers.

Mandl, H. & Gerstenmaier, J. (Hrsg.). (2000). Die Kluft zwischen Wissen und Handeln. *Empirische und theoretische Lösungsansätze*. Hogrefe.

Mientus, L. & Borowski, A. (2024). Content Representations kohärent gedacht. In A. Wehner, N. Masanek, K. Hellmann, T. Heinz, F. Grospietsch & I. Glowinski (Hrsg.), *Vernetzung von Wissen bei Lehramtsstudierenden – Eine Black-Box für die Professionalisierungsforschung?* (S. 89–103). Klinkhardt. https://doi.org/10.25656/01:31763

Mientus, L. & Borowski., A. (2024). Knowledge Awareness – Content Representations as a Useful Tool. In G. Kaya, M., Sardag, I. & Donmez (Eds.). *Proceedings Book Series-V of the ESERA 2023 Conference. Connecting Science Education with Cultural Heritage, Strand number* (co-ed. M. R. Jimenez Liso, H. Özcan, C. Fazio, & I. A. Costa), (pp. 382 - 392). Cappadocia, Türkiye. Nobel Bilimsel Eserler. https://drive.google.com/file/d/1LVEbjDDvMxrNOP52uD2lyiEi6TqwrjC5/view

Mientus, L., Hume, A., Wulff, P., Meiners, A. & Borowski, A. (2022). Modelling STEM Teachers Pedagogical Content Knowledge in the Framework of the Refined Consensus Model: A Systematic Literature Review. *Education Sciences*, 12 (6), 385. https://doi.org/10.3390/educsci12060385

Mientus, L., Wulff, P., Nowak, A. & Borowski, A. (2023). Fast-and-frugal means to assess reflection-related reasoning processes in teacher training – Development and evaluation of a scalable machine learning-based metric. *Zeitschrift für Erziehungswissenschaft*. https://doi.org/10.1007/s11618-023-01166-8

Mientus, L., Wulff, P., Nowak, A., & Borowski, A. (2021). ReFeed: computerunterstütztes Feedback zu Reflexionstexten - Ein Lehrkonzept zur Förderung der Reflexionskompetenz angehender Physiklehrkräfte an der Universität Potsdam. In: M. Kubsch, S. Sorge, J. Arnold & N. Graulich (Hrsg.): *Lehrkräftebildung neu gedacht - Ein Praxishandbuch für die Lehre in den Naturwissenschaften und deren Didaktiken*, Waxmann. S. 160 - 165. https://doi.org/10.31244/9783830993490

Nilsson, P. & Elm, A. (2017) Capturing and Developing Early Childhood Teachers' Science Pedagogical Content Knowledge Through CoRes. *Journal of Science Teacher Education*, 28:5, 406-424, https://doi.org/10.1080/1046560X.2017.1347980

Park, S. & Oliver, J.S (2008). Revisiting the Conceptualisation of Pedagogical Content Knowledge (PCK): PCK as a Conceptual Tool to Understand Teachers as Professionals. *Research in Science Education*, 38, 261–284. https://doi.org/10.1007/s11165-007-9049- 6

Poldner, E., van der Schaaf, M., Simons, P.R.-J., van Tartwijk, J., & Wijngaards, G. (2014). Assessing student teachers' reflective writing through quantitative content analysis. *European Journal of Teachacher Education*, 37(3), 348–373.

Renkl, A. (1994). *Träges Wissen: Die "unerklärliche" Kluft zwischen Wissen und Handeln* (Forschungsbericht Nr. 41). München: Ludwig-Maximilians-Universität, Lehrstuhl für Empirische Pädagogik und Pädagogische Psychologie, ISSN 1614-6336.

Sannert, R., van Driel, J., & Krell, M. (2025). Can Content Representation (CoRe) Accurately Capture Key Components of Science Teachers' PCK? A Methodological Perspective. *Journal of Science Teacher Education*, 1–25. https://doi.org/10.1080/1046560X.2025.2516293

Shulman, L. S. (1986). Those Who Understand: Knowledge Growth in Teaching. *Educational Researcher*, 15(2), 4-14.

Shulman, L.S. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review*, 57(1), 1-22.

Ullmann, T.D. (2019). Automated Analysis of Reflection in Writing: Validating Machine Learning Approaches. *International Journal of Artificial Intellegence in Educacion* 29, 217–257. https://doi.org/10.1007/s40593-019-00174-2

Van Driel, J., & Berry, A. (2012). Teacher Professional Development Focusing on Pedagogical Content Knowledge. *Educational Researcher*, 41, 26 - 28. https://doi.org/10.3102/0013189X11431010

Van Driel, J., Verloop, N., & Vos, W. (1998). Developing science teachers' pedagogical content knowledge. *Journal of Research in Science Teaching*, 35, 673-695. https://doi.org/10.1002/(SICI)1098-2736(199808)35:6<673::AID-TEA5>3.0.CO;2-J

Wulff, P., Mientus, L., Nowak, A. & Borowski, A. (2022). Utilizing a Pretrained Language Model (BERT) to Classify Preservice Physics Teachers' Written Reflections. *International Journal of Artificial Intelligence in Education*. https://doi.org/10.1007/s40593-022-00290-6

EUROPEAN SCIENCE EDUCATION RESEARCH ASSOCIATION ESERA 2025 Copenhagen

Technology And Pedagogy In Science Teacher Education: Promoting Teacher Candidates' Skills In Instructional Design And Learning Management Systems

Mohammed Estaiteyeh and Xavier Fazio
Brock University, Canada

Two main models exist in teacher education programs to advance teacher candidates' (TCs') use of technology in teaching: 1) stand-alone courses on educational technology, and 2) infused model in which digital skills are integrated into teaching methods courses. In this paper, the authors present a collaboration that combines both approaches to promote technology use in science teacher education. We report on an assignment in the educational technology course that requires TCs to capitalize on their skill in science curriculum development to create an online learning module using learning management systems (LMS). This paper aims to analyse the content of TCs' developed online modules and present TCs' experiences in this assignment, with a focus on their skills in using LMS.

The authors adopt a qualitative approach. Participants are 10 TCs enrolled in both the educational technology course and the science methods course in the teacher education program at a university in Canada (secondary division). The authors analyse the online modules developed by the TCs and their reflections.

TCs' work and reflections showcase the positive impact of the training they received and the importance of the online module assignment in promoting their 1) pedagogical skills in science instructional design and 2) technological and pedagogical skills in incorporating digital tools into their lessons and using LMS. The assignment showed the importance of collaboration between educational technology and science education instructors to promote TCs' technological, pedagogical, and content knowledge. This research highlights the successes of professional development practices, especially ones focused on interdisciplinary collaborations in teacher education programs.

Keywords: Science teacher education, learning management systems, instructional design

Introduction and Objectives

Although stand-alone educational technology courses in teacher education allow teacher candidates (TCs) to develop proficiency in using digital tools (Roblyer & Hughes, 2019), they often lack integration with broader content knowledge and pedagogical skills (Estaiteyeh & Rong, 2026; Foulger et al., 2015). Alternatively, teacher educators can infuse technology in subject-specific courses like curriculum and methods courses in science teacher education programs to make technology training more relevant and practically applicable (Koehler et al., 2013). Indeed, Williamson et. al. (2023) emphasize collaboration among educators from different disciplines to foster a multidisciplinary method of technology integration in teacher education. In such infusion models, technology-supported learning strategies are taught, modeled, and practiced throughout the entire preparation program, with all teacher educators assuming responsibility for supporting science TCs' growth in teaching with technology (Sprague et al., 2022). However, time constraints and the need to cover a broad range of topics in science curriculum and methods courses limit science teacher educators from fully incorporating technology in their courses.

In this paper, the authors present a balanced approach that combines the stand-alone and infused approaches to promote technology use in science teacher education. The authors are two teacher

educators in a teacher education program in Canada who collaborated to complement each other's work in their respective courses. The first author teaches the stand-alone educational technology course while the second author teaches the science education course. In the educational technology course, TCs focus on the effective use of digital technologies in the classroom (Estaiteyeh et al., 2025). In the science methods course, TCs are introduced to curriculum design, teaching strategies, and assessment methods in secondary science education. We report on one of the assignments in the educational technology course that requires TCs to capitalize on their skill in science curriculum development to create an online learning module, all while advancing their skills in using learning management systems (LMS). Thus, this paper addresses the following research objectives:

1) Analysing the content of TCs' developed online modules.
2) Presenting TCs' experiences and reflections on this assignment, with a focus on their skills in using LMS.

Literature Review And Theoretical Framework

Preparing Tcs For Online Teaching And Using Learning Management Systems

With the increased prevalence of online learning and as per the lessons learned from teaching during the COVID-19 pandemic, there is a need to better equip TCs for technology-enhanced teaching practices, especially in online environments (DeCoito & Estaiteyeh, 2022; Barbour & Hodges, 2024). Success in online teaching depends on strong course design, appropriate material selection, effective pedagogical strategies, and clear communication with students and families alike (Fernández et al., 2017; Recker et al., 2013). Several studies in Canada have demonstrated the positive impacts of online teaching preparation and training on science TCs' readiness to support this teaching modality (Burns et al., 2020), especially in synchronous learning environments (Estaiteyeh et al., 2024). However, there is a gap in the literature on preparing TCs for asynchronous online teaching and instructional design for virtual environments.

Furthermore, essential to the success of online teaching is the effective use of LMS, which is the platform that is primarily used in online environments. Thus, it is also important that TCs get sufficient training in using LMS, with a focus on student engagement and community building in online settings (Vivolo, 2019) and the use of a variety of interactive virtual resources (Smith et al., 2018). However, despite the importance of LMS, research on their use by TCs is limited. Accordingly, this research aims at advancing TCs' technological and pedagogical skills in using LMS to create effective online learning experiences for the students.

Technological, Pedagogical, and Content Knowledge (TPACK) Framework

This research is informed by the TPACK framework (Koehler et al., 2013). Shulman (1987) defines pedagogical content knowledge (PCK) as the capacity of a teacher to transform their content knowledge into forms that are pedagogically powerful yet adaptive to variations in students' abilities and backgrounds. Koehler et al. (2013) extend Shulman's PCK to integrate technology into teacher's pedagogy. In accordance with the technology infusion framework (Williamson et al., 2023) explained earlier, the authors emphasize how content, pedagogy, and technology interest across different courses in the teacher education program. In doing this work, TCs will capitalize on content and pedagogical knowledge acquired in science education courses to advance their pedagogical and technological knowledge fostered in the education technology course.

Methods

The authors adopt a qualitative approach (Creswell & Creswell, 2018) utilizing document analysis (Stake, 2020) to address the research objectives. Ten TCs (two males and eight females) participated in the study. Participants were enrolled in both the educational technology course and the science methods course in the first year of the two-year teacher education program at a university in Canada (secondary school teacher certification). The science education course ran for 24 weeks (Fall and Winter terms), while the educational technology course ran for 12 weeks in the Winter term.

Assignment Description

As part of the educational technology course, the instructor provided TCs with two workshops on online teaching and LMS features and functionalities. This training included providing relevant resources and tutorials, modelling by the instructor, and direct applications by TCs. Afterwards, the instructor introduced the online learning module assignment. This assignment built on what TCs had learned in the Fall term in the science education course (instructional design using the backward design model, student-centred teaching and assessment strategies). In this assignment, TCs worked individually or in pairs to design and develop an online learning module using Brightspace, the LMS adopted by most district school boards partnered with the University. The module should be developed for students in a class within the and focused on a specific concept within TCs' subject area (e.g., general science, biology, chemistry, physics). The module was planned by TCs to be completed mostly asynchronously by their prospective students. First, TCs completed the instructional design phase of the module. Then, they hosted their module on Brightspace LMS. In addition to developing the modules, TCs submited individual reflections on this assignment.

Data Sources and Analysis

The authors describe and analyse 1) the online modules developed by the TCs (total of seven modules) and 2) the individual reflections submitted by each TC (10 reflections). Sample reflection questions included: What did you benefit the most from this project? What challenges did you face (individual or group challenges)?

Data analysis adopted a deductive approach (Creswell & Creswell, 2018), using pre-determined themes (e.g., module contents, teaching and assessment staregies, incorporated digital tools, and LMS functionalities). The first author conducted the analysis, and the second author reviewed it by providing corrections. The two authors met to finalize the findings. This process of iterative and collaborative analysis was done to ensure the reliability and validity (Creswell & Creswell, 2018).

Results

Modules' Analysis

As shown in Figures 1 and 2, TCs used several LMS features and functionalities to host their module such as discussion boards, assignments, rubrics, quizzes, and digital publishing while attending to accessibility and inclusion guidelines. TCs were also able to augment their science lesson plans by incorporating digital tools such as multimedia, online simulations, virtual labs, and digital assessments. Although this was the first experience for almost all TCs in using LMS as teachers, their work on the online modules showed the positive impact of the provided training and the relevance of this assignment in preparing them for future use of the LMS software. Equally important, the assignment showed the importance of collaboration between educational technology and science education instructors to promote TCs' TPACK.

Figure 1. Screenshot of a module on DNA transcription showing the structure and flow of the module on Brightspace.

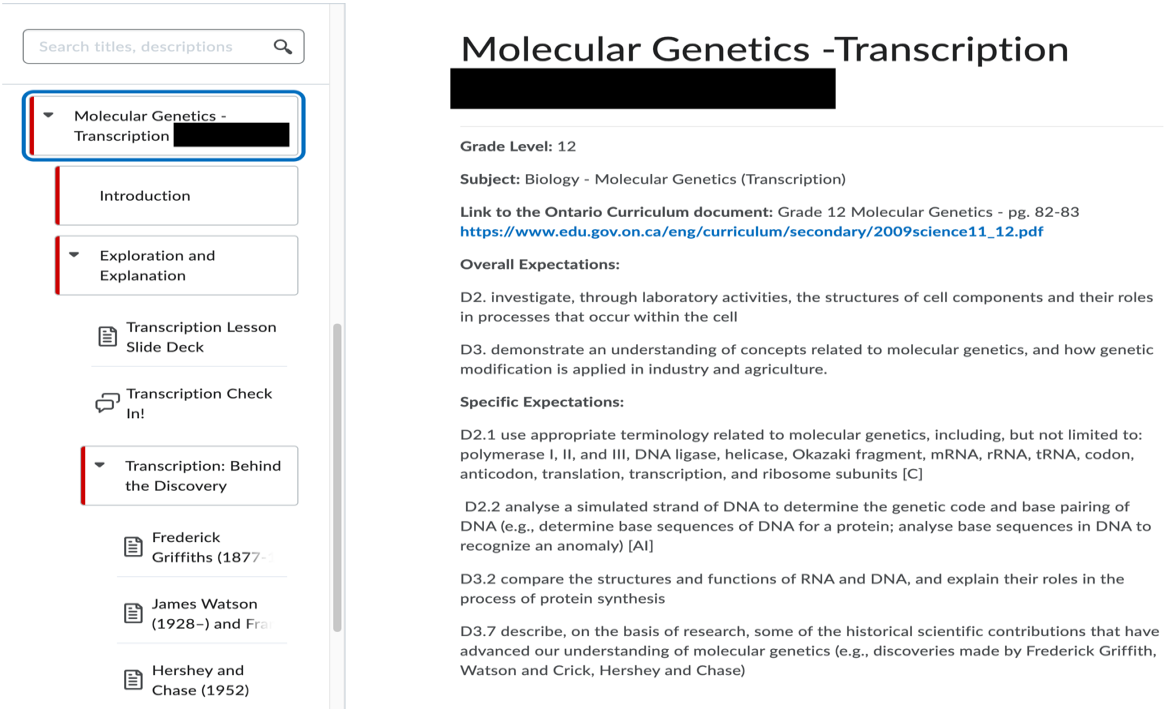
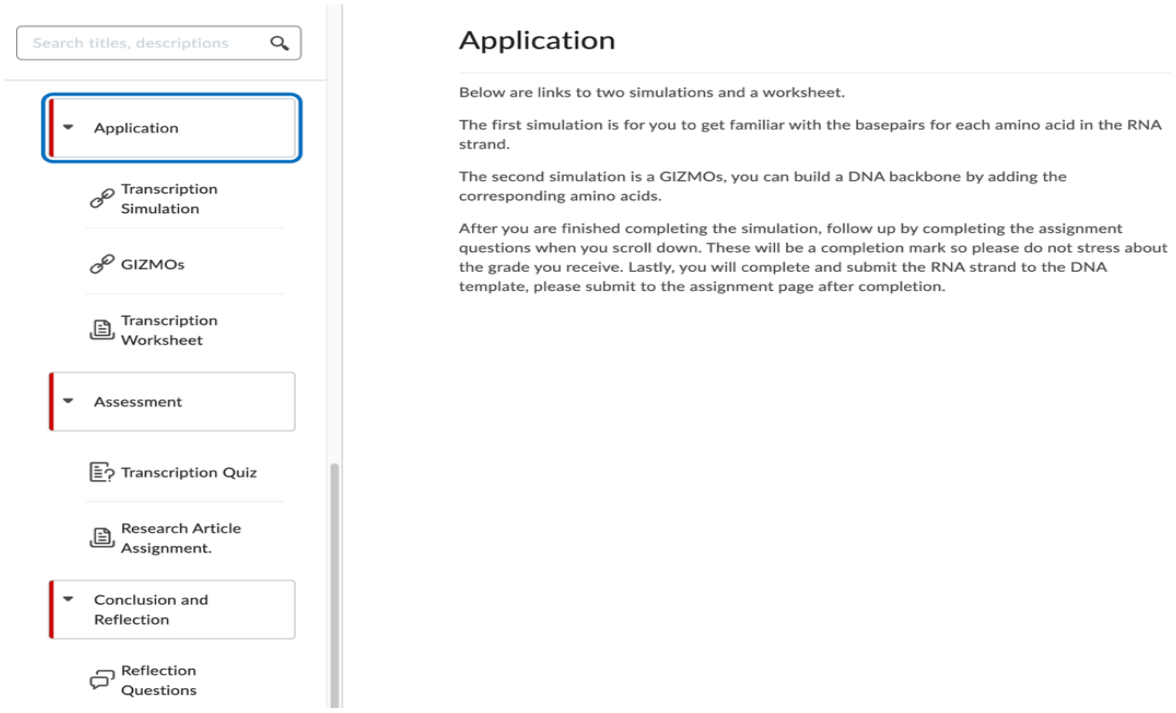


Figure 2. Screenshot of a module on DNA transcription showing the incorporation of digital tools within the module.



Teacher Candidates' Reflections

The reflections of TCs reiterated the positive impact of the training they received and the importance of the online module assignment in promoting their 1) pedagogical skills in science instructional design, 2) technological and pedagogical skills in incorporating digital tools into their lessons and using LMS. For example, TCs said:

> I think that I benefited most from finding new tech tools which can specifically be used within my teachable of science. I was able to find new virtual simulations and tutorials

which I may not have found if I did not take this course. Before taking this course, I did not consider the idea of virtual simulations, virtual field trips, and virtual labs. Having science as one of my teachables, I have realized how useful these virtual tools could be while teaching an online class and needing students to meet the lab-based curriculum expectations. I also benefited from learning how to host a class on Brightspace as this is something I will most likely need to do in the near future either during my teaching placements or within my own class.

This project gave me important insights into instructional design and online module development. Moreover, working on this subject allowed me to improve my ability to organize content effectively and create interesting learning experiences for students. In addition, I learned how to use Brightspace to host online modules, which increased my skills in using learning management systems. Overall, this project provided me with practical experience and knowledge that would be very beneficial in my future teaching career.

Significance of the Study

This research advances knowledge about science teachers' preparation and readiness for technology-enhanced and online teaching. This work informs science teacher educators, educational researchers, and higher education curriculum designers about the successes of professional development practices, especially ones focused on interdisciplinary collaborations in teacher education programs.

References

Barbour, M. K., & Hodges, C. B. (2024). Preparing teachers to teach online: A critical issue for teacher education. *Journal of Technology and Teacher Education*, *32*(1), 5–27. https://doi.org/10.70725/394261afynbl

Burns, A., Danyluk, P., Kapoyannis, T., & Kendrick, A. (2020). Leading the pandemic practicum: One teacher education response to the COVID-19 crisis. *International Journal of E-Learning & Distance Education, 35*(2), 1-25. https://www.ijede.ca/index.php/jde/article/view/1173

Creswell, J. W., & Creswell, J. D. (2018). *Research design: Qualitative, quantitative, and mixed methods approaches* (5th ed.). SAGE Publications, Inc.

DeCoito, I., & Estaiteyeh, M. (2022). Online teaching during the COVID-19 pandemic: Exploring STEM teachers' curriculum and assessment practices in Canada. *Disciplinary and Interdisciplinary Science Education Research, 4*(8). https://doi.org/10.1186/s43031-022-00048-z

Estaiteyeh, M., DeCoito, I. & Takkouch, M. (2024). STEM teacher candidates' preparation for online teaching: Promoting technological and pedagogical knowledge. *Canadian Journal of Learning and Technology, 50*(4), 1-20. https://doi.org/10.21432/cjlt28594

Estaiteyeh, M., Heenan, J., & Sovegjarto, B. (2025). Listening to teacher candidates and teacher educators: Revising educational technology courses in a Canadian teacher education program. *Education Sciences, 15*(6), 730. https://doi.org/10.3390/educsci15060730

Estaiteyeh, M., & Rong, W. (2026). An environmental scan of educational technology courses in teacher education programs in Ontario. *Canadian Journal of Learning and Technology, 51*(3), 1-20. https://doi.org/10.21432/cjlt29011

Fernández-Batanero, J. M., Román-Graván, P., Reyes-Rebollo, M. M., & Montenegro-Rueda, M. (2021). Impact of educational technology on teacher stress and anxiety: A literature review. *International Journal of Environmental Research and Public Health, 18*(2), 548. https://doi.org/10.3390/ijerph18020548

Foulger, T. S., Buss, R., Wetzel, K., Lindsey, L., & Pasquel, S. (2015). *Nudging tech infusion into student teaching: Determining institutional readiness for large-scale, site-based, professional development*. 27–32. https://www.learntechlib.org/primary/p/149962/

Koehler, M. J., Mishra, P., & Cain, W. (2013). What is technological pedagogical content knowledge (TPACK)? *Journal of Education*, *193*(3), 13–19. https://doi.org/10.1177/002205741319300303

Recker, M., Sellers, L., & Ye, L. (2013). Teacher design using online learning resources: A comparative case study of science and mathematics teachers. *Education Research International*, *2013*, 1–11. https://doi.org/10.1155/2013/243248

Roblyer, M. D., & Hughes, J. E. (2019). *Integrating educational technology into teaching: Transforming learning across disciplines* (8th ed.). Pearson.

Shulman, L. S. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review, 57*(1), 1-22.

Smith, A. C., Warren, J. M., & Ting, S. M. R. (2018). *Developing online learning in the helping professions: Online, blended, and hybrid models*. New York: Springer Publishing Company.

Sprague, D. R., Williamson, J., & Foulger, T. S. (2022). Design guidelines for post-COVID era preparation programs: Action steps toward technology infusion. *Journal of Technology and Teacher Education*, *30*(2), 177–187. https://doi.org/10.70725/001588fanhql

Stake, R. (2020). Case studies. In *Handbook of qualitative research* (pp. 435–454). Sage.

Vivolo, J. (2019). *Managing online learning: The life-cycle of successful programs*. Routledge.

Williamson, J., Sprague, D. R., & Foulger, T. S. (2023). Characteristics and indicators of technology-infused programs: Supporting a paradigm shift in teacher preparation. *Journal of Technology and Teacher Education, 31*(2), 203–226. https://doi.org/10.70725/453621yeceuo

EUROPEAN SCIENCE EDUCATION RESEARCH ASSOCIATION ESERA 2025 Copenhagen

Science Teacher Educators: Career Narratives And Life Histories

Peer Daugbjerg
VIA University College, Denmark

A significant notion in science teacher education as in other teacher education is modelling, phrased as 'How I teach is the message'. This is both a professional and a personal stance, or stances as it spreads over several elements for the profession as a teacher educator but also makes it clear that it is the individual teacher educators personal performance applying these elements that is what teacher students meet during their education. This makes teacher education a personal effort for teacher educators and reflects the significance of teacher educators lived experiences in their teaching of coming teachers. This raise the question whether it gives different relations between work and personal life, and furthermore is science teacher educators a unique group here with distinct characteristics in their experience of meaning. My research interest calls for focus on the individual science teacher educator as it is them that do the actual teaching about science teaching. This means that I must learn from individual science teacher educators, what are their life histories, how do they narrate them during life history interviews. My analysis indicates that science teacher educators' careers are influenced by significant professional events in their lives and that second order teaching has a strong position in their professional compass.

Keywords: Science teacher educators, Career Narratives.

Introduction – Context And Background

The recruitment of teacher educators in Denmark has for the last 25 years gone through a structured qualification. This qualification is compulsory for anyone who wants to teach at a University College in Denmark including teacher educators. After 3½ years the teacher educator hands in a maximum 40 pages long written request to become a permanent member of the teacher education staff (Departmental order on teacher educator qualification, 2025). The request must cover teaching of teacher students and teachers including planning and development and implementation of international research aspects in this work. The issue of implementation of research has internationally received attention through the notion of teacher educators' varied researcherly dispositions (Tack, et al 2023). This is especially a concern for researchers from university-based teacher educations. This aspect has also been researched in Denmark (Duch et al, 2021) leading to the formulation of three idealistic types of educators at University Colleges and their relation research and development: 'The profession-oriented educator', 'The research-oriented educator', and 'The educative oriented educator'. The typologies show the spectrum of research interest among Danish university college educators but does not - as all typologies – reveal nuances and personal aspects of the research orientation. A more individualistic approach through life histories can unveil such details (Lorist & Swennen, 2016).

The structured professional development for university college educators in Denmark is not common in other countries. Studies revealed that teacher educators' recruitment is incidental, with no pre-planned policy to form well-balanced teams that provide coherent teacher education programmes (Guberman et al, 2021). It appears that Denmark holds a special position regarding a structured state-run qualification programme for a permanent position in teacher education. However, the Association of Dutch Teacher Educators run a certification programme which includes evaluation of novice teacher educators' products and portfolios (Lunenberg et al, 2014a). This certification is voluntary and does not cover all Dutch teacher educators.

A significant notion in teacher education is modelling, phrased as 'How I teach is the message' by the International Forum for Teacher Education Development (InFo-TED, 2024). This is both a professional and a personal stance, as the forum puts forward 13 building blocks for the profession as a teacher educator but also makes it clear that it is the individual teacher educators personal performance applying these building blocks that is what teacher students meets during their education. This makes teacher education a personal effort for teacher educators and reflects the significance of teacher educators lived experiences in their teaching of coming teachers (ATEE Empowering RDC, 2024).

Research Interest

A firsthand understanding of an insider – my own – is that of a great variation within science teacher educators' professional development and personal practice. The field of science teacher educators is not well researched, however there is an emerging field of international studies on being and becoming a teacher educator as well as on their lives and work (Swennen & White 2021; Jaworski & Woods, 2008; Lorist & Swennen, 2016). These studies bring forward the voices of teacher educators (Swennen & White, 2021) and critical stances to these voices (Holdsworth, 2021). As stated above the Danish qualification of teacher educators might provide a different background for the voices of Danish teacher educators. Does this give different relations between work and personal life, and furthermore is science teacher educators a unique group here with distinct characteristics in their work-life experience. This leads me to my research questions for this presentation.

Research Question

- How is science teacher educators work related to their lives?

Methodological Considerations

My stated research interest calls for focus on the individual science teacher educator as it is them that do the actual teaching about science teaching. This means that I must learn from individual science teacher educators, what are their life histories, how do they narrate them during life history interviews (White & Timmermans, 2021; Swennen & Lorist, 2016).

I can though not only interview science teacher educators. I have also to observe them during their workdays. I must contextualise my science teacher educators' narratives in the teacher educator profession and add a practice perspective on science teacher education to their narratives, so I must do more than interview them. Traianou (2007) emphasises the importance of studying actual practice:

> … the assessment of an individual's knowledge should be based on how this person performs, and not on what this person says about his/her own performance or what he/she can and cannot do in artificial situations (Traianou, 2007, p. 40).

Traianou (2007) puts her finger on the need to study science teacher educators as closely as you can get to real situations. Thus, rather than simply recounting verbatim the science teacher educators' own accounts of their practice, nor confining one's study to their performance in teaching situations, you should apply a research method that brings together diverse observational data and presents science teacher educators in all their complexity. I therefore also make observations of the participating science teacher educators teaching and performing other work functions during entire everyday work.

The Applied Method

The research design departs from the above methodological considerations which is in close alignment with a previous study on school science teachers in Denmark (Daugbjerg, 2013).

1) Life history and career narrative interview of approximately one hour
    i) Art based elements: go-cards and the like, drawing option
2) Two more-or-less whole day (each approximately 6 hours) observations pr. participants with emphasis on teaching practice.
3) Follow-up interview of approximately one hour
    i) Filling identified common aspects not covered by interview and observations
    ii) Validating preliminary interpretations of first individual interview and observations
    iii) Emotional aspects of science teacher education (e.g. joy, anxiety, nervousness)

Conceptual Framing Of The Research

Here I will briefly present research literature that presents and works with the key concepts in my research endeavour.

Second Order Teaching

Teacher educator work can be summarised in six characteristic roles of teacher educators: teacher of teachers, researcher, coach, curriculum developer, gatekeeper and broker (Lunenberg et al, 2014b). Lunenberg et al (2014b) relates in their review of teacher education these roles but especially the 'teaching of teachers' role to the notion of second order teaching. They emphasise the importance of teacher educators ability to articulate tacit knowledge and underlaying theory through explicit modelling (Lunenberg et al, 2014b).

A more recent state of the art research from Denmark puts forward a definition of second order teaching:

> Second order teaching encompasses the educative reflections concerning planning, enactment, analysis, and development of teaching, that actors in the teacher education contexts address, and the praxis they unfold to facilitate coming teachers' ability to future teaching (Ellebæk, Dolin & Daugbjerg, 2022).

Life History

Life history has frequently been used to identify significant events in peoples' lives (Goodson & Sikes, 2001). Also, within teacher education it is a known approach to understand teacher educators lives and work (Lorist & Swennen, 2016; Fisher & Powell, 2023)

Narrative Inquiry

There are several different traditions within narrative inquiry. I subscribe to a seminal work by Clandinin & Connelly (2000). Updated by Horsdal (2011):

> The focus in my approach is not to understand the individual person – how she or he really is beyond the surface – but how the narrator tries to make sense of lived experience through her narration (Horsdal, 2011, p. 108).

Narrative inquiry has also been used to understand teacher educators work e.g. White & Timmermans (2021) study on school-based teacher educators.

Findings

My participants are 8 males and 5 females, an overall cohort of Danish science teacher educators counts 62 whereof 38 are male and 24 are female (Nielsen, 2022). My group of participants is a convenience sample of volunteers, from a field that I have been a member of for nearly 30 years.

That makes my research a bit scarring because some of the participants have been my national colleagues for about a generation.

Table 1. Overview of participants biographic data.

Alias	Birth	Parents	Coming of age	Education	Career
Leif	1979	Vocational trained Ergo therapist	Rural area, scouting	Master in chemistry 2010 PhD Mol. Biophysics 2013	Science Researcher TE 2022: Physics/Chemistry
Lars	1960	Teachers	Fishing, handball	Teacher 1985, Master of education 2004	Teacher TE 2001: Biology, Nature/Tech
Nete	1980	Vocational trained Nurse	Sports	Teacher 2006 Master of SE 2022	Teacher TE 2022: Physics/Chemistry
Niels	1985	Farming	Choir, outdoor life	Music studies Master of Geography 2009	High school teacher TE 2018: Geography
Alex	1961	Unskilled	Music,	Teacher 1990 Master of education 2000	Teacher TE 2009: Physics/Chemistry
Anders	1955	Own shop	Scouting, running	Teacher 1978 Master of education 2000	Teacher and consultant TE 2003: Nature/Tech, Further education
Veronika	1972	Teachers	Gymnastics, scouting	Biologist 2000 PhD zoology 2003	Science Researcher TE 2009: Biology
Viola	1965	Teachers, artists	Drama, scouting, sports	Biologist 1990 PhD outdoor pedagogy 2020	High school and TE 1993: Biology
Villiam	1953	Teachers	India, music	Teacher 1985 Master of education ????	Teacher, social worker TE 2002: Biology, Nature/Tech
Sanne	1972	Farming, teachers	Sports, Arts	Theology Teacher 2000, ME 2013	Teacher, consultant TE 2016: Biology
Steen	1966	Semiskilled	Sports	Physics and math 1993	High school and TE 1996: Physics/Chemistry, Math
Kia	1983	Farming	Scouting	Geology 2009 PhD meteorites 2014	Science centre TE 2016: Nat/Tech, Geography
Karl	1970	Welfare professionals	Sports including chess	Geography and history 2001	Teacher TE 2004: Geography, Further education

They represent a geographical distribution in Denmark with participants from all 6 university colleges in Denmark, they represent all the four science subjects in Danish school and teacher education. Biographic data that present the overall life histories are presented in the table below. Interviews and observations were conducted from November 2023 – February 2025.

Comparison of my participants with the overall cohort of Danish Science teacher educators reveals that my sample quite representative for science teacher educators in Denmark in general.

Table 2. Comparison of my participants experience as science teacher educator and a larger cohort of Danish Science teacher educators.

Experience as Science teacher educator	National cohort (N=57) (Nielsen, 2022)	My participants (N=13)
0-4 years	21%	15%
5-9 years	16%	23%
10-14 years	9%	0%
15-19 years	23%	23%
20 years or above	32%	38%

Table 3 Comparison of my participants educational background and a larger cohort of Danish Science teacher educators – several has more than one education e.g. a teacher education and a Master of Science Education or a Master of Science and a PhD degree.

Science teacher educators educational background	National cohort (N=57) (Nielsen, 2022)	My participants (N=13)
Teacher education	36%	46%
Science master	62%	54%
Science education Master	22%	38%
Other master	31%	0%
PhD	31%	31%
Other education	33%	15%

Voices Of Science Teacher Educators

My participants reflect the importance of second order teaching as a way to be a teacher of teachers:

> And then the challenge with second order teaching. That is what I find most interesting (Kia).

Kia has worked with young children at a science centre prior to entering teacher education, here she applied a variety of teaching approaches. These experiences are mirrored in her approach working with science modelling with her science teacher students as a tool to relate to them and make them relate to science.

> And then I work simply with [modelling], rather than sitting and getting frustrated that they can't understand it [the science subject as presented in a text]; I say, that is okay that you do like this [make a model] (Kia).

Kia asks the science teacher students to work with a science phenomenon through different media as they see fit to optimize their learning.

My participants also reflect on specific elements of science education and the duality of teaching and learning.

> Science, aesthetics, and the fascination. Evolution as the red thread and the connection between learning and teaching (Veronika).

Veronika also reflects on the relation between science education research and science teacher education and its options for double synergies. Veronika has been a science researcher prior to entering teacher education.

> Because I research into teaching, and that must be anchored. So, I anchor it in my own [teacher education] praxis. I try to include it [research] and try to use the synergies (Veronika).

My participants also refer to significant events in their career

> I had these two supervisors … who also were Danish language teachers. They had a lot of focus on language … and then ever since I have had a lot of focus on language in science and mathematics (Sten).

Sten also narrates another significant event from a stay abroad, where he met a science supervisor who encouraged him to work extensively with practical work in the science lab. He recalls the instruction he was given:

> '*When you think you have investigated it sufficiently, then you make a report and then you take the next'*. So, there was much more freedom. And there were much in the teaching that dealt with experimental methods, contrary to what I was used to back at University in Denmark (Sten).

Stens work with coming physics teachers is based on a lot of practical experimental work in the science lab, so Sten has implemented his own experience with lab work in his praxis. He emphasizes the importance of his science teacher students to be comfortable working with experiments themselves and together with students in school.

Some of my participants work with in-service training of school science teachers and how their former career as a school science teacher eases them in their role as a broker for school science teachers in their professional development.

> Well, I love to do continuous education for teachers, but that is also because I have been doing it for so many years. And I have been a colleague with them. I can see that some of the new young ones [science teacher educator colleagues] that come the university way, they hurt themselves on them [school teachers]. Really schoolteachers are the most critical race you can teach, but that is because they sit in it [teaching] daily themselves (Lars).

Table 4. Summary of how work and life relate in science teacher educator roles seen in my participants career narratives.

Teacher of teachers	Broker	Researcher
Commitment in the relation to teacher students using own teacher experience.	Relation to teachers - Own experience as a teacher.	Experience with research: - Prior to entering teacher education

Focus on making science teacher students comfortable with doing practical experimental work with school students based on own experience with science lab work.		- As a part of being a teacher educator

Conclusion

The presented voices indicate that science teacher educators' careers are influenced by significant professional events in their lives and that second order teaching has a strong position in their professional compass. There are general teacher educator aspects in the narratives e.g. relating to teacher students and schoolteachers, but there are also references to science education elements such as science modelling or experimental work and grand narratives of science like evolution as a red thread.

References

ATEE Empowering RDC (2024). R&D Empowering Teacher Education | ATEE (visited 21-1-2026).

Departmental order on teacher educator qualification (2025). Bekendtgørelse om lektorkvalificering, lektorbedømmelse og docentbedømmelse af undervisere ved erhvervsakademier, professionshøjskoler, Danmarks Medie- og Journalisthøjskole og visse maritime uddannelsesinstitutioner (visited 21-1-2026).

Daugbjerg, P. (2013). *The entanglement of science teacher's lives and work*. Aalborg University Press. 220 pages.

Duch, H., Larsen, V. & Lund , B. (2021) FoU i lektorkvalificering og dets betydning for undervisning. *Scandinavian Journal of vocations in development.* Vol. 6, No. 1 2021, side 1–17, ISSN: 2464-4153 - https://doi.org/10.7577/sjvd.3909.

Ellebæk, J. J., Dolin, J. and Daugbjerg, P. (2022) *Den dobbelte didaktiske dimension – i læreruddannelses naturfag*, NAFA, 34 pages. Microsoft Word - PD_DDD i CESE skabelon - delrapport.docx (visited 21-1-2026).

Fisher, R. and Powell, D. Eds. (2023) *The lives and work of 12 further education based teacher educators in England*, University of Huddersfield Press, 88 pages.

Goodson, I, and Sikes, J. (2001) *Life history research in educational settings*, Open University Press, 126 pages.

Guberman, A., Ulvik, M., MacPhail, A. & Marchand, H. O. (2021) Teacher educators' professional trajectories: evidence from Ireland, Israel, Norway and the Netherlands, *European Journal of Teacher Education*, 44:4, 468-485, DOI: 10.1080/02619768.2020.1793948

Holdsworth, P. (2021) Being a reflective educator: professionalism or a pipe dream? In Swennen, A. and White, E. (Eds.), *Being a teacher educator* (pp. 10-26). Routledge 180 pages.

Horsdal, M. (2011) *Telling lives*, Routledge, 184 pages https://doi.org/10.4324/9780203805046

InFo-TED (2024) *International Forum for Teacher Educator Development* Home - InFo-TED (visited 21-1-2026)

Jaworski, B. & Wood, T. (Eds). (2008) *The Mathematics Teacher educator as a developing professional*, Sense Publishers, 360 pages.

Lorist, P. & Swennen, A. (2016) *Life and work of teacher educators*, HU University of Applied Sciences Utrecht, 44 pages.

Lunenberg, M., Dengerink, J., Korthagen, F., Attema-Noorderwier, S., Geursen, J. & Koster, B. (2014a) The Dutch case. In Lunenberg et al 2014b *The professional teacher educator* (pp. 79-103) Sense Publisher 166 pages.

Lunenberg, M., Dengerink, J. & Korthagen, F. (2014b) *The professional teacher educator* Sense Publisher 166 pages.

Nielsen, B. L. (2022) *Survey til kortlægning af kompetenceudviklingsbehov blandt naturfaglige læreruddannere i Danmark* Naturfagsakademiet, ISBN-pdf: 978-87-93894-37-2, 23 pages. Microsoft Word - 9788793894372_Survey til kortlægning af kompetenceudviklingsbehov blandt naturfaglige læreruddannere i Danmark.docx (visited 21-1-2026).

Swennen, A. & White, E. eds. (2021) *Being a teacher educator*, Routledge 180 pages.

Tack H., Guberman, A., MacPhail, A. & Vanderlinde, R. (2023): Higher education-based teacher educators' researcherly disposition: An international perspective, *European Journal of Teacher Education*, DOI: 10.1080/02619768.2023.2195974

Traianou, A. (2007) *Understanding teacher expertise in primary science*, Sense publisher 166 pages.

White, E. & Timmermans, M. (2021) *The teacher educators handbook*, Critical Publishing, 82 pages.

EUROPEAN SCIENCE EDUCATION RESEARCH ASSOCIATION ESERA 2025 Copenhagen

Examining Pre-Service Chemistry Teachers' Perceptions About Their Interactions With Mentors And Peers During The COVID-19 Pandemic

Paulo A. C. Loureiro[1], Luciane Goes[2] and Carmen Fernandez[2]
[1]University of Georgia (UGA), USA
[2]University of São Paulo (USP), Brazil

This study explores the pre-service chemistry teachers' perception of mentoring relationships within the context of the Brazilian Pedagogical Residency Program (PRP), focusing particularly on the challenges posed by the COVID-19 pandemic and the shift to remote learning. The PRP, a public policy designed to enhance teacher training, pairs pre-service teachers with experienced in-service mentors and fosters peer mentoring to develop practical teaching skills. This study investigates how these mentoring relationships contributed to the development of pre-service teachers' teaching practices, especially considering challenges posed by the pandemic. Two key research questions were addressed: the role of in-service mentors and peers in shaping teaching practices, and how the pandemic affected these mentoring relationships. Data were collected through interviews, experience reports, and audiovisual recordings from six pre-service teachers who participated in the PRP between 2020 and 2022. The findings emphasize the essential role of in-service mentors in providing guidance; however, communication barriers were enhanced by the remote learning context. Although peer mentoring emerged as a valuable source of emotional and professional support, the physical absence of mentors led to more superficial mentor-mentee interactions. The study underscores the importance of strong communication and deeper engagement in mentoring relationships, particularly during times of crisis. It also suggests that future improvements in mentoring training and program design could enhance the effectiveness of teacher training programs. The research contributes to understanding how mentoring dynamics influence pre-service teacher development and provides insights for refining educational policies in Brazil and beyond.

Keywords: Pre-service teacher education, Professional development, Educational Policy

Introduction

Mentoring is discussed in the literature from different perspectives. More traditional and classical views of mentoring consider it as a process where knowledge is transferred from the mentor to the mentee in a more hierarchical manner (Spooner-Lane, 2017). In contrast, more modern views emphasize a collaborative and mutually beneficial approach to educational mentoring (Larsen et al., 2023).

Regardless of which perspective researchers align with, they consistently highlight the importance of the relationship between mentors and mentees in the mentoring process. In this context, Brazil has recently implemented public policies that describe mentoring programs for pre-service teachers, such as the Brazilian Pedagogical Residency Program (PRP). Science pre-service teachers have been a primary focus of educational policies, particularly due to alarming university dropout rates. Research attributes this high rate the absence of active and interdisciplinary teaching and learning strategies (Silva & Figueiredo, 2018).

Additionally, pre-service teachers in Brazil have a highly demand coursework that requires them to take pedagogical core courses while also taking content-specific pedagogical courses and content-specific courses, contributing to these rates. Previous studies indicate that challenges in mathematics-related coursework may contribute to science pre-service teachers drop-out rates (Heusel et al., 2023). With that said, it is important to have a deep understanding of how these

new policies, focused on mentoring programs, are influencing student-teachers to persist in and complete their degrees.

Since the onset of the COVID-19 pandemic in 2020, much has been discussed about its impact on fields such as education and pre-service teacher training. However, little is known about how it may have hindered mentoring programs like PRP. This investigation draws on data from this period, which adds uniqueness and importance to understanding whether and to what extent the pandemic may have affected pre-service teachers' experiences in a mentoring program.

This study aims to identify aspects of the relationship between mentors (in-service teachers) and mentees (pre-service teachers) that may have provided support to the mentees as they began their teaching practices, according to their perspectives. Two research questions are posed:

RQ1: According to pre-service chemistry teachers' perceptions, what role did in-service teacher mentors and peers play in helping them develop better teacher practices?

RQ2: According to pre-service chemistry teachers' perceptions, how did the pandemic and the remote learning context hinder their relationships with peers and in-service teacher mentors?

Framing

Teacher Perception

In Science Education literature, studies frequently draw on teachers' and students' perceptions to analyse experiences, practices, and learning environments. However, despite its widespread use, the concept of perception is often taken for granted and remains theoretically underdefined. In this study, perception is understood not as a passive registration of events, but as an active cognitive process through which individuals interpret, organize, and attribute meaning to their experiences.

From a cognitive perspective, perception is grounded in prior experiences and embodied interactions with the world. According to Kiefer and Trumpp (2012), perception and cognition are inseparable, as cognitive processes are rooted in sensorimotor experiences accumulated over time. This embodied view suggests that individuals do not merely perceive situations as they are, but rather reconstruct them based on previous experiences, actions, emotions, and contextual cues. Thus, what pre-service teachers perceive in mentoring relationships is shaped by their trajectories, expectations, and the specific conditions under which those interactions occur.

Goldstone et al. (2010) further argue that perception is not limited to what is immediately visible or apparent. Instead, perception is educable and adaptable, evolving as individuals learn to attend to features of situations while ignoring others. In educational contexts, this means that learners and teachers develop perceptual frameworks that guide how they interpret complex environments, such as classrooms, professional relationships, or collaborative practices.

Importantly, this perspective challenges the idea that perception is superficial or opposed to deeper understanding. As Goldstone et al. (2010) demonstrate, perceptual processes can be aligned with conceptual reasoning, allowing individuals to make sense of abstract or complex phenomena through learned interpretive lenses. In teacher education, this implies that pre-service teachers' perceptions of mentoring and peer interactions are not merely subjective impressions, but meaningful constructions that reflect how they make sense of professional learning experiences.

Literature Review

Mentoring Relationships

As previously stated, mentoring relationships are extremely important to determine the efficacy of a mentoring program. In science teacher education, these relationships are even more important, because teachers need to envision classrooms as communities of practice. Teachers need to envision science classrooms that engage students with learning science as communities. Mentor-mentee effective relationships can help pre-service teachers to develop the skills they need to build such classroom environments (Abed & Abd-El-Khalick, 2015).

The literature on mentoring in teacher education presents both traditional and contemporary perspectives that reflect different assumptions about learning, professional development, and the roles of mentors and mentees. More traditional views conceptualize mentoring as a hierarchical process in which knowledge, norms, and practices are transmitted from a more experienced teacher to a novice in a largely unidirectional manner (Spooner-Lane, 2017). In this model, the mentor is positioned as an expert whose primary role is to guide, evaluate, and support the mentee's adaptation to the profession.

In contrast, more recent approaches frame mentoring as a collaborative and mutually beneficial process, emphasizing dialogue, shared reflection, and co-construction of professional knowledge (Larsen et al., 2023). From this perspective, mentoring is understood as a relational practice in which both mentors and mentees actively negotiate meanings, roles, and expectations. Rather than focusing solely on transmission of established practices, contemporary mentoring models highlight reciprocity, trust, and professional learning for all participants involved.

Despite differences in conceptualization, researches indicates that mentored teaching practice can be a powerful component of initial teacher education. Studies have shown that mentoring by experienced teachers can support pre-service teachers in developing pedagogical skills, professional confidence, and a sense of belonging to the teaching profession (Spooner-Lane, 2017). However, the literature also cautions that mentoring is not inherently beneficial. Ineffective mentoring relationships, characterized by poor communication, limited feedback, or misaligned expectations, can negatively impact teacher development and, in some cases, be more detrimental than the absence of mentoring altogether (Tuma et al., 2021).

Effective communication emerges as a central element in productive mentor–mentee relationships. Roehrig et al. (2008) emphasize that frequent and meaningful interactions between mentors and mentees enable pre-service teachers to reflect on practice, receive targeted feedback, and emulate effective teaching strategies. Communication that is dialogic rather than prescriptive allows mentees to engage more deeply with their professional learning and to critically examine their instructional choices.

In the context of science teacher education, mentoring relationships assume particular importance. Preparing science teachers involves more than developing general pedagogical skills; it requires helping future teachers envision science classrooms as communities of practice in which students actively engage in inquiry, modelling, argumentation, and collaborative knowledge construction. Abed and Abd-El-Khalick (2015) argue that effective mentoring can support pre-service science teachers in developing the pedagogical and epistemic skills necessary to foster such classroom environments. Through observation, modelling, and reflective dialogue, mentors can help mentees align their teaching practices with contemporary goals of science education.

COVID-19 And Science Teacher Education

The COVID-19 pandemic profoundly disrupted science teacher education worldwide, challenging established assumptions about teaching, learning, and mentoring. Central to these challenges was the difficulty of enacting science-as-practice approaches, widely emphasized in contemporary science curricula, which rely on classroom interaction, inquiry, collaboration, and situated engagement with scientific practices. In remote and hybrid learning contexts, ensuring meaningful engagement with science practices became particularly challenging for both in-service and pre-service teachers (Haidusek-Niazy et al., 2023).

Scholars have raised critical questions about whether online and remote experiences can effectively support the development of pre-service science teachers' capacity to enact core instructional practices. Campbell et al. (2021) argue that practice-based approaches to science teacher education, such as rehearsals, approximations of practice, and clinical experiences, were significantly constrained during the pandemic. The abrupt shift to remote instruction limited opportunities for pre-service teachers to engage in authentic classroom environments and to interact with students in ways aligned with inquiry-oriented and justice-informed science teaching.

In Brazil, the pandemic had a particularly strong impact on pre-service teachers enrolled in programs that relied on school-based experiences. Student teachers who were expected to be physically present in schools were suddenly removed from classroom contexts, restricting their opportunities to familiarize themselves with school routines, student interactions, and the social dynamics of teaching. As a result, mentoring relationships, traditionally grounded in shared physical spaces and *in situ* observation, were reshaped by the hinderances of remote interaction.

At the same time, the pandemic context gave rise to new forms of mentoring and professional support. Haidusek-Niazy et al. (2023) document the emergence of peer mentoring and reverse mentoring practices during the COVID-19 crisis, particularly in technologically mediated environments. In many cases, pre-service and early-career teachers supported more experienced mentors in navigating digital tools and online teaching platforms, temporarily reversing traditional hierarchical roles. Additionally, peer mentoring among teachers became a critical source of emotional, pedagogical, and technological support, often compensating for weakened or disrupted formal mentoring structures.

Understanding pre-service teachers' perceptions of mentoring and peer interactions during this period is therefore essential for capturing how science teacher education was reconfigured under pandemic conditions. By examining these perceptions, this study contributes to ongoing discussions about the possibilities and limitations of mentoring in times of crisis and offers insights into how alternative mentoring arrangements may inform future models of science teacher education.

Methodology

The Brazilian Pedagogical Residency Program (PRP) is a public policy in Brazil aimed at enhancing pre-service teacher training by immersing participants in the teaching routine during the final three semesters of their undergraduate studies, as part of their student teaching. Participants collaborate with experienced in-service teacher mentors at designated schools, engaging in tasks such as observations, lesson planning, and reflective practice. A unique feature of the PRP is its emphasis on collaboration, where pre-service teachers also act as peer mentors,

discussing and criticizing each other's lesson plans to foster critical reflection and practical skill development.

This study involved six pre-service chemistry teachers with no prior teaching experience who participated in the PRP between 2020 and 2022. Part of the program took place during the COVID-19 pandemic, when activities were conducted through emergency remote learning. This context required a nuanced analysis, as mentoring relationships and teaching practices were shaped by the constraints of remote interaction.

Data were collected through audiovisual recordings, written experience reports, and semi-structured interviews. All ethical procedures were followed, including the signing of informed consent forms granting permission for data use. To ensure anonymity, participants' names were replaced with pseudonyms throughout the analysis.

The data were coded focusing on pre-service teachers' perceptions of their relationships with mentors and peers (Saldaña, 2025). Coding was conducted inductively, allowing categories to emerge from the data in alignment with the research questions. This process supported an in-depth examination of how participants interpreted their mentoring experiences.

From this, we looked for themes that described the codes through thematic analysis (Clark & Braun, 2017). Initial coding was conducted individually, with categories refined through iterative revisions of the dataset. Two researchers independently analysed the data and subsequently discussed the findings to reach consensus, ensuring rigor, reliability, and validity in the qualitative analysis (Kuckartz, 2014).

From this process, three main themes emerged: (i) Navigating Support in Relationships with In-Service Mentors; (ii) COVID-19 Enhanced Challenges; and (iii) Peer Mentoring as a "Safe Space".

Findings And Discussion

Navigating Support In Relationships With In-Service Mentors

Pre-service teachers recognized the value of in-service mentors, particularly for lesson planning and for understanding the constraints and possibilities of the school context. Mendeleev emphasizes that mentors' classroom experience and familiarity with school routines were crucial for planning intervention activities. This support helped pre-service teachers situate their proposals within the realities of the school environment.

In addition to practical guidance, mentors were perceived as open and supportive in their interactions. According to Oppenheimer, "I always felt that the preceptors were present and interested, and were willing to help, you know?!" (Oppenheimer, Interview 1). At the same time, the pre-service teacher highlights that this support was accompanied by freedom to innovate, as mentors encouraged discussion and autonomy in planning activities: "[...] they [in-service teachers] were willing to discuss, I felt this freedom for us to come up with whatever we wanted" (Oppenheimer, Interview 1).

Together, these perceptions suggest that mentors played an important role by balancing guidance with autonomy. Even within a remote or hybrid context, pre-service teachers valued mentors' contributions to planning and decision-making, particularly when these interactions allowed space for dialogue and creative pedagogical choices.

COVID-19 Enhanced Challenges

Despite recognizing the importance of mentors, pre-service teachers pointed out two main concerns that hindered their experience in the PRP: communication and superficiality in

relationships. Communication issues were especially evident in the early stages of the program, when the teachers were often absent from weekly group meetings. According to the participants, this absence negatively affected coordination and planning processes.

Oppenheimer recalls a specific situation in which communication failures directly impacted the development of activities: “I remember one of the preceptors did not respond to one of my colleagues, I don't remember who it was. The person sent him an audio message, and he never listened to it, so there was a communication failure in the planning” (Oppenheimer, Interview 1). Such episodes reinforced the perception that maintaining open communication channels was particularly challenging during remote interactions.

In addition to communication barriers, pre-service teachers described their relationships with mentors as superficial. Enrico explains that his contact with the teachers was largely restricted to PRP-related activities, which limited deeper interaction and integration. He acknowledges that failures occurred on both sides, particularly regarding communication, which contributed to this sense of distance.

This superficiality, however, does not appear to be identified as the core problem, but rather because of communication challenges and contextual constraints. Marie reflects on the organization of the subproject’s weekly meetings, noting that greater participation from the teachers could have strengthened relationships with the undergraduates. Pre-service teachers also demonstrated understanding of the broader context, recognizing that the pandemic and emergency remote teaching likely reduced in-service teachers’ availability. As Enrico reflects, “I don't think I pursued enough, and I say this also because I already thought the teachers were too overwhelmed with the pandemic” (Enrico, Interview 1).

Marie further elaborates on these challenges in her supervised internship report, acknowledging that access to mentor teachers was compromised by remote and hybrid teaching conditions. However, she suggests that the issue extended beyond availability alone: “The remote teaching thing is really bad. [...] I had no direction, but so did the teachers, because the Department of Education wanted something every time” (Marie, Report).

Previous studies indicate that mentoring by experienced teachers can be a valuable component of initial teacher education (Can-Kucuk et al., 2022), while ineffective mentoring can hinder mentees’ experiences (Tuma et al., 2021). In line with these findings, the results of this study reveal how disrupted communication and limited interaction constrained mentoring relationships during the pandemic. Even so, pre-service teachers continued to recognize the importance of mentors, while acknowledging that the lack of physical presence and sustained interaction hindered the development of deeper professional relationships.

Peer Mentoring As A “Safe Space”

In contrast to the challenges experienced with in-service mentors, pre-service teachers consistently described peer interactions as supportive and meaningful. Boyle highlights the contribution of peers to lesson planning during weekly meetings, which he viewed as particularly positive. According to him, collaborative planning enabled exposure to different perspectives and enriched decision-making: “planning a group teaching sequence was interesting, because the conversation between the three of us [pre-service teachers] during the process of preparing the classes allowed for contrasting views on the same subject in favor of student learning” (Boyle, Report).

Peer meetings were also described as safe spaces for discussion and reflection. Mendeleev explains that videoconferences with other participants in the subproject felt comfortable because

the group members were already familiar with one another. This sense of familiarity fostered openness and trust, encouraging participants to share ideas and concerns freely.

Marie reinforces this perception, emphasizing the collaborative nature of peer discussions: “We [pre-service teachers] brought the ideas we had, the other colleagues discussed them, I thought it was really good, really positive” (Marie, Interview 1). The longevity of their relationships and shared experiences within the program contributed to a sense of safety that supported reflection and mutual learning.

These findings align with previous research suggesting that informal mentors, such as peers, can provide important emotional and professional support during teacher preparation (Desimone et al., 2014). While in-service teachers offered practical knowledge about school contexts and constraints, peers played a complementary role by creating spaces for dialogue, emotional support, and collaborative sense-making. Together, these different forms of mentoring contributed to pre-service teachers’ professional learning during a particularly challenging period.

The findings of this study highlight the importance of informal mentoring, particularly among peers, as participants reported feeling safe to express their opinions about lesson plans and teaching activities developed by others. This sense of safety appears to be central to peer mentoring interactions, enabling open dialogue, critical reflection, and mutual support during the planning process. The idea of a safe space for discussing pedagogical ideas is not limited to peer mentoring but is fundamental to mentoring relationships more broadly, as previously emphasized by Luft et al. (2022).

Although the emergence of peer and reverse mentoring during the COVID-19 pandemic has been discussed in the literature (Haidusek-Niazy et al., 2023), these forms of mentoring have been primarily examined among in-service teachers. The findings of the present study extend this discussion by showing that peer mentoring also played a central role among pre-service teachers, functioning as a critical source of pedagogical and emotional support during emergency remote teaching.

These results also reaffirm that teachers’ autonomy was significantly constrained during the pandemic by institutional, technological, and regulatory demands (Campbell et al., 2021). In this context, older educators, who traditionally served as mentors, were often overwhelmed by the need to adapt to new technologies, limiting their capacity to provide sustained support to novice teachers (Kraft et al., 2020). As a result, peer mentoring among pre-service teachers emerged not only as complementary practice but as a necessary space for professional learning and sense-making in a period of crisis.

Conclusions

Overall, the pre-service teachers recognized the value of both in-service mentors and peers in their professional development. Mentors contributed primarily through professional guidance, offering feedback on lesson planning and classroom activities that supported reflection on pedagogical practices. These interactions helped pre-service teachers identify strengths and areas for improvement, reinforcing the importance of experienced teachers in initial teacher education.

This appreciation underscores the role of mentoring programs such as the Brazilian Pedagogical Residency Program (PRP) in strengthening the connection between universities and schools. By immersing pre-service teachers in school contexts, the PRP provides opportunities for situated learning, collaborative reflection, and engagement with the realities of teaching. At the same time,

the findings suggest that mentoring relationships are central to how pre-service teachers make sense of these experiences and adjust their practices.

The COVID-19 pandemic, however, significantly reshaped mentoring dynamics within the program. Communication difficulties and limited interaction hindered the development of deeper mentor–mentee relationships, often resulting in more superficial exchanges. These challenges were largely attributed to emergency remote teaching conditions, institutional demands, and the overload experienced by in-service teachers during the pandemic.

Despite these constraints, peer mentoring emerged as a strong and consistent source of support. Pre-service teachers described peer interactions as safe spaces for sharing ideas, expressing concerns, and collaboratively reflecting on teaching practices. Even in a context marked by uncertainty and disruption, peer relationships helped sustain professional learning and emotional support, highlighting the relevance of informal mentoring structures in teacher education.

Taken together, these findings point to the need for future research and program design to place greater emphasis on mentoring skills, particularly communication and expectation-setting. Further studies should expand the scope of analysis to explore the broader mentoring context in teacher education programs and investigate how peer mentoring can be intentionally fostered among pre-service teachers. Strengthening mentoring practices, both formal and informal, may enhance the quality of science teacher education and contribute to the long-term success of public policies such as the PRP.

Acknowledgement

The authors are grateful for the financial support, Grants #2013/07937-8, #2021/03489-7, and #2022/09243-2 São Paulo Research Foundation (FAPESP) and #312017/2021-9 National Council for Scientific and Technological Development (CNPq).

References

Abed, O. H., & Abd-El-Khalick, F. (2015). Jordanian Preservice Primary Teachers' Perceptions of Mentoring in Science Teaching. *International Journal of Science Education, 37*(4), 703–726. https://doi.org/10.1080/09500693.2015.1010629

Campbell, T., Melville, W., Verma, G., & Park, B. Y. (2021). On the Cusp of Profound Change: Science Teacher Education in and Beyond the Pandemic. *Journal of Science Teacher Education, 32*(1), 1–6. https://doi.org/10.1080/1046560X.2020.1857065

Can-Kucuk, D, Gencer, S., Akkus, H. (2022). Development of pre-service teachers' pedagogical content knowledge through mentoring, *Chemistry Education Research and Practice*, *23*, 599-615.

Clarke, V., & Braun, V. (2017). Thematic analysis. *The Journal of Positive Psychology*, *12*(3), 297–298. https://doi.org/10.1080/17439760.2016.1262613

Desimone, L. M., Hochberg, E. D., Porter, A. C., Polikoff, M. S., Schwart, R., & Johnson, L. J. (2014). Formal and informal mentoring: Complementary, compensatory, or consistent? *Journal of Teacher Education*, *65*(2), 88-110.

Goldstone, R.L., Landy, D.H. and Son, J.Y. (2010). The Education of Perception. *Topics in Cognitive Science*, *2,* 265-284. https://doi.org/10.1111/j.1756-8765.2009.01055.x

Haidusek-Niazy, S., Huyler, D. & Carpenter, R.E. (2023). Mentorship reconsidered: A case study of K-12 teachers' mentor-mentee relationships during the COVID-19 pandemic. *Social Psychology of Education, 26,* 1269–1288. https://doi.org/10.1007/s11218-023-09788-w

Heusel, L., Glaesser, J., Kilian, P., Merk, S., & Kelava, A. (2023). Comparing dropout intentions of math students on trainee teacher courses versus bachelor of science courses using intensive longitudinal data. *Frontiers in Education*, 8, 1205949. https://doi.org/10.3389/feduc.2023.1205949

Kiefer, M. & Trumpp, N. (2012). Embodiment theory and education: The foundations of cognition in perception and action. *Trends in Neuroscience and Education, 1*(1), 15-20.

Kraft, M., Simon, N., & Lyon, M. (2020). *Sustaining a sense of success: The importance of teacher working conditions during the COVID-19 pandemic* (EdWorkingPaper No. 20-279). Retrieved August 18, 2025, from https://www.edworkingpapers.com/sites/default/files/ai20-279.pdf

Kuckartz, U. (2014). *Qualitative text analysis: A guide to methods, practice & using software.* SAGE Publications. https://doi.org/10.4135/9781446288719

Larsen, E., Jensen-Clayton, C., Curtis, E., Loughland, T., & Nguyen, H. T. M. (2023). Re-imagining teacher mentoring for the future. *Professional Development in Education*, 1–15. https://doi.org/10.1080/19415257.2023.2178480

Luft, J. A., Navy, S. L., Wong, S. S., & Hill, K. M. (2022). The first 5 years of teaching science: The beliefs, knowledge, practices, and opportunities to learn of secondary science teachers. *Journal of Research in Science Teaching, 59*(9), 1692–1725. https://doi.org/10.1002/tea.21771

Roehrig, A. D., Bohn, C. M., Turner, J. E., & Presselly, M. (2008). Mentoring beginning primary teachers for exemplary teaching practices. *Teaching and Teacher Education, 24*(3), 684–702.

Saldaña, J. (2025). *The Coding Manual for Qualitative Researchers* (5th ed). SAGE.

Silva, K.N., Figueiredo, M.C. (2018) Curso de licenciatura em química: motivações para a evasão discente. *ACTIO: Docência em Ciências, 3*(2), 237-254. https://doi.org/10.3895/actio.v3n2.7441

Spooner-Lane, R. (2017). Mentoring beginning teachers in primary schools: research review. *Professional Development in Education*, *43*(2), 253-273.

Tuma, T. T., Adams, J. D., Hultquist, B. C., & Dolan, E. L. (2021). The Dark Side of Development: A Systems Characterization of the Negative Mentoring Experiences of Doctoral Students. *CBE Life Sciences Education*, *20*(2), Article ar16. https://doi.org/10.1187/cbe.20-10-0231

EUROPEAN SCIENCE EDUCATION RESEARCH ASSOCIATION ESERA 2025 Copenhagen

Physics as Culture: Dialogues for a Critical and Sustainable Teacher Education

Jéssica dos Reis Belíssimo, Roberto Nardi and Geovana dos Reis Belíssimo
São Paulo State University, Brazil

The progress toward a sustainable society, focused on building a viable and equitable future, has become a key issue on the international stage. According to research in the field, tackling this difficulty requires a focus on culture as well as the development of critical, reflective educators. In the context of physics teacher preparation, it is critical that potential educators get an in-depth comprehension of physics as both, a scientific subject and a cultural construct. This study sought to investigate the fundamental components involved in the foundational training of physics educators, with the goal of suggesting methods that promote sustainable scientific education rooted in the recognition of physics as a vital part of culture. We examined the discourses of undergraduate physics students, gathered through a questionnaire, to accomplish this. The analysis was conducted using Pêcheux's Discourse Analysis, with the assistance of theoretical frameworks in physics pedagogy and teacher education. The attendees mainly view physics to elucidate natural occurrences, largely overlooking the historical, social, ideological, and philosophical dimensions that shape the discipline. This viewpoint highlights an absence of thoughtful consideration among upcoming educators. The arrangement of the undergraduate curriculum, frequently divided into distinct sections, could play a role in these patterns, and impede the cultivation of critical thinking skills. As a result, the research emphasizes the necessity of developing curricular strategies in the early training of physics educators that foster critical, transformative, and sustainable scientific education.

Keywords: Physics as culture, sustainable development, teacher training.

Introduction

The development of a sustainable society, committed to constructing a feasible and equitable future, has emerged as one of the foremost global imperatives. Inspired by the need to tackle complex sustainability issues spanning economic, social, environmental, and ethical domains, the United Nations (UN) drafted a landmark report titled "The 2030 Agenda for Sustainable Development" (UN, 2015).

In this sense, the exploration of culture's influence in promoting an engaged, sustainability-focused community has garnered significant academic attention and discussion. Viesba-Garcia et al. (2019) argue that sustainability education helps society move from its existing state to a more desired reality based on sustainable principles. Culture emerges as a critical component in this process, given its essential function in facilitating societal adaptability, stimulating the production of new knowledge, and consolidating values and traditions aligned with sustainability. Thus, achieving sustainable development is deeply connected to the cultural evolution and appreciation of communities—a process facilitated through education.

The initial education of physics teachers, grounded in the principles of cultural integration and sustainable development, is predicated upon the practice of critical reflection. Freire (2020) asserts that critical reflection enables educators to engage in a deeply meaningful process of professional self-recognition, which is actualized through the integration of cultural elements. When looking at how to train physics teachers using critical reflection as a framework, Nardi & Castiblanco (2018) emphasize that the teaching of Physics Didactics must develop methodologies capable of addressing content in ways that cultivate undergraduates' critical thinking skills, thereby empowering them to construct independent understandings of teaching practices. Lima

& Bozelli (2024) further argue that critical reflection positions teachers as intellectual agents who fulfill a vital social role by creating, promoting, and disseminating cultural knowledge.

Given these considerations, the present study seeks to investigate key aspects of the initial education of physics teachers, with the aim of delineating strategies conducive to a sustainable scientific education framework that is deeply rooted in the conceptualization of physics as culture.

Physics As Culture In The Education Of Critical Intellectual Teachers

One of the pioneers in Brazil to explore the importance of critical reflection in teacher education was the educator Paulo Freire. In several of his works (Freire, 2019; 2020), he expressed that the transformation of the contemporary world occurs through the critical reflection and action of men and women upon the world. In dialogue with these perspectives, Giroux (1997) argues that educational practice grounded in critical reflection provides educators with greater autonomy, in favor of an education rooted in the struggle for the transformation of social reality, aiming to overcome economic, social, and political injustices. Contreras (2002), in turn, when considering a model of teacher education grounded in critical reflection, conceives the teacher as a transformative intellectual, whose pedagogical action is intrinsically connected to the promotion of social equity through the construction of a more democratic and sustainable society.

Thus, in deliberations regarding the inclusion of Physics as culture in the education of critically reflective teachers, the imperative emerges to conceive a Physics teaching process that incorporates a dynamic and active scientific culture, in accordance with the Freirean perspective, that is, one that seeks the transformation of the contemporary world toward a sustainable world. As observed by Zanetic (1990), this purpose implies consideration of certain conditions, including: (1) the improvement of teaching and learning processes so that students become capable of solving theoretical problems both in Physics and in everyday life; (2) the deconstruction of the veneration of the traditional scientific method that currently prevails; (3) the conceptualization of Physics as a component of social history, that is, Physics as it developed alongside historical events; and (5) the presentation of contemporary Physics and the explicit discussion of its relevance in the contemporary global context, since only through this approach is it possible to foster the perception of Physics as a cultural element.

In this context, the need emerges to attribute significance to the development of Physics and to its capacity to influence social transformation. Zanetic (1990) expresses concern regarding the economic, political, religious, and cultural aspects that make up the History of Physics. This is especially relevant, since, about culture, Science, particularly Physics, often remains invisible. From this perspective, culture is frequently restricted to literary works and artistic expressions such as painting, dance, and music, a direct consequence of the educational system, which does not contemplate the teaching of science as culture and thus contributes to alienating Physics from people’s everyday lived experience.

The deficiency in the development of a scientific culture is not a problem restricted to Brazil, but rather a reality observable in several countries, due to the promotion of a culture that becomes disconnected from reality. The connection between science and economic and social foundations is of great importance for understanding its role in the cultural context. It is through this interrelation that the construction of a Physics education that is both critical and pragmatic becomes possible.

For Zanetic (1990), the conception of Physics as culture requires the inclusion of externalist components, namely: influences of a socioeconomic nature, ideological approaches, formulations of scientific methods, the dynamic history of Physics, experimentation, scientific theories, and their practical applications. The integration of these elements is fundamental to confer concrete

relevance to Physics in the education of citizens. Another important aspect in considering Physics as a cultural component is interdisciplinarity, as it enables the integration of Physics with other fields of knowledge and with the world more broadly. Thus, as discussed by Nardi and Castiblanco (2018), it becomes necessary for teachers of this discipline to draw on other forms of knowledge beyond the specific Physics content learned at university, incorporating externalist components into their teaching practices.

Theoretical And Methodological Foundation

The foundation of this study's theoretical and methodological framework is rooted in Pêcheux's Discourse Analysis (DA), as described by Orlandi (2015), and is further enriched by insights from a theory of teacher education with a critical stance, as outlined by Freire (2020). Additionally, we integrated contributions from the physics education domain, drawing on the works of Nardi & Castiblanco (2018) and Zanetic (1990).

We collected the research data by administering a questionnaire with ten open-ended essay questions in a didactic-pedagogical course to final-year students enrolled in a physics degree program at a Brazilian public university. The data analysis was carried out by developing an analytical framework based on the theoretical and methodological principles discussed thus far. As highlighted by Orlandi (2015), the construction of an analytical framework enables the researcher to navigate the boundaries of interpretation and to delineate the research object with precision.

A total of 14 undergraduate students enrolled in the course participated in the study. Owing to space constraints, this research selected the discourses of four participants for dissemination. The selection was based on the representativeness of their responses in relation to the broader group of participants.

The principles of Discourse Analysis (DA) guided the construction of the corpus for analysis, aligning it with the objectives of this research. Orlandi (2015) emphasizes that theoretical, not empirical, criteria determine the selection of the corpus. This approach reflects the foundational premise of DA, which does not aim to encompass all empirical elements associated with the object of study but rather focuses on those elements that align with the specific analytical objectives at hand.

Discourse Analysis Of The Undergraduate Students

We developed two collaborative gatherings in this context. The first one sought to examine undergraduate students' understanding of the concept of physics, employing the following question as a point of departure: "How would you explain to a high school student what physics is?" Table 1 systematically organizes the responses provided by the undergraduate participants.

Table 1. Undergraduates (with fictitious names) give speeches about physics

NAMES	GRADUATES' RESPONSES TO THE QUESTION
Gisele	I would explain that physics is the ability to explain why "things" move.
Luana	I would explain that physics is a natural science that aids in our understanding of the world around us.
Marcos	Physics is a way of experiencing things.
Mario	I would explain that physics is the science that explains how the universe works based on energy transformations.

Undergraduate students' writings show that they think of physics mainly in terms of how it explains natural events, with its historical, philosophical, ideological, and social aspects being less important. This comprehension is intrinsically linked to the imaginative formations of physics and scientific knowledge that undergraduate students have developed because of their production experiences. Most students point to their initial exposure to physics during high school as predominantly instrumental, emphasizing the resolution of mathematical exercises and the memorization of concepts.

These findings are consistent with existing literature in the field. Undergraduates, according to Nardi and Castiblanco (2018), tend to look back on their high school experiences when reflecting on their basic education, particularly in cases when critical reflection is not effectively addressed in teacher preparation programs. Zanetic (1990) further highlights that the dissociation of Physics from its cultural dimensions can be attributed to the way the subject is taught in high schools. This teaching approach is typically focused on the "teaching/learning" process of solving exercises and problems, with limited attention given to experimentation, theoretical analysis, and the exploration of the historical and conceptual development of Physics as a field of knowledge.

Moreover, the discourses produced by undergraduate students reveal a noticeable gap in their engagement with an educational-critical approach, as these discourses fail to incorporate the historical, social, and political elements that influence the construction of scientific knowledge.

Building upon these considerations, we designed the second collaborative gathering to explore in greater depth how undergraduate students conceptualize the relationship between physics and culture. To this end, we presented the following question: "In your opinion, what is the relationship between Physics and culture? Please explain." Table 2 below systematically organizes the responses provided by the undergraduate students.

Table 2. Speeches by undergraduates (fictitious names) about physics as a culture

NAMES	GRADUATES' RESPONSES TO THE QUESTION
Gisele	I believe that every area of knowledge is a form of culture. This includes physics.
Luana	I believe that Physics is culture, as it is part of the knowledge produced by civilizations historically.
Marcos	In the same way that science and society are collaborative with each other, Physics and culture are too.
Mario	Physics explains sound and music… It explains the climate that governed the establishment of peoples in different regions, transforming customs and cultures.

Examining the discursive outputs of undergraduate students shows that they express their ideas through unique imaginary constructs, which can be generally categorized into two projection types. The initial category, as expressed by the perspectives of all undergraduate students aside from Gisele and Luana, perceives physics and culture as distinct realms, where one either influences or enhances the other. The second category, as articulated by Gisele and Luana, views physics as a manifestation of culture—an inseparable and inherent phenomenon It is necessary to acknowledge that physics reflects society to conceptualize it as culture. According to Zanetic (1990), the knowledge we acquire in science emerges from social interactions and reflects the cultural context in which it is developed. Scientific knowledge is an integral component of this culture, and it is both influenced by other fields of knowledge. Therefore, perceiving physics as culture implies recognizing it as a product of social dynamics.

In light of these considerations, it is evident that the imaginary formations which suggest a division between physics and culture align with the discussions outlined in our first collaborative gathering. Basic education, which primarily emphasizes the resolution of mathematical exercises, and the undergraduate physics curriculum, which organizes knowledge according to segmentation and the reflective teacher model, both influence these representations—and these educational structures may shape the way undergraduates perceive physics as a cultural element.

Consequently, it is understandable that, despite two undergraduates establishing a direct connection between physics and culture, the prevailing educational conditions do not provide sufficient opportunities to foster a comprehensive understanding of the social, historical, ideological, and political dimensions of science. Zanetic (1990) argues that Physics, as culture, cannot be divorced from "external" factors, such as socioeconomic influences, ideological frameworks, the "definitions" of scientific methods, and the dynamic history of physics. These elements are essential for supporting experimentation, scientific theories, and their applications. Thus, physics assumes a pivotal role as a fundamental cultural component in the formation of individuals in contemporary society.

Final Considerations

Overall, this study aimed to explore key elements related to the initial training of physics educators, with the goal of outlining guidelines that facilitate sustainable scientific education based on the understanding of physics as culture.

The discourse analysis revealed two distinct projections within the imaginaries of undergraduate students: one sees physics and culture as distinct entities, while the other regards physics as an integral and indivisible component of culture.

The first viewpoint’s key conceptions, which separates physics from cultural contexts, clearly support discussions about the impact of basic education, which frequently concentrates solely on mathematical exercises, as well as the structure of the undergraduate physics program, which divides knowledge into different components.

This fragmentation leads to an understanding of physics as culture within the initial training of physics teachers, but that is incomplete and devoid of its essential cultural dimensions. Although two students managed to link physics with culture in the second projection, their training conditions fall short of offering a solid basis for cultivating a complete awareness of the diverse contexts that influence physics.

Finally, based on the premise that critical reflection offers a promising approach for the appropriation of physics as culture, there arises a need to reconsider the organizational structure of undergraduate programs. Such a reevaluation is essential to create educational environments that foster discussions and critical reflections on the historical, social, philosophical, and ideological contexts of physics as a cultural subject. Critical, transformative, and sustainable scientific education must be a part of physics teacher preparation programs from the start.

Acknowledgement

The authors thank the Coordination for the Improvement of Higher Education Personnel (CAPES) and the National Council for Scientific and Technological Development (CNPq) for the financial support for the development and dissemination of the research.

References

Contreras, J. (2002). *Teacher autonomy*. Cortez.

Freire, P. (2020). *Pedagogy of autonomy: Knowledge necessary for educational practice* (63rd ed.). Paz e Terra.

Freire, P. (2019). *Pedagogy of the Oppressed* (71st ed.). Paz e Terra.

Giroux, H.A. (1997). *Teachers as intellectuals*: towards a critical pedagogy of learning. Porto Alegre: Artes Médicas.

Lima, A. C. A., & Bozelli, F. C. (2024). The didactic-pedagogical training of undergraduate physics students in a dual-modality context: some disagreements. *Ensaio Pesquisa em Educação em Ciências*, 26, e48740. https://doi.org/10.1590/1983-21172022240177

Nardi, R., & Castiblanco, O. (2018). *Didactics of Physics*. (2nd ed.). Escrituras.

Orlandi, E. P. (2015). *Discourse Analysis: Principles & Procedures* (12th ed.). Pontes.

Viesba-Garcia, E., Viesba, L. M., & Rosalen, M. (2019). Environmental Education for Sustainability: Focus on Continuing Education. *Humanidades & Tecnologia*, 16(1), 10-24. https://repositorio.unifesp.br/handle/11600/51759

Zanetic, J. (1990). *Physics is also culture* [Doctoral dissertation, University of São Paulo]. São Paulo: Faculty of Education, University of São Paulo.

EUROPEAN SCIENCE EDUCATION RESEARCH ASSOCIATION ESERA 2025 Copenhagen

Beyond Human Mentors – Exploring AI-Driven Reflection In Teacher Training

Jens Damköhler, Wolfgang Lutz and Thomas Trefzger
University of Würzburg, Germany

This paper reports on integrating AI-based reflection coaches into a Physics Teaching & Learning Lab in pre-service teacher education and examines how students relate this support to supervision. The intervention provided structured experience with generative AI while scaffolding reflection across cycles of preparation, school-class visits, reflection, and adaptation. We conducted guided end-of-course interviews with 12 of 13 participants and analysed the data using content-structuring qualitative content analysis complemented by a deductive marker analysis of relationship-relevant qualities. Students largely reported little to no direct impact of chatbot use on their supervisory relationships with the course lecturers and predominantly conceptualized the chatbot as a tool rather than an independent supervisor. At the same time, their accounts invoked relationship-relevant qualities, especially closeness (limited by boundary-setting and restricted availability), relatedness (a low-pressure space enabling reassurance before approaching lecturers), and genuineness (overly validating interaction styles perceived as inauthentic). Overall, chatbots may support reflection and indirectly shape relational dynamics, but do not substitute authentic human experience in supervision.

Keywords: Teacher education, Generative AI, Teacher-student relationships

Introduction

Generative AI tools such as chatbots are rapidly becoming part of educational practice and, consequently, a relevant topic for teacher education (OECD, 2026). However, early evidence from our context suggests that many pre-service teachers still gain little systematic experience with AI tools in their university courses, and that this lack of experience matters: students without prior use tend to report lower perceived competence/self-efficacy and a more cautious attitude toward AI, whereas experience with AI use is associated with greater confidence and a higher likelihood of future use (Lutz et al., 2025).

Against this background, we designed the present course innovation with the intention to first, provide physics teacher trainees with the opportunity to engage with AI tools in a didactically meaningful, structured way; and second, to explore whether such tools can productively support processes that are known to be central for teacher professional learning, most notably reflection on practice. Reflection is a core component of many practice-based formats, yet it is also resource-intensive: it requires time, individual attention, and sustained guidance, which is difficult to provide consistently in university courses.

Our intervention is embedded in an iterative Teaching & Learning Lab course format in which students design and realize experimental learning stations and repeatedly revise them across several school-class visits (see **Figure** 1 for the overall sequence).

To strengthen the reflection phases within this cycle, we integrated AI-based reflection coaches (custom GPTs) intended to guide students through structured reflective dialogues and to support concrete adaptations for subsequent realizations.

While research and public discourse often focus on performance, ethics, or learning gains, an equally important – yet less frequently examined – dimension concerns relationships in teacher education. Mentoring and supervision are inherently relational, and introducing an AI tool into

reflective support raises a subtle question: even if students only perceive the chatbot as a tool, might their descriptions still reveal relationship-relevant qualities (e.g., perceived closeness, relatedness, or genuineness) that shape how supervision is experienced? Prior work in our project suggests precisely such a pattern: students tend to report little direct change in their relationship with human mentors, yet they also articulate relationally meaningful experiences with the chatbot interaction (e.g., neutrality, emotional relief, and authenticity as a boundary) (Damköhler et al., 2025).

This paper addresses the following research questions:

- RQ1: How do physics student teachers describe the impact of chatbot-based reflection coaching on their supervisory relationship(s) with course lecturers?
- RQ2: How do students conceptualize the chatbot as an interaction partner (e.g., human-likeness and underlying conceptions of AI)?
- RQ3: Which relationship-relevant qualities do students invoke, explicitly or implicitly, when describing chatbot-supported reflection and supervision?

To answer these questions, we conducted guided interviews with course participants and analysed the data using content-structuring qualitative content analysis complemented by a deductive marker analysis of relationship-relevant qualities.

Theory

AI Literacy

As suggested by Lutz et al. (2025), guided and targeted engagement with AI tools and the positive experiences that may result from such engagement can contribute to students' confidence in their own capability to use AI effectively. To describe these competencies more precisely, the concept of AI literacy has been developed in analogy to established literacy frameworks; e.g., digital literacy, computational literacy, data literacy, scientific literacy (Long & Magerko, 2020). In this view, AI literacy captures not only functional use, but also the understanding and critical evaluation of AI systems in educational contexts.

One operationalization of this construct is provided by the Meta AI Literacy Scale MAILS (Carolus et al., 2023), which conceptualizes AI literacy as a set of competencies related to using and applying AI, understanding AI, detecting AI, and reflecting on ethical implications of AI use. Furthermore, it contains a concept of AI self-efficacy (which includes aspects of AI problem solving and AI learning) and AI self-competency (which is based on AI persuasion literacy and AI emotion regulation). In the present study, this framework served primarily as a basis for designing interview prompts that elicit students' experiences with chatbot-supported reflection.

Teacher-Student Relationships

While AI literacy provides a useful framework for understanding competencies needed for responsible and effective AI use, the present paper additionally draws on research on teacher-student relationships and related constructs. This is because chatbot-supported reflection may be experienced not only as a functional tool interaction, but also in terms of relationship-relevant qualities such as perceived closeness, relatedness, and genuineness that can shape how reflective support and supervision are approached. This relational lens is further supported by the 'Computers Are Social Actors' (CASA) perspective, which suggests that people may respond to computer-based interaction using social scripts and expectations, even when they are fully aware that they are interacting with a machine (Nass et al., 1994). Importantly, meta-analytic findings indicate that both positive and negative teacher-student relationships show medium-to-large

associations with students' engagement (and smaller but still significant links to achievement), underscoring why relational quality is central for learning processes (Roorda et al., 2011).

Attachment Theory

From an attachment perspective, relationships with significant adults can function as a secure base that enables exploration and learning. In educational contexts, this is often operationalized via dimensions such as closeness (warmth and openness), conflict, and dependency; closeness captures whether an interaction climate supports trustful, open communication (Pianta, 1999, 2001). In our context, this lens helps interpret students' answers regarding boundaries, availability, and interpersonal nuance as conditions that may limit or enable closeness – regardless of whether the interaction partner is framed as a tool or a person.

Self-System Theory / Self-Determination Theory

Drawing on the Self-Determination Theory, the satisfaction of three basic psychological needs – autonomy, competence, and relatedness – is considered fundamental for the development of supportive relationships (Ryan & Deci, 2000). In supportive educational relationships, relatedness is fostered when learners feel accepted and psychologically safe; autonomy is supported when guidance is non-controlling; and competence is supported through structure and feedback that enables progress. Applied to reflective support, SDT helps capture why students might value a "low-pressure" space (relatedness/safety), benefit from structured prompts (competence support), yet still insist on human mentoring for authenticity and situated judgement (Roorda et al., 2011).

Learner-Centred Teacher-Student Relationship

Research on teacher-student relationships highlights that relational quality is not a "nice-to-have" but a robust correlate of students' engagement and learning. Meta-analytic work shows that affective relationship qualities – especially warmth and support – are consistently associated with students' engagement and, to a smaller extent, achievement (Cornelius-White, 2007). For this paper, TSR provides a vocabulary for describing how supportive interactions are experienced which includes empathy, warmth, genuineness, nondirectivity, higher order thinking, encouraging learning/challenge, adapting to individual and social differences (Cornelius-White, 2007).

Course Design

Course Sequence Of The Teaching & Learning Lab

As previously described, the Physics Teaching & Learning Lab (TLL) at the University of Würzburg is organized as an iterative course format that connects university-based preparation with authentic teaching-related experiences in a secure framework (Damköhler et al., 2025; Völker & Trefzger, 2011). Over the semester, students design and run their own experimental learning station and accompany small groups of school students working on hands-on physics tasks. The course follows a recurring cycle of preparation (preparatory phase) – visits by school classes – reflection – adaptation (see Figure 1).

Figure 1. Structure of the TLL

During the preparatory phase, students develop an inquiry-oriented station including materials, instructions, and prompts that are suitable for a short, self-contained learning unit. The station is

then implemented during a visit by a school class, where the TLL is operated in a station-based format: each station is typically completed in 30 minutes by small groups of school students, and each student tutor runs their station about four times across the visit.

After each class visit, the teacher trainees enter a reflection phase in which experiences from implementation are documented, discussed, and analytically processed. This reflection is typically supported by the two lecturers, who provide feedback and help connect observations to instructional goals and design principles. Based on these reflections, students adapt their stations in a targeted way before the next implementation. This cycle is repeated across three class visits, with exactly two weeks between visits, allowing students to iteratively refine their station design and their instructional practice across successive realizations.

Implementing AI-Based Reflection Coaches

The AI-based reflection coaching was integrated into the reflection and adaptation phases of the TLL cycle. After each visit by a school class, the course provides a structured opportunity to analyse the previous run and to derive concrete improvements for the next implementation. The revised format was supported by individual dialogue-based coaching from two AI reflection coaches, while the overall course structure (reflection followed by targeted adaptation) remained unchanged.

These sessions with the AI-based reflection coaches took place in the two scheduled reflection/adaptation sessions following the first and second class visits. The chatbot-led dialogues were designed to (a) structure students' retrospective analysis of their station realization, (b) prompt justification and elaboration to deepen reflection, and (c) support the development of feasible adaptations for the next class visit. The two coaches were used with different focal points: one coach emphasized an analytic reflection on the quality of the implementation, while the other coach additionally promoted the deliberate evaluation of alternative options and encouraged a critical stance toward AI-generated suggestions.

Following the individual coaching dialogues, reflections were brought back to the course context: students summarized and contextualized their insights and planned changes, and these were then discussed regarding their suitability for the course structure and supported by the lecturers. In addition to the AI use for coaching purposes, the implementation also included a meta-level engagement with the technology in which students exchanged experiences and reflected on further effects of the technology (e.g., perceived boundaries of AI support, ethical considerations, and potential implications for supervision in the TLL).

Design And Development Of The Reflection Coaches

The reflection coaches were developed as customized chatbots based on GPT-4 using the GPT development environment within ChatGPT. Their design followed a principle of aligning coaching prompts with clearly specified theoretical foundations and with an anticipated structure of productive reflection dialogues. For both coaches, relevant background materials were provided and integrated so that the chatbots could explicitly draw on them during the conversation. The first coach was based on the framework of basic dimensions of teaching quality (Praetorius et al., 2018), while the second coach was based on Korthagen's onion model (Korthagen, 2004), a framework addressing teacher personality and professional development.

For each coach, the team first anticipated the course of a plausible coaching conversation based on the underlying theory and then decomposed it into smaller conversation blocks (i.e., coherent phases with specific functions such as eliciting a description of the implementation, probing for explanations, generating alternatives, or consolidating an action plan). The chatbots' behaviour was then specified through a combination of (1) the integrated theoretical background materials

and (2) systematic prompting: a precise role description (reflection coach), a set of general behavioural rules (e.g., guiding the dialogue, asking follow-up questions, supporting structured reflection), and block-specific instructions defining the intended interactional moves and goals within each phase of the dialogue.

Before student use, both coaches were subjected to pre-testing in simulated coaching conversations across different scenarios by several test persons. This iterative testing served to check whether the chatbots' guidance reliably instantiated the intended coaching structure, whether follow-up questions supported depth rather than superficial agreement, and whether the dialogue design consistently led to the intended outcome – namely, a justified reflection and a concrete plan for adaptation before the next class visit.

Method

Course Context And Sample

The study was conducted in the summer semester of 2024 in a Physics TLL at the University of Würzburg. The course was attended by 13 pre-service teachers; N = 12 of them participated in the evaluation study. Participation in the interviews was voluntary.

Data Collection

Data were collected through guided, semi-structured interviews which lasted approximately 10 to 15 minutes and were conducted at the end of the semester by the two course lecturers. The interview guide was developed with reference to the previously described MAILS framework (Carolus et al., 2023) and adapted to the specific course context. Rather than administering MAILS as a test, selected item formulations were used as prompts to recall students' experiences and perspectives regarding chatbot-supported reflection, including perceived differences between human and AI interaction and the perceived influence of chatbot use on their supervision-related conversations. For example, the MAILS item "I can distinguish if I interact with an AI or a 'real human'" was contextualized into an interview question about differences between a chatbot conversation and a conversation with a real person.

All interviews were audio-recorded and transcribed. Transcripts were lightly edited for readability (e.g., reducing fillers) without changing the intended meaning of statements.

Content-Structuring Qualitative Content Analysis

The material was analysed using content-structuring qualitative content analysis following Kuckartz und Rädiker (2022). As recommended in this approach, we defined the coding unit as a single sentence (i.e., the smallest textual unit to be assigned to a category), while consecutive sentences belonging together contextually served as the context unit. In line with Kuckartz, multiple coding was allowed.

To address the aims of the present paper, analysis proceeded in two coding passes.

First Coding Pass: Explicit Topical Categories (Guide-Based, Inductively Refined).

In the first pass, we organized students' explicit statements using a set of deductive top-level categories derived from the interview guide. These top-level categories captured the main topics addressed by the students and provided a structured overview of how students articulated their views. The deductive top-level categories were: (1) "Independent supervisor?", (2) "Differences to a real conversation?", (3) "Influence on conversations with lecturers?", and (4) "Changed relevance of lecturers?". Following the logic of content-structuring analysis, these categories were then refined inductively: subcategories were developed from the interview material to

capture the diversity of students' perspectives. Given the relatively small number of interviews and the high thematic variety, the category system was developed based on the entire dataset.

Second Coding Pass: Deductive Marker Analysis Of Relationship-Relevant Qualities.

A second coding pass focused on relationship-relevant qualities that students referred to implicitly or explicitly, even when they did not explicitly frame their statements as 'relationship' talk. This step was motivated by the observation that students often stated that chatbot use had little or no direct impact on their supervisory relationships, while simultaneously describing interaction qualities that are central to theories of teacher-student relationships. For this reason, we conducted a deductive marker analysis using a set of relationship-quality markers derived from three theoretical perspectives: attachment theory, learner-centred teacher-student relationship research, and self-system theory. Based on these frameworks, we developed a formalized codebook containing short definitions and anchor examples for each marker (e.g., closeness, relatedness, genuineness, higher-order thinking, encouraging learning). The codebook was used to identify segments indicating these qualities across the interviews.

Importantly, we did not build separate category families for different "targets" (e.g., student-chatbot vs. student-mentor). Instead, the same marker set was applied to segments referring to the chatbot, to lecturers, and to statements that remained unspecific with respect to a relationship partner. This approach reflects our analytic interest in students' relational expectations and interaction qualities in the context of reflective support, which can be articulated without explicitly naming the relationship partner.

Coding was conducted primarily by one researcher. Selected segments and ambiguous cases were discussed within the two-person research team until a shared interpretation was reached.

Results

All interview quotes were translated from German by the authors for publication. The translations aim to preserve meaning and tone.

RQ1 Described Impact On Supervisory Relationships

Most students described little to no direct impact of the chatbot conversations on their supervisory relationships and conversations with the course lecturers. When asked about changes in the lecturers' relevance, nine of twelve students reported no (n = 7) or only minor (n = 2) changes and highlighted the continuing value of human supervisors *("I see the AI as a helpful tool, but your practical experience is hard to match – especially in the Teaching & Learning Lab setting. So, overall, I wouldn't say it changed much."* – Patrick). Students often framed chatbot use and lecturer conversations as serving different functions: chatbot dialogues supported individual reflection on one's own station, whereas lecturer conversations were described as more situational, experience-based, and oriented toward practical problem solving *("What I talked about with you was something completely different from what I talked about with the AI."* – Caro).

A smaller group reported indirect links between chatbot use and lecturer interaction. Three participants described the chatbot sessions as providing conversation triggers (*"[...] it didn't really influence things, but it did provide new input for topics to talk about [...]"* – Martina) and two described a pre-relief effect – using the chatbot to voice uncertainties or "stupid questions" without embarrassment before approaching lecturers *("I think I was more likely to ask the AI a few 'stupid questions'[...]"* – Saph). One participant explicitly reported a more relaxed relationship with lecturers *("I think I would have felt a bit more under observation if I had the entire conversation with you."* – Emily).

Several students also noted practical constraints, particularly limited time to implement or discuss chatbot suggestions with lecturers *("[…] it didn't feel like we truly had enough time afterwards to implement what came out of the AI session"* – Caro]), and a few preferred more direct human exchange (e.g., small-group discussions) *("I actually would have preferred a conversation with you in a small group of four."* – Franka).

RQ2 Conceptualization Of The Chatbot

Overall, students predominantly conceptualized the chatbot as a tool-like technology rather than an independent 'person'. Typical descriptions framed it as a programmed system, a machine, a search-engine-like resource, a tool, a digital extension of the lecturers, or a neutral instance for thinking through one's own practice. At the same time, a small number of accounts portrayed the chatbot interaction as a relatively separate field of support – notably because students engaged with it without involving the lecturers – while still emphasizing that this did not generally apply to all situations and could not replace the interpersonal qualities of human supervision (*"[...] in the sense that you're texting it, it is something of its own, because we didn't involve you [the lecturers] at all. […] In this case, it worked well."* – Annika). A frequently mentioned difference to 'real' conversation concerned the chatbot's interaction style: although it had been instructed not to evaluate or provide feedback, students experienced it as overly validating and often strongly praising, and thus as qualitatively distinct from human feedback.

RQ3 Relationship-Relevant Qualities

Across the interviews, students' remarks frequently invoked relationship-relevant qualities, most prominently closeness, relatedness, and genuineness. Regarding closeness (warmth and openness), several students emphasized a clear boundary between interacting with a machine and with a person, which for them limited the degree of relational openness (e.g., *"You still must distinguish. You're talking to a machine, not to a human being. That difference must remain."* – Alexa). Beyond the human-machine boundary, some students link limited closeness to the chatbot's restricted availability. As one student noted, the AI could only be used *"for a very limited period of time,"* which did not necessarily coincide with moments when questions emerged, and they explicitly wondered how the experience might differ if it were *"permanently available"* (Saph). Others pointed to missing interpersonal nuances such as implicit undertones in communication (e.g., *"What the AI can't do is capture what's implicit. The undertone you pick up when people talk to each other. I don't think AI can do that."* – Annika), while only very few suggested that the interaction could, in specific moments, resemble communication with a person (e.g., *"No. In the end, it could just as well have been a human I was communicating with"* – Peter).

With respect to relatedness, students described the chatbot interaction as a safe, low-risk environment that could provide emotional reassurance, particularly in phases of uncertainty (e.g., *"At the beginning I was really lost about how to implement things, and the AI did give me a bit of emotional reassurance."* – Franka).

Finally, genuineness emerged as a salient boundary condition: some students criticized the interaction style as overly validating and strongly praising, which they experienced as inauthentic (e.g. *"Yes, because of the excessive praise. I found that really irritating at times"* – Peter).

In addition, students also mentioned that chatbot use could support higher-order thinking (e.g., by prompting reflection and critical evaluation of outputs) and encouraging learning (e.g., through structuring and guiding the reflective process), even though these aspects were typically described as complementary rather than substituting human support.

Discussion

Overall, the findings suggest that the chatbots functioned primarily as supportive tools for reflection, rather than being perceived as an independent supervisory figure. At the same time, students' answers contained multiple relationship-relevant cues – even when participants explicitly stated that chatbot use had little impact on supervisory relationships. In particular, students' references to closeness, relatedness, and genuineness indicate that chatbot-supported reflection can intersect with relational dynamics in teacher education in subtle ways: restricted availability and a clear human-machine boundary limited perceived closeness; the chatbot could still provide a low-pressure space for articulating uncertainty; and interaction styles perceived as overly validating highlighted genuineness as a decisive boundary condition. Overall, these patterns suggest that it is worthwhile looking beyond direct claims of 'relationship change' and pay attention to the relational qualities students mention when describing reflective support.

These insights translate into concrete implications for course design. First, availability is not only relevant for relational reasons but also pragmatically: if reflective tasks emerge outside narrow time windows, restricted access may prevent students from using the tool in a moment of need and may thereby limit closeness. In a subsequent iteration of the course, we therefore reduced constraints on availability. Initial feedback from students in that follow-up project (Herz et al., 2025) points in the direction that more flexible access can support meaningful use. Second, our results underline the importance of combining chatbot reflection with human supervision. Several students described the two support formats as operating "either-or," with too little time to discuss and implement insights. Future designs should therefore create structured opportunities to jointly discuss, validate, and translate chatbot outputs into concrete adaptations – for instance in small-group debriefings with lecturers – so that AI support complements rather than competes with human mentoring.

Finally, the results also call for a brief cautionary note regarding students' conceptions of AI. While many students framed the chatbot as a programmed tool, one described it as a "neutral instance." Even if meant in the sense of "non-judgmental," such framing may unintentionally reduce vigilance toward potential biases or limitations of AI-generated suggestions. This reinforces the need to embed chatbot use in explicit AI literacy work – particularly around critical evaluation of outputs and an awareness that 'helpful' and 'neutral' are not the same. Importantly, students themselves strongly emphasized that, for complex real-world teaching problems, chatbot suggestions require careful examination and cannot substitute the authenticity and experience-based judgement of human supervisors. In this sense, chatbots may scaffold reflective processes, but they do not replace what students perceive as uniquely valuable in supervision: authentic human experience.

Conclusion And Outlook

The present study suggests that our chatbot-based reflection coaching was primarily experienced as supportive scaffolding rather than an independent form of supervision, while students' accounts nevertheless contained relationship-relevant statements. At the same time, conclusions are constrained by several limitations: the study draws on a small sample from a single course (N=12), relies on end-of-course self-reports, and the interviews were conducted by the course lecturers, which may have shaped how openly participants discussed critical views. In addition, coding was conducted primarily by one researcher.

Future work will therefore extend beyond interview accounts by **analys**ing students' recorded reflection products given immediately after teaching-related experiences, allowing us to examine whether chatbot use is associated with changes in the structure and depth of reflection and in the

specificity of subsequent adaptations. Further iterations should also systematically change key design parameters – most notably availability and the structured integration of chatbot reflection with lecturer-led small-group debriefs – to identify configurations that support meaningful use without weakening human supervision. Finally, triangulating interviews, reflection products, and (where available) chatbot interaction traces in a longitudinal design can clarify how relational expectations and AI literacy practices (including critical evaluation and assumptions of "neutrality") develop through repeated, guided use.

Acknowledgements

This project was funded within the framework of WueDive, a project supported by the German "Stiftung Innovation in der Hochschullehre" aimed at advancing digital teaching at the University of Würzburg. WueDive initiates and coordinates activities through the establishment of a Digital Higher Education Hub, fostering engagement with emerging learning demands and learning opportunities.

Transparency Statement

In producing this manuscript, generative AI tools were used to support literature research, outlining, parts of the writing process, and – on an exploratory basis – data analysis. All uses were monitored and verified by the authors, who take full responsibility for the content.

References

Carolus, A., Koch, M. J., Straka, S., Latoschik, M. E. & Wienrich, C. (2023). MAILS - Meta AI literacy scale: Development and testing of an AI literacy questionnaire based on well-founded competency models and psychological change- and meta-competencies. *Computers in Human Behaviour: Artificial Humans*, *1*(2), 100014. https://doi.org/10.1016/j.chbah.2023.100014

Cornelius-White, J. (2007). Learner-Centred Teacher-Student Relationships Are Effective: A Meta-Analysis. *Review of Educational Research*, *77*(1), 113–143. https://doi.org/10.3102/003465430298563

Damköhler, J., Lutz, W. & Trefzger, T. (2025). ChatGPT als Reflexionscoach: Einblicke in das Würzburger Lehr-Lern-Labor. In H. van Vorst (Vorsitz), *Jahrestagung der Gesellschaft für Didaktik der Chemie und Physik,* Bochum.

Herz, P., Damköhler, J., Lutz, W. & Trefzger, T. (2025). ChatGPT im Lehr-Lern-Labor: Potenziale eines KI-basierten Assistenten bei der Entwicklung von Experimentierumgebungen. *PhyDid B* (akzeptiert).

Korthagen, F. A. J. (2004). In search of the essence of a good teacher: towards a more holistic approach in teacher education. *Teaching and Teacher Education*, *20*(1), 77–97. https://doi.org/10.1016/j.tate.2003.10.002

Kuckartz, U. & Rädiker, S. (2022). *Qualitative Inhaltsanalyse. Methoden, Praxis, Computerunterstützung: Grundlagentexte Methoden* (5. Auflage). *Grundlagentexte Methoden*. Beltz Juventa. http://www.content-select.com/index.php?id=bib_view&ean=9783779955337

Long, D. & Magerko, B. (2020). What is AI Literacy? Competencies and Design Considerations. In R. Bernhaupt, F. '. Mueller, D. Verweij, J. Andres, J. McGrenere, A. Cockburn, I. Avellino, A. Goguey, P. Bjørn, S. Zhao, B. P. Samson & R. Kocielnik (Hrsg.), *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems* (S. 1–16). ACM. https://doi.org/10.1145/3313831.3376727

Lutz, W., Damköhler, J. & Trefzger, T. (2025). Künstliche Intelligenz: Akzeptanz und AI-Literacy unter Lehramtsstudierenden. In H. van Vorst (Vorsitz), *Jahrestagung der Gesellschaft für Didaktik der Chemie und Physik,* Bochum.

Nass, C., Steuer, J. & Tauber, E. R. (1994). Computers are Social Actors. *Human Factors in Computing Systems*, 72–78.

OECD. (2026). *OECD Digital Education Outlook 2026: Exploring Effective Uses of Generative AI in Education*. https://doi.org/10.1787/062a7394-en https://doi.org/10.1787/062a7394-en

Pianta, R. C. (Hrsg.). (1999). *Enhancing relationships between children and teachers*. American Psychological Association. https://doi.org/10.1037/10314-000

Pianta, R. C. (2001). *STRS Student-Teacher Relationship Scale: Professional Manual*. Psychological Assessment Resources Inc.

Praetorius, A.-K., Klieme, E., Herbert, B. & Pinger, P. (2018). Generic dimensions of teaching quality: the German framework of Three Basic Dimensions. *ZDM – Mathematics Education*, *50*(3), 407–426. https://doi.org/10.1007/s11858-018-0918-4

Roorda, D. L., Koomen, H. M. Y., Spilt, J. L. & Oort, F. J. (2011). The Influence of Affective Teacher–Student Relationships on Students' School Engagement and Achievement. *Review of Educational Research*, *81*(4), 493–529. https://doi.org/10.3102/0034654311421793

Ryan, R. M. & Deci, E. L. (2000). Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being. *The American psychologist*, *55*(1), 68–78. https://doi.org/10.1037/0003-066X.55.1.68

Völker, M. & Trefzger, T. (2011). Ergebnisse einer explorativen empirischen Untersuchung zum Lehr-Lern-Labor im Lehramtsstudium. *PhyDid B*.

EUROPEAN SCIENCE EDUCATION RESEARCH ASSOCIATION ESERA 2025 Copenhagen

Analysis Of Physics And Chemistry Pre-Service Teachers' Perceptions About Their Teaching Identity And Professional Development

Liliana López-López and Cristina García-Ruiz
Science Education, Universidad de Málaga, Spain

Developing a Teaching Professional Identity (TPI) is crucial for effective teaching practice, particularly during initial teacher education. This study explores the perceptions of eight preservice secondary science teachers (PSSTs) about their professional development during their Master's in Education program (MEd), specifically examining how self-reflection on teaching competencies contributes to their identity construction. Through a qualitative case study approach, we analysed PSSTs' responses to an ad-hoc survey, focusing on nine teaching competencies and their relationship with five key factors affecting TPI (teaching experience, motivation, self-image, Master's expectations, and task perception). In general, the analysis reveals that PSSTs showed a balanced awareness of their strengths and challenges. Findings suggest that PSSTs' identity formation is significantly influenced by their practical teaching experiences and self-image, revealing the important role of initial teaching education programs in supporting their transition into teaching careers. Hence, while teaching experience plays a crucial role in shaping their confidence and competencies, there is a clear recognition of the need for continuous self-assessment, positive attitudes, and the development of both personal and social skills to foster a harmonious and effective learning environment. In short, these results highlight the need for a more comprehensive approach in initial teacher education programs, where the development of both professional skills and personal identity is nurtured through reflection, experience, and positive engagement with the teaching profession.

Keywords: Pre-service teacher education, teacher identity, professional development

Introduction

The International Teaching and Learning Survey (TALIS) (Organisation for Economic Co-operation and Development [OECD], 2025) reveals that teachers who have recently graduated report feeling insufficiently prepared, both in terms of subject-matter knowledge, pedagogical and practical aspects, to teach the subjects for which they are responsible. Additionally, the growing demands for equity and inclusion (Karousiou et al., 2019) and the educational shift towards personalised and student-centred pedagogies (Schleicher, 2018) represent a challenge in defining teachers' roles, leading to graduated teachers reporting high levels of stressed in their early years (OECD, 2025). This situation leads some in the secondary teaching workforce to perceive themselves not as subject teachers but rather as graduates in a scientific discipline who transmit content. As a result, a spontaneous approach to teaching predominates, grounded in prior experience as learners, directly impacting the construction of their teaching identity, their instructional practices, and their professionalism (Imbernón, 2019).

Research on teacher identity is therefore essential because, as Wenger (1998) explains, it examines "how learning changes who we are" (p. 5). Moreover, the concept of identity enables teachers to reflect on the relationship between the individual and the world, thereby addressing the role of context and valuing the sociocultural nature of learning (Gee, 2000). Nevertheless, despite the existence of review studies on teacher identity, further research is required to ensure a specific focus on the identity of science teachers (Avraamidou, 2014), particularly during their initial training period. This interest is grounded in the idea that, in order to make the transition from student to teacher, pre-service science teachers (PSSTs) must not only acquire a set of skills,

knowledge, and an understanding of pedagogical approaches, but also create and recreate their self-image as active members of a professional community—an aspect that is directly related to the construction of their teacher identity (Sutherland et al., 2010).

In light of the above, promoting and fostering the development of strong teacher identities is essential for teachers themselves, the research community, and educational policy. The benefits of analysing the professional identity of science teachers (TPI) are directly linked to students' learning success, the strengthening of teachers' self-image, and the assurance of the development of effective educational policies (Suárez & McGrawth, 2022).

Theoretical Framework

In the teaching-learning process, teachers are a key agent with a direct impact on students' learning and development (Jennings & Greenberg, 2009), leading both society and educational systems to revalue the teaching profession in a context characterised by constant change and fluctuation (Nias, 2014). As a consequence, in recent years, there has been growing interest in understanding teachers' professional lives through the study of their TPI and its influence on teaching quality, motivation to teach, commitment to the profession, good pedagogical practices, and decision-making in school contexts (Beauchamp & Thomas, 2009; Buchanan, 2015). For teachers, understanding their TPI can strengthen teaching practice insofar as it aligns with fundamental questions such as "who am I?" or "what should I do?" (Mockler, 2020), which directly influence pedagogical decision-making and teacher–student relationships.

TPI encompasses teachers' perceptions, beliefs, and attitudes about their professional role (Cordingley et al., 2019), significantly influencing classroom practices and policy implementation (Karousiou et al., 2019). Although, over the years, researchers have approached TPI from different theoretical perspectives and proposed various definitions, there are some commonalities widely acknowledged, such as its complexity and multidimensionality, its evolution with personal and professional experiences, and its variation across individuals and cultures (Hanna et al., 2019).

Within the context of teacher education, the sociocultural approach results particularly valuable, as it allows for a broader understanding of professional development that goes beyond the acquisition of knowledge and technical skills (Gee, 2000). Furthermore, this approach has facilitated analysis of how teachers perceive themselves, how they are recognized by others, and how factors such as gender, personal histories, and prior experiences influence the construction of their professional identity (Avraamidou, 2014).

Nevertheless, research on pre-service teachers' TPI remains at an early stage in understanding how these identities are constructed, which factors influence their transformation, and what role they play in motivating both teachers and students to learn (Schutz et al., 2018). This gap highlights the need for more integrative frameworks that connect teacher identity with key dimensions of professional practice, development, and effectiveness across changing educational contexts.

In an era characterized by rapid change and uncertainty, teachers face diverse expectations from multiple stakeholders while navigating complex educational transformations (Nias, 2014), making essential to promote ever since teacher education the construction of a robust TPI to respond to these challenges while maintaining high-quality instructional practices effectively ensuring in this way educational quality and successful teaching careers.

For doing so, it becomes fundamental to research into key factors and domains shaping TPI from teacher education program, analysing, among others, the influence of motivation (drive to be or

become a teacher), self-image (how individuals view and feel as teachers), self-efficacy (belief in their capability to perform their teaching activities effectively) or task perception (beliefs about what a teacher considers to be good teaching) (Suárez & McGrath, 2022).

These TPI elements intersect with teachers' competencies, affecting their professional development and classroom effectiveness. Hence, the relationship between teaching competencies and TPI becomes particularly relevant when examining how teachers negotiate their professional roles and responsibilities. Studies suggest that teachers with well-developed professional identities demonstrate a greater capacity to implement educational innovations and maintain a commitment to their practice (Sachs, 2016). This interplay between competencies and identity formation provides a crucial framework for understanding teacher professional development and effectiveness in contemporary educational settings.

Aims And Research Questions

With the purpose of contributing to the growing body of research on TPI while offering insights into effective teacher preparation and professional development strategies, this study explores the interconnection between teaching competencies and TPI development. Focusing on how PSSTs' experiences and initial teacher education influence their professional identity formation, we aim to answer the following research question: What are the perceptions of PSSTs about their teaching professional development during their initial training stage, and how does self-reflection on teaching competencies contribute to the construction of teachers' identity?

Methodology

Participants

This research was developed as a case study design with 8 PSSTs of the MEd from the University of Málaga, from the speciality of "Physics and Chemistry". All participants held a bachelor's or a master's degree in either science or engineering, which is a requisite to enroll in the MEd. The demographic composition of the group included three males and five females, with ages ranging from 25 to 35 years.

Research Instrument, Data Collection And Analysis

Through an *ad-hoc* survey-type task, PSSTs were asked to identify and justify their professional development level for the teaching competencies (TC) promoted during the MEd, related to curriculum assessment (TC1), professional communication (TC2), social climate (TC3), reflection innovation (TC4), institutional culture (TC5), collaborative decision-making (TC6), instructional design

We collected data through an online survey during the 2022/2023 (PSST1-PSST4) and 2023/2024 (PSST5-PSST8) academic years. We then proceeded to develop a qualitative analysis of PSSTs' responses individually using coding techniques performed with the Atlas.ti software (version 25.0.1). Thus, the researchers and co-authors of this communication read the individual responses and co-related them to factors linked to TPI development, particularly the previous experiences of the teachers and their initial teacher education, following the Suárez and McGrath (2022) framework. Hence, based on common patterns and key aspects found in the PSSTs' responses, we then coded and categorised data independently within domains and factors most affecting TPI in teacher education (teaching experience [TE], motivation [MO], self-image [SI], MEd expectations (instead of job satisfaction) [ME] and task perception [TP]), finally negotiating the coding consensus (Creswell, 2013).

Findings

Table 1 illustrates how PSSTs' responses were classified each teaching competencies described in the survey and the subsequent categorisation according to the main factors affecting TPI, also providing an example of response.

Table 1. Examples of the categorization of PSSTs' responses within each teaching competence and TPI factor.

PSST	TEACHING COMPETENCIES AND FACTORS AFFECTING TPI
PSST 5	**Teaching competence:** *Affective interaction (TC8)*
	TPI Factor: *MEd expectations (ME)*
	Response: *"I believe this attitude is developed through practice and experience, so I hope to improve in the best possible way during the remaining months of my master's."*
PSST 6	**Teaching competence:** *Reflection innovation (TC4)*
	TPI Factor: *Motivation (MO)*
	Response: *"Although I am not very familiar with the subject, I think I can manage to give feedback and try to improve the proposal when necessary."*
PSST 8	**Teaching competence:** *Professional communication (TC2)*
	TPI Factor: *Self-image (SI)*
	Response: *"I do consider that I have this competence more developed since although I have not yet worked as a teacher, I have given many talks and workshops to secondary school students, and I have some practice expressing myself in writing and orally with them."*
PSST 7	**Teaching competence:** *Social climate (TC3)*
	TPI Factor: *Teaching experience (TE)*
	Response: *"I believe it is important to have social skills to create a positive learning environment and promote coexistence in the classroom. It is something I don't have much experience in, but I believe it can improve over time."*
PSST2	**Teaching competence:** *Curriculum assessment (TC1)*
	TPI Factor: *Task perception (TP)*
	Response: *"Regarding the evaluation, I consider it one of the most difficult points to carry out, since we not only have to take into account the grade of an exam, but also their previous level, the student's performance in class, their proactivity, etc."*

Table 2. Relationship between the nine teaching competencies and the factors influencing TPI.

TEACHING COMPETENCIES	FACTORS AFFECTING TPI					TOTAL (per TC)
	TE	**MO**	**SI**	**ME**	**TP**	
TC1 Curriculum assessment	5	1	6	2	3	17
TC2 Professional communication	6	2	6	0	2	16
TC3 Social climate	2	4	4	0	6	16
TC4 Reflection innovation	3	2	4	3	2	14
TC5 Institutional culture	5	2	3	1	0	11
TC6 Collaborative decision-making	2	0	4	0	8	14
TC7 Instructional design	2	6	2	3	0	13
TC8 Affective interaction	3	5	2	1	2	13
TC9 Evidence-based improvement	3	0	4	1	8	16
***TOTAL** (per factor)*	**31**	**22**	**35**	**11**	**31**	130

Table 2 provides an overview of the relationship between the nine teaching competencies and the factors influencing TPI as perceived by the eight PSSTs, relating the number of mentions of each factor within each teaching competence. Notably, collaborative decision-making (TC6) and evidence-based improvement (TC9) show strong connections to task perception (TP) (8 mentions

each), while professional communication (TC2) has strong links to both teaching experience (TE) and self-image (SI) (6 mentions each), and instructional design (TC7) shows a strong connection to motivation (MO) (6 mentions). This distribution also suggests that specific competencies, particularly those related to curriculum and assessment (TC1), tend to engage multiple identity factors simultaneously.

In total, PSSTs included up to 130 mentions in their survey responses about the teaching competencies (Table 3), mainly concerning self-image (35), teaching experience (31) and task perception (31). On the other hand, motivation (22) and MEd expectations (11), were the less mentioned competencies in the study, respectively.

Table 3. Frequency of mentions emerged from the analysis per PSST.

FACTORS AFFECTING TPI	PPSTs								TOTAL (per category)
	1	2	3	4	5	6	7	8	
MEd EXPECTATIONS (ME)	**0**	**5**	**0**	**1**	**1**	**1**	**3**	**0**	**11**
Educational methodologies	0	2	0	1	1	0	0	0	4
Teaching work	0	0	0	0	0	1	2	0	3
Functioning of the educational institution	0	1	0	0	0	0	1	0	2
Observation	0	1	0	0	0	0	0	0	1
Participation	0	1	0	0	0	0	0	0	1
MOTIVATION (MO)	**4**	**2**	**3**	**3**	**3**	**1**	**5**	**1**	**22**
Intention to improve	2	1	2	0	3	1	5	1	15
Interests	0	1	1	3	0	0	0	0	5
Teaching professional capacity	2	0	0	0	0	0	0	0	2
SELF-IMAGE (SI)	**8**	**0**	**3**	**5**	**2**	**7**	**1**	**9**	**35**
Self-assessment	3	0	2	4	2	5	1	9	26
Personality	2	0	1	1	0	2	0	0	6
Curricular aspects	1	0	0	0	0	0	0	0	1
Oral expression	1	0	0	0	0	0	0	0	1
Written expression	1	0	0	0	0	0	0	0	1
TEACHING EXPERIENCE (TE)	**2**	**3**	**4**	**3**	**3**	**7**	**3**	**6**	**31**
Lack of teaching experience	2	1	1	0	1	3	2	4	14
Previous teaching experience	0	1	3	3	2	4	1	2	16
Teaching resources	0	1	0	0	0	0	0	0	1
TASK PERCEPTION (TP)	**5**	**9**	**2**	**6**	**2**	**0**	**5**	**2**	**31**
Classroom management	1	2	1	0	1	0	0	1	6
Teacher collaboration	1	1	0	1	1	0	1	1	6
Attitude	2	2	1	3	0	0	1	0	9
Teaching and learning process assessment	1	2	0	0	0	0	2	0	5
Teacher-student relationship	0	1	0	1	0	0	0	0	2
Pedagogical methods	0	1	0	1	0	0	1	0	3
TOTAL (per PPST)	19	19	12	18	11	16	17	18	130

With reference to the five main factors affecting TPI, Table 3 shows the different subcategories encompassed within each of these factors. Regarding **self-image**, 'self-assessment' stands out as the main subcategory (26 mentions), highlighting the value of self-awareness and personal reflection in the construction of their professional identity. Concerning **teaching experience**, the results reveal a closely balanced division of opinions between 'Lack of experience' (17 mentions) and ‘Previous teaching experience' (16 mentions), reflecting the contrast between initial insecurity and the importance attributed to prior non-formal experiences in the development of their competencies. In terms of **task perception**, most responses highlight the attitude with which

PSSTs approach the teaching profession (9 mentions), emphasising a positive attitude toward overcoming challenges, followed by 'Classroom management' and 'Teacher collaboration' (6 mentions each), which indicates that the PSSTs acknowledge the importance of fostering a structured and collaborative environment that promotes active learning. Subsequently, with respect to **motivation**, the PSSTs highlight their intention to improve (15 mentions) their personal skills to ensure the success of the teaching-learning process, as well as their social skills, in a way that guarantees harmony in the classroom environment. Finally, the PSSTs express, as **expectations of the MEd**, the need to improve their training regarding new educational methodologies (4 mentions) and teaching practices (3 mentions), in order to adapt to new educational needs and ensure the success of the learning process.

Conclusions And Implications

This study examines PSSTs' perceptions of their professional development through a qualitative analysis, correlating teaching competencies and five key factors defining Teaching Professional Identity (TPI): teaching experience, motivation, self-image, MEd expectations, and task perception. The findings of this study lead us to make the following conclusions, which should be considered with caution due to the reduced number of participants in this case study.

Results show that PSSTs believe self-reflection, particularly through self-assessment, is crucial for building their professional identity. Likewise, the study highlights the value that PSSTs attribute to their own capabilities, limitations, and progress, revealing that the construction of professional identity is not solely the result of the accumulation of experience, but rather a continuous process of renegotiating their self-perception as teachers in relation to their competencies, expectations, and emotions. In this sense, reflection on one’s own teaching self-image emerges as a key mechanism for the development of TPI.

Teaching experience plays a key role, as PSSTs experience tension between initial insecurity due to lack of experience and the value they place on prior experiences. In this context, offering early, guided, and diverse teaching practice opportunities within initial teacher education programs is essential to help PSSTs connect theoretical content with classroom realities, thereby progressively strengthening their sense of professional competence and belonging.

Regarding task perception, a positive attitude toward challenges, classroom management, and teacher collaboration are key elements in shaping their identity. PSSTs also emphasize their motivation to improve both personal and social skills, highlighting the importance of comprehensive training that covers both professional and personal competencies.

Overall, this study underscores that reflection on teaching competencies and fostering an educational environment that allows PSSTs to assess and develop their abilities are essential for building a strong professional identity. In this regard, initial teacher education programs should create spaces for self-reflection and competency development, facilitating a successful transition into teaching practice and long-term professional success. This approach has important implications for the design of teacher training programs, which should integrate both technical competencies and the personal and reflective development of future teachers. Along these lines, such programs should adopt an integrated approach to professional development, articulating teaching competencies with factors linked to TPI and providing structured spaces for reflection, the promotion of teaching experiences, and attention to the socioemotional dimension, thus contributing to the development of a solid TPI. In this regard, the identification of key domains of professional identity can be used as a practical framework to guide assessment processes, course design, and reflective practices in initial teacher education, reinforcing the intentional development of TPI (Hanna et al., 2019).

Finally, despite the limitations derived from the reduced sample size, this research offers a competency-based perspective on the development of TPI during the initial training of science teachers. Future studies could extend this work through larger and more diverse samples, as well as comparative studies across disciplines and/or educational contexts. Such approaches would allow for a deeper understanding of how teaching competencies and professional identity construction interact, contributing to the design of teacher education programs that foster competent, reflective, and professionally committed teachers.

Acknowledgement

This work is part of the R+D+i Project "Development and monitoring of pre-service and novice science teachers' teaching identity. Study of the influence of the inquiry processes, emotional and gender profiles (INQUIRY-IDEG)" (reference PID2022-140001OA-I00), funded by MICIU/AEI/1.13039/501100011033 and FEDER (UE). Dr García-Ruiz thanks the RYC2020 program (reference: RYC2020- 029033-I), funded by MICIU/AEI/1.13039/501100011033 and ESF "Investing in your future".

References

ATLAS.ti Scientific Software Development GmbH (2023). ATLAS.ti Mac (version 25.0.1) [Qualitative data analysis software]. https://atlasti.com

Avraamidou, L. (2014). Studying science teacher identity: current insights and future research directions. *Studies in Science Education*, *50*(2), 145-179. https://doi.org/10.1080/03057267.2014.937171

Beauchamp, C., and Thomas, L. (2009). Understanding teacher identity: An overview of issues in the literature and implications for teacher education. *Cambridge Journal of Education, 39*(2), 175–189. https://doi.org/1.1080/03057640902902252

Buchanan, R. (2015). Teacher identity and agency in an era of accountability. *Teachers and Teaching, 21*(6), 700-719. https://doi.org/10.1080/13540602.2015.1044329

Cordingley, P., Crisp, B., Johns, P., Perry, T., Campbell, C., Bell, M., and Bradbury, M. (2019), *Constructing Teachers' Professional Identities, Education International,* Educational International & UNESCO.

Creswell, J. W. (2013). *Research design: Qualitative, quantitative, and mixed methods approaches.* Sage.

Gee, J. P. (2000). Identity as an analytic lens for research in education. *Review of Research in Education*, 25, 99–125. https://doi.org/10.3102/0091732X025001099

Hanna, F., Oostdam, R., Severiens, S. E., and Zijlstra, B. J. H. (2019). Domains of teacher identity: A review of quantitative measurement instruments, *Educational Research Review, 27*, 15-27. https.//doi.org/10.1016/j.edurev.2019.01.003

Imbernón, F. (2019). Secondary educatin teachers' training: The eternal nightmare. *Profesorado. Revista de Currículum y formación del profesorado, 23*(3), 151-163. https://doi.org/10.30827/profesorado.v23i3.9302

Jennings, P. A., and Greenberg, M. T. (2009). The prosocial classroom: Teacher social and emotional competence in relation to child and classroom outcomes. *Review of Educational Research, 79*(1), 491-525. https://doi.org/10.3102/0034654308325693

Karousiou, C., Hajisoteriou, C., and Angelides, P. (2019) Teachers´ professional identity in super-diverse school settings: Teachers as agents of intercultural education, *Teachers and teaching*, *25*(2), 240-258. https://doi.org/10.1080/13540602.2018.1544121

Mockler, N. (2020). Navigating professional identity as a teacher of history. In T. Allender (ed), *Historical thinking for history teachers*. Routledge.

Nias, L. (2014). Changing times, changing identities: Grieving for a lost self. *Education Research and Evaluation: For Policy and Practice?* Routledge.

OECD (2025). *Results from TALIS 2024: The estate of teaching. TALIS*. OECD Publishing. https://doi.org/10.1787/90df6235-en

Sachs, J. (2016) Teacher professionalism: Why are we still talking about it, *Teachers and Teaching*, 413-425, http://dx.doi.org/10.1080/13540602.2015.1082732

Schleicher, A. (2019). *PISA 2018. Insights and interpretations*. OECD Publication office.

Schutz P. A., Cross D. I., Hong J., and Osbon J. N. (2007) Teacher identities, beliefs, and goals related to emotions in the classroom. In P. A. Schutz, and R. Pekrun R. (eds.) *Emotion in Education* (pp. 223-241). Academic Press.

Suárez, V., and McGrath, J. (2022). *Teacher professional identity: How to develop and support it in times of change. OECD Education Working Papers No. 267.* OECD Publishing

Sutherland, L., Howard, S., and Markauskaite, L. (2010). Professional identity creation: Examining the development of beginning preservice teachers' understandings of their work as teachers. *Teaching and Teacher Education, 26*, 455–465. https://doi.org/10.1016/j.tate.2009.06.006

Wenger, E. (1998). *Communities of practice: Learning, meaning, and identity*. Cambridge University Press.

EUROPEAN SCIENCE EDUCATION RESEARCH ASSOCIATION ESERA 2025 Copenhagen

Pre-Service Physics Teachers' Conceptions About What It Means To Understand Physics: A Phenomenographic Study

Gregory P. Thomas
University of Alberta, Canada

The development of conceptual understanding is a long-standing goal of science education. However, a gap exists in the literature regarding what pre-service physics teachers' conceptions are of what it means to understand physics. Given the importance of teachers' epistemic conceptions for shaping their pedagogy, this gap is surprising. This study employed phenomenography to determine the qualitatively various ways that pre-service physics teachers conceptualize what it means to understand physics. Phenomenography is a second-order approach to research in which conceptions, (a) are viewed as being the product of interactions between humans and the world around them, and (b) arise from a human being's thinking about their external world. Fourteen pre-service physics teachers were interviewed individually for around thirty minutes each regarding their experiences as physics majors and their thoughts about what they considered it meant to understand physics. Five categories of description emerged from the analysis: (1) feeling, (2) applying, (3) making meaning, (4) communicating, and (5) accumulating. The first four categories occupy a higher level in the outcome space than the 'accumulating' category, as students reported that 'applying' and 'making meaning' were contingent on processes represented by the two sub-categories of 'accumulating.' The potential value of these findings is outlined.

Keywords: Phenomenography, physics, understanding.

Literature and Study Rationale

The understanding of concepts is closely related to high quality and/or in-depth learning. In science education there has been consistent attention to conceptual understanding and its development (e.g., Driver et al., 1994; Potvin et al., 2020) and conceptual change (e.g., Duit & Treagust, 2012; Lin et al., 2019). In this paper, however, the attention is on individuals' conceptions of understanding, itself, rather than on what it means to understand any particular science concept.

Previous research seeking individuals' views on what it means to understand has been reported. These studies employed phenomenography. The concept of understanding was identified by Marton et al. (1993), and Säljö (1982) as one of six conceptions of learning. Irving and Sayre (2012) investigated eighteen university physics students' conceptions of understanding and reported, similar to Waterhouse and Prosser (2000), that individuals understanding was when one could use and apply knowledge, and that one's level of understanding was determined according to different levels of task requirement and context complexity.

In phenomenographic research in science education, Zhao (2015) explored mainland Chinese students' conceptions of learning science. Lukie (2021) explored and compared high school physics students,' high school physics teachers,' and university physics professors' conceptions of what it means to understand physics. He reported five non-hierarchical categories: feelings, achievement, communication, making meaning, and application. The variations between the groups of participants related to their levels of knowledge, domain expertise, experience, and roles.

There is little, if any, research regarding pre-service science teachers' conceptions of what they consider understanding to be. Given that conceptions of understanding can be linked to teacher pedagogy, curriculum interpretation, learning processes, and domain expertise, the research reported in this paper is timely. It is important that teachers and their students have a shared, consistent view of what it means to understand science subjects. There should be a common epistemic foundation that can be shared and communicated between them. Otherwise, the purposes of teaching and learning might not be similar or identical between classroom participants. This study investigated pre-service physics teachers' conceptions of what it means to understand physics.

Research Design

Phenomenography: An Overview

Phenomenography is a "research method for mapping the qualitatively different ways in which people experience, conceptualize, perceive, and understand various aspects of, and phenomena in, the world around them" (Marton, 1986, p. 31). Phenomenographers adopt a second-order approach to research; their description of a phenomenon is based on the experience/s of that phenomenon as described by others (Marton & Booth, 1997; Trigwell, 2006). Marton (1986) suggests that "each phenomenon, concept, or principle can be understood in a limited number of qualitatively different ways" (p. 30). Phenomenographers attempt to identify and categorize the various, multiple conceptions that a population might have for a phenomenon and describe the variations in those conceptions. These categories of conceptions are presented as the 'outcome space' that represents the minimum number of categories that explain all the variations in the data. The outcome space should, (a) reveal something distinct about how the phenomenon is experienced, (b) present each category in its logical relationship with other categories, and (c) present the fewest number of categories that can represent the data and its analysis (Marton & Booth, 1997). This study aimed to determine, represent, and explain the outcome space representing pre-service physics teachers' conceptions of what it means to understand physics.

Participants, Data Collection, And Analysis

Fourteen pre-service teachers, physics majors enrolled in a Bachelors of Education degree at a large North American comprehensive university, consented to participate. Data were collected using semi-structured interviews of around 30 minutes each during which the participants answered open-ended questions (Dunkin, 2000, Bowden, 2005, Åkerlind, 2005a) about what they considered it meant to understand physics and about their experiences as physics learners. The interviews were transcribed and analysis began with the transcripts being read numerous times while listening to the audiotape in "to clarify what the participant meant" when responding to the questions (Åkerlind, 2005b, p. 328). The phenomenon in question, i.e., understanding physics, was then "narrowed down to and interpreted in terms of selected quotes" (Marton, 1986, p. 42). The selected quotes and their interpreted meanings were compared to identify sources of variation and agreement, and to ascertain which could be grouped together and which could remain separate. After these processes had been undertaken several times, labels for the categories of conceptions were determined and the categories were arranged (in the outcome space) in a way that respected and reflected the pre-service teachers' self-reports regarding what they considered it meant to understand physics.

Results and Discussion

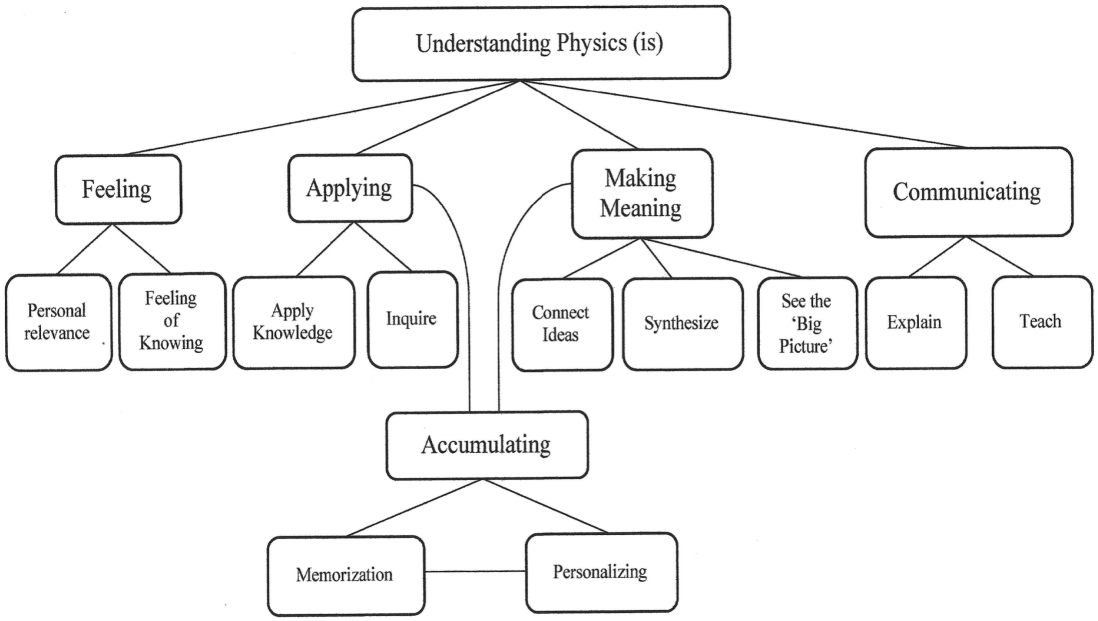
Five conceptions of understanding physics are evident: Feeling, Applying, Making Meaning, Communicating, and Accumulating. Eleven sub-categories emerged: Personal Relevance,

Feeling of Knowing, Apply Knowledge, Inquire, Connect Ideas, Synthesize, See the 'Big Picture,' Explain, Teach, Memorization, and Personalization. The structure of the outcome space (Figure 1) is hierarchical. This is in contrast to the outcome spaces reported by Lukie (2021) and Zhao (2015) who both reported circular outcome spaces. However, it is consistent with those outcome spaces reported by Irving and Sayre (2012) and Waterhouse and Prosser (2000). In outlining these conceptions, examples of students' interview comments are provided to illustrate the researcher's interpretations.

Accumulating

The participants said that what it means to understand Physics was to accumulate information and memory elements via *Memorization*, which involved conscious attention to information retention, often at a surface level, as exemplified by comments such as "understanding involves…taking notes of the key terms, doing definitions of those terms, writing down formulas, and trying to draw diagrams…if I can't remember, then I'm just trying to write it down and I'll try to figure it out later," and *Personalizing* information that involved rewording, e.g. "…putting what a lecturer is saying into my own words," or creating visualizations of the materials and ideas provided by teachers and instructors. Students stated clearly that 'Accumulating' was a key and necessary component of understanding physics; a precursor to applying and making meaning. However, they were unanimous that Accumulating, by itself, constituted a lower, subordinate level of understanding than applying and making meaning. Hence it is placed in a lower area in the outcome space. In what follows, the four other, superordinate conceptions are briefly explained.

Figure 1. The Outcome Space Representing Pre-service Physics Teachers' Conceptions of Understanding Physics.-



Feeling

The participants said that what it means to understand physics was to experience a feeling; a positive emotional response. Two sub-categories were identified: A feeling of *Personal Relevance* referring to when students saw physics as directly relatable to their lives, as exemplified by comments such as, "I like being able to look at things around me and know how they work…it's just fun," and a *Feeling of Knowing*, which meant that they could understand the material intuitively. This is exemplified by students' comments such as, "understanding physics

means it kind of (sic) just makes sense…an intuitive thing." Scholarship on feelings of knowing is highly visible in the literature, especially that which is related to metacognition (e.g., Efklides, 2006). Further, the importance of emotions for learning and understanding science is gaining increasing attention (e.g., Bellocchi & Ritchie, 2015).

Applying

The participants said that what it means to understand physics was to apply the physics one knows. Two sub-categories were identified: *Applying Knowledge* as using knowledge to solve problems and pass exams, as exemplified by comments such as, "I know I understand if I can do the questions,' and applying knowledge in the pursuit of *Inquiring* as being able to inquire and think critically about information and ask research questions in the field of physics, as exemplified by comments such as, "If I understand physics I can…develop my own procedure that makes sense…set up my own problem [to investigate] as thoroughly as I can." The sub-category of applying knowledge has been reported in previous studies (e.g., Irving & Sayre 2012; Lukie, 2021; Waterhouse & Prosser 2000). The second sub-category of *Inquiring* has not previously been reported to this researcher's knowledge.

Making Meaning

The participants said that what it means to understand Physics was to make meaning. Three sub-categories were identified: *Connecting Ideas* that involves seeing connections between physics concepts and ideas as exemplified by comments such as, "understanding involves…seeing how what we're learning fits into what I already know about a topic," *Seeing the 'Big Picture'* as being able to see physics as a field of study that can be connected to everyday life, often through the lens of mathematics and other areas of science, for example, "I see a car drive down the street, and I think of all the moving parts, and the mechanical engineering, and the thermodynamics…that's the basis of what physics is," and *Synthesizing*, as being able to deconstruct, reconstruct and revise concepts in potentially new ways, as suggested for example in, "[understanding physics is] seeking and finding patterns and logical structures in the world…mathematics is the main tool used to do that…[it's about] finding out how 'puzzle pieces' like, for example, energy, kilometres, hours, and formulas, fit together." To this researcher's knowledge, this subtle distinction between categories of making meaning has not previously been reported.

Communicating

The participants said that what it means to understand Physics was to communicate what one knows with others. Two sub-categories were identified: *Explaining*, meaning being able to explain physics to someone else, for example, "…being able to explain a difficult concept to somebody in layman's (sic) terms," and *Teaching*, meaning communicating with the intention of facilitating learning, for example being able to, "…tutor at university…to teach physics to somebody." The distinction between explaining and teaching is consistent that noted in past studies (e.g., Lukie, 2021; Irving & Sayre, 2012, Waterhouse & Prosser, 2000).

Conclusion And Implications

The significance of these findings relates to considering the everyday classroom event of a physics teacher asking their students, "Do you understand?" When they ask this question, what is it that are they really asking? Further, do teacher/s and students share similar epistemic positions on what it means to understand physics? The findings of this research suggest that a variety of conceptions of what it means to understand physics are possible for pre-service physics

teachers. Lukie (2021) reported similar variations between high school physics students and between high school physics teachers. The conceptions identified in this paper can be used, and are being used by this researcher, for initiating discussions with pre-service and practicing science teachers about what it means for individuals to understand physics. The outcome space shown in Figure 1 can be and is being used as a template for structuring such discussions. Further phenomenographic studies across science subject specialisms with pre-service and practicing teachers is required to expand the literature and potential use of such findings across teacher education.

Acknowledgement

This paper draws on research was part of the project 'Using audio podcasts and supporting text materials to stimulate metacognitive experiences in pre-service science teachers regarding metacognition and its development' supported by the Social Sciences and Humanities Research Council of Canada.

References

Åkerlind, G. S. (2005a). Phenomenographic methods: A case illustration. In J. Bowden & P. Green (Eds.), *Doing developmental phenomenography* (pp. 103-127). RMIT University Press.

Åkerlind, G. S. (2005b). Variation and commonality in phenomenographic research methods. *Higher Education Research and Development*, *24*, 321-334. https://doi.org/10.1080/07294360500284672

Bellocchi, A., & Ritchie, S. M. (2015). "I Was Proud of Myself That I Didn't Give Up and I Did It": Experiences of Pride and Triumph in Learning Science. *Science Education, 99*(4), 638-668. https://doi.org/10.1002/sce.21159

Bowden, J. A. (2005). Reflections on the phenomenographic team research process. In J. A. Bowden & P. Green (Eds.), *Doing developmental phenomenography* (pp. 11-31). RMIT University Press.

Driver, R., Asoko, H., Leach, J., Mortimer, E., & Scott, P. (1994). Constructing scientific knowledge in the classroom. *Educational Researcher, 23*(7), 5-12. https://doi.org/10.3102/0013189X023007005

Duit, R., & Treagust, D. (2012). How can conceptual change contribute to theory and practice in science education? In B. J. Fraser, K. G. Tobin, & C. J. McRobbie (Eds.), *Second international handbook of science education* (pp. 107-118). Springer. http://doi.org/10.1007/978-1-4020-9041-7_9

Dunkin, R. (2000). Using phenomenography to study organisational change. In J.A. Bowden & E. Walsh (Eds.), *Phenomenography: Qualitative research methods series* (pp. 137-152). RMIT University Press.

Efklides, A. (2006). Metacognition and affect: What can metacognitive experiences tell us about the learning process? *Educational Research Review, 1*(1), 3–14. https://doi.org/10.1016/j.edurev.2005.11.001

Irving, P. W., & Sayre, E. C. (2012). Upper-level physics students' conceptions of understanding. *American Institute of Physics Conference Proceedings, 1513*(1), 198-201. https://doi.org/10.1063/1.4789686

Lin, T-J. Lin, T-C., Potvin, P., & Tsai, C-C. (2019). Research trends in science education from 2013 to 2017: A systematic content analysis of publications in selected journals. *International Journal of Science Education, 41*(3), 367-387. https://doi.org/10.1080/09500693.2018.1550274

Lukie, M. P. (2021), *High School Physics Students', Teachers' and, Professors' Conceptions about What it Means to Understand Physics: A Phenomenographic Study.* Unpublished PhD Thesis. Edmonton: The University of Alberta. https://doi.org/10.7939/r3-6xvc-sv40

Marton, F. (1986). Phenomenography: A research approach to investigating different understandings of reality. *Journal of Thought*, *21*(3), 28-49. http://www.jstor.org/stable/42589189

Marton, F., & Booth, S. A. (1997). *Learning and awareness*. Routledge. https://doi.org/10.4324/9780203053690

Marton, F., Dall'Alba, G., & Beaty, E. (1993). Conceptions of learning. In R. Säljö (Ed.), *Learning discourse: Qualitative research in education. International Journal of Educational Research*, *19*(3), 277-299.

Potvin, P., Nenciovici, L., Malenfant-Robichaud, G., et al. (2020). Models of conceptual change in science learning: establishing an exhaustive inventory based on support given by articles published in major

journals. *Studies in Science Education, (56)*2, 157-21. https://doi.org/10.1080/03057267.2020.1744796

Säljö, R. (1982). *Learning and understanding. A study of differences in constructing meaning from a text.* Acta Universitatis Gothoburgensis.

Trigwell, K. (2006). Phenomenography: An approach to research into geography education. *Journal of Geography in Higher Education*, *30*(2), 367-372. https://doi.org/10.1080/03098260600717489

Waterhouse, F. & Prosser, M. (2000). Students' experience of understanding university physics. *Australian Association for Research in Education Conference*, 1-10. http://www.aare.edu.au/data/publications/2000/wat00345.pdf

Watson, E. R. (2021). *Connecting Epistemic Beliefs about Physics Knowledge and Curriculum Concerns in Saskatchewan: A Mixed Analysis Study.* [Doctoral Dissertation, University of Alberta]. Education and Research Archive, University of Alberta. https://doi.org/10.7939/r3-0yef-pg89

Yang, F-Y, & Tsai, C-C. (2012). Personal epistemology and science learning: A review of empirical studies. In B. J. Fraser, K. G. Tobin, & C. J. McRobbie (Eds.), *Second international handbook of science education* (pp. 259-270). Springer.

Zhao, Z. (2015). Mainland Chinese Students' Metacognition, Including their Conceptions of Learning: A Phenomenographic Study in Hebei and Shandong Provinces. [Doctoral Dissertation, University of Alberta]. Education and Research Archive, University of Alberta. https://era.library.ualberta.ca/items/a53b175f-349d-46ca-8b6c-ba318c9a99ff

EUROPEAN SCIENCE EDUCATION RESEARCH ASSOCIATION ESERA 2025 Copenhagen

Fostering An Understanding Of The Significance Of Insect Care In Pre-Service Teacher Training

Karen Onodera
Faculty of Education, Okayama University, Japan

This study investigates the effectiveness of a teaching intervention designed to enhance pre-service teachers' understanding of "thinking from the animal's perspective" in Living Environment Studies. A six-session intervention was integrated into a Living Environment Studies course for 24 pre-service teachers at a private women's university in Japan. Through discussions, lesson planning, and reflective activities focused on insect care, they explored the pedagogical value of perspective-taking in animal care. Post-intervention data from questionnaires and lesson plan analyses indicated that 83.3% of the pre-service teachers understood the importance of perspective-taking, with 66.7% linking it to fostering respect for life. Findings suggest that structured interventions can effectively equip pre-service teachers with strategies to cultivate empathy and a biocentric worldview in the children they will teach. Future research should explore integrating the coexistence of nature and humans and strengthening connections between Living Environment Studies and science education to enhance holistic animal care.

Keywords: Living Environment Studies, Insect Care, Thinking from the Animal's Perspective

Introduction

Living Environment Studies And The Educational Significance Of Animal Care

Animal care has been an integral part of Japanese primary education since the Meiji era. Initially rooted in science education, it has since become one of the core learning activities within Living Environment Studies (LES), as noted by Saito and Yoshimura (2023). This subject was established following the revision of the national curriculum guidelines in 1989 and fully implemented in primary schools in 1992 as part of Japan's educational reform. Taught in the first and second grades, LES helps children learn how to navigate their daily lives and grow through direct, hands-on experiences with people, their community, and the natural world. By exploring these connections, children begin to understand their place in the world and learn to interact responsibly with others and the natural environment. A primary goal of LES is to help children realize that nature is a vital part of their own lives. It encourages them to reflect independently on how humans and the environment can coexist harmoniously. In this way, the subject builds a foundation for a lifetime of harmony with the world. Within these lessons, caring for animals is especially important; it helps children develop a meaningful connection with other living beings, reflect on animal–human relationships, and cultivate empathy and respect for all life. The current national curriculum guidelines emphasize that animal care should involve observation and interaction that enable children to understand animals' needs and perspectives (MEXT, 2018).

This educational orientation is consistent with the natural tendencies of humans to understand and respond to animals, as indicated by psychological research. Fujisaki (2002) reported that humans naturally perceive emotions in animals and adjust their interactions accordingly, while Fujisaki (2004) emphasized that this ability is present from early development. Yamada (2012) noted that attributing emotions to animals is a general human characteristic. However, previous studies in LES have indicated that merely providing opportunities for children to interact with animals is insufficient for learning, and that structured learning experiences are necessary to help children shift from a human-centred perspective toward an understanding that incorporates animals' natural habitats, life processes, and ecological contexts (Onodera & Fujii, 2023).

Educational Value Of Insect Care In Living Environment Studies

When focusing on the types of animals kept in Japanese primary schools, recent studies indicate a clear shift in school-based animal care practices. The keeping of birds and mammals such as chickens and rabbits has declined due to concerns about infectious diseases and management burdens, whereas the keeping of relatively low-maintenance animals, including fish, amphibians, and insects, has increased (Nakajima, 2021). Among these animals, insects occupy a particularly significant position in LES. Insects are regarded as one of the most accessible materials through which children can experience and feel connected to nature in their everyday lives (Yamashita & Shuto, 2008). Previous research has demonstrated that even insects that children tend to find less appealing, such as crickets, can become objects of care and concern through sustained rearing and observation, leading to changes in children's perceptions and the development of attitudes that value and protect living beings (Saeki & Tsuchiya, 2012). Furthermore, the Science Council of Japan (2011) has emphasized the educational value of insects as school teaching materials, highlighting their manageable size, ease of rearing, species diversity, and suitability for learning about ecological roles and life processes. Because of these characteristics, insects serve as engaging hands-on examples of how life and ecosystems work, reinforcing why they are so highly recommended for school activities.

Given these characteristics and current educational contexts, insect care represents a particularly appropriate and meaningful focus for examining how children can be guided to think from the animal's perspective within animal care in LES.

Challenges In Teacher Education For Perspective-Taking In Animal Care

In classroom practice, facilitating this shift requires teachers to intentionally design learning situations that encourage children to think from the animal's perspective. Such situations may include activities in which children imagine animals' living environments, compare natural habitats with rearing cases, and reflect on how human actions influence animals' lives. Through these processes, children can begin to connect emotional engagement with cognitive understanding, thereby forming foundational perspectives related to respect for life and coexistence between nature and humans. Despite the recognized importance of these pedagogical approaches, existing research on teacher education for animal care in LES has largely focused on technical and managerial aspects, such as appropriate species selection and daily care routines (Miyazono & Miyagawa, 2012; Suzuki, 2006). While these studies provide valuable practical guidance, they have paid limited attention to how teachers can support children in thinking from the animal's perspective and linking such perspective-taking to ethical attitudes, including empathy and respect for living beings. Moreover, although research on teacher education in LES has accumulated since the subject's introduction, much of this work has emphasized understanding the subject's philosophy or improving general lesson design skills. As a result, there remains a notable lack of empirical studies examining how pre-service teachers learn to design animal care lessons that intentionally cultivate children's ability to consider animals' perspectives as a foundation for humane and responsible relationships with animals.

Purpose Of The Study

This gap in teacher training highlights the need for interventions specifically designed to enhance pre-service teachers' understanding of the importance of "thinking from the animal's perspective" in animal care. Accordingly, this study aims to investigate the effectiveness of such a teaching intervention implemented within a mandatory LES course for pre-service teachers. By developing and implementing this intervention, the study examines whether it can promote a deeper understanding of this concept and better equip future educators to foster empathy and

respect for animals in the children they will teach, thereby contributing to more comprehensive and compassionate animal care practices in Japanese primary schools.

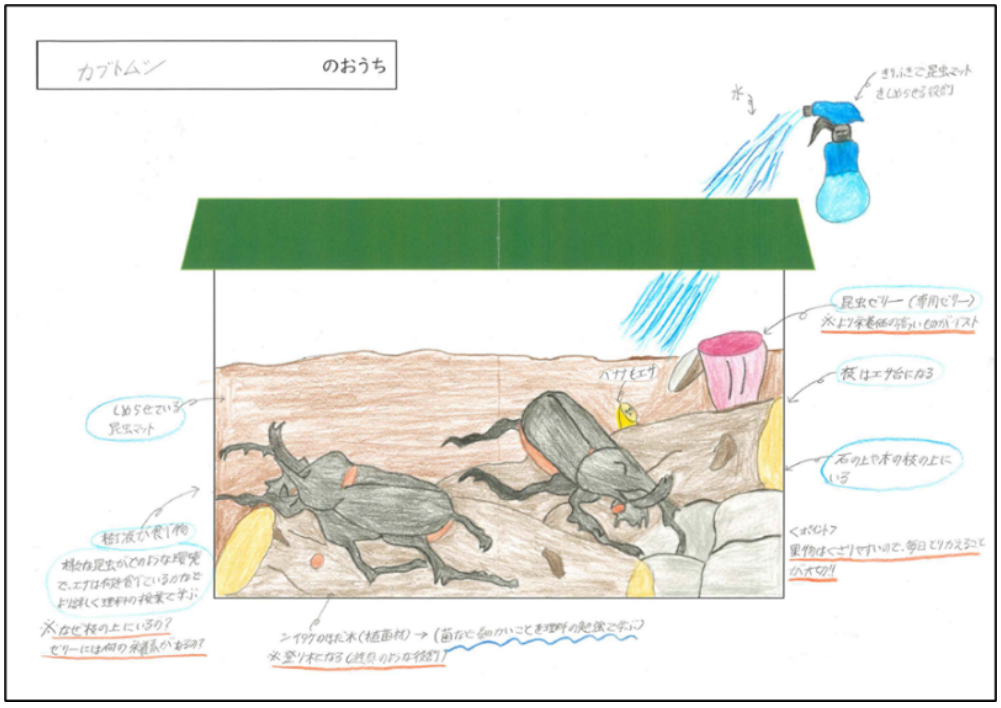
Method

Participants

The participants in this study were 24 second-year undergraduate pre-service teachers enrolled in a mandatory LES course at the faculty of education of a private women's university in Japan. The course constituted a core component of their pre-service teacher education program for obtaining primary school teaching certification. Before taking part in this study, they had already completed their foundational coursework in LES. Specifically, they studied the national curriculum standards issued by the Japanese Ministry of Education (MEXT), which are known as the Course of Study. This ensured that they were generally familiar with the government's official goals, core content, and the specific learning objectives required for primary schools across Japan. In addition to theoretical instruction, they engaged in experiential learning activities that mirrored those undertaken by primary school children, allowing them to examine LES from both learner and teacher perspectives. The course also addressed the continuity between LES and the rest of the curriculum. It emphasized how LES serves as an essential bridge to more specialized subjects including science and social studies, which children begin to study in the third grade.

Prior to the intervention, they had engaged in learning activities related to animal care. As part of this learning, they participated in an activity in which they designed a "home for insects" (Figure 1), focusing primarily on identifying and arranging the elements necessary for maintaining an appropriate rearing environment. This activity encouraged pre-service teachers to consider basic requirements for insect care, such as shelter and materials, from the perspective of preparing a suitable living space. However, these prior learning experiences provided limited opportunities for them to explicitly reconsider animal care from the animal's perspective or to examine how such perspective-taking could be intentionally integrated into lesson goals and instructional structures. Therefore, the instructional intervention in this study was designed to build upon pre-service teachers' existing knowledge of LES and animal care, while explicitly addressing this pedagogical gap by focusing on the educational significance of "thinking from the animal's perspective" and its incorporation into lesson design.

Figure 1. Worksheet used in the pre-intervention "home for insects" activity.



This study was reviewed and approved by the ethics committee of the university at which the author was affiliated at the time of data collection. Participation was voluntary, and informed consent was obtained from all pre-service teachers. They were informed that their decision to participate or not would not affect their course evaluation, and all data were anonymized and used solely for research purposes.

Intervention Lessons

A six-session intervention was designed to enhance pre-service teachers' understanding of the importance of “thinking from the animal's perspective” in animal care practice. The intervention was integrated into a 15-session LES course and focused on insect care as a concrete context for examining this concept. The intervention combined short lectures, guided discussions, and lesson design activities to support pre-service teachers in linking theoretical perspectives with practical lesson planning. An overview of the six intervention sessions is presented in Table 1.

In Sessions 10 and 11, pre-service teachers were introduced to the concept of “thinking from the insect’s perspective” through research findings on lower primary school children’s perceptions of insects and participated in facilitated discussions on its ethical and educational significance. In Sessions 12 and 13, pre-service teachers developed LES lesson plans on animal care, with explicit instructions to incorporate opportunities for children to consider insects’ perspectives within learning objectives, activities, and worksheets. Sessions 14 and 15 focused on peer review, revision, and reflection, enabling pre-service teachers to critically examine how effectively their lesson designs embodied the intended pedagogical focus.

Table 1. Intervention Lessons-

Session	Session Content
10	Introduction to the concept of "*thinking from the insect's perspective*" and its relevance to LES. This included a presentation of research findings regarding lower primary school children's perceptions of insects and their perspectives.
11	Facilitated discussion on the significance of incorporating "thinking from the animal's perspective" in animal care, prompting pre-service teachers to consider the ethical implications and potential benefits.
12-13	Pre-service teachers developed LES lesson plans focusing on animal care with an emphasis on "thinking from the animal's perspective". This included the design and creation of accompanying worksheets for primary school children to encourage engagement with the concept.
14	Peer review and constructive feedback sessions on the developed lesson plans and worksheets. Pre-service teachers revised and refined their teaching materials based on this feedback.
15	Pre-service teachers presented their final lesson plans and worksheets. A facilitated group discussion followed, focusing on the learning outcomes of the intervention, challenges encountered in the lesson planning process, and the overall significance of "thinking from the animal's perspective" in animal care.

Data Collection And Analysis

To evaluate the effectiveness of the instructional intervention in promoting pre-service teachers’ understanding of "thinking from the animal’s perspective," a post-intervention questionnaire was administered in July 2023. This took place following a 15-session LES course that incorporated a targeted six-session intervention. The questionnaire was designed to capture a comprehensive view of how pre-service teachers understood lesson design through a single open-ended question.

They were asked to describe, in bullet points, their primary takeaways regarding animal care lessons and the underlying rationale for their views. This single integrative prompt encouraged them to articulate their learning in their own words without being influenced by leading terminology. To safeguard the internal validity of the study, specific concepts such as "thinking from the animal's perspective" were not explicitly presented in the question. This design allowed for an examination of whether such ideas had been inductively internalized and prioritized by pre-service teachers.

The primary dataset consisted of the free-response text obtained from these questionnaires. To enable a more careful interpretation and bolster construct validity, the study employed data triangulation by analysing lesson plans and worksheets created during the intervention alongside the questionnaire responses. This cross-referencing served to verify whether the understandings expressed in written reflections were consistently reflected in pre-service teachers' actual lesson designs and learning activities. The qualitative analysis utilized a process of inductive coding, beginning with an exhaustive reading of the data to identify initial themes grounded in the pre-service teachers' own language. Through the method of constant comparison, these codes were iteratively tested against the entire dataset to ensure categorical consistency.

To mitigate researcher bias and achieve interpretive rigor, codes were refined into overarching themes over multiple rounds of review until thematic saturation was reached. Each theme was corroborated by representative excerpts to provide a clear evidence trail, ensuring the results remained firmly anchored in the raw data and demonstrated the plausibility of the emerging findings.

Findings

Learning Processes During The Intervention Lessons

During Sessions 10 to 15, gradual developments were observed in pre-service teachers' understanding of animal care, particularly regarding the importance of thinking from the insect's perspective, as reflected in their discussions, lesson planning processes, and reflective activities conducted during the intervention lessons.

Session 10 focused on establishing the goals of animal care activities in LES and introducing research findings on how children perceive the feelings of reared insects. Through individual worksheet writing and peer discussions, pre-service teachers articulated various reasons for the importance of adopting an insect-centred perspective, including fostering respect for life, helping children recognize their own anthropocentric assumptions, and promoting coexistence with other living beings. Overall, they came to view the cultivation of an insect-centred perspective as essential for respecting life and living together with insects in LES.

In Session 11, discussions centred on how lessons and activities could support a shift from human-centred to insect-centred thinking among children. Pre-service teachers proposed experiential activities such as role-playing insects confined in rearing cases or imagining changes to their own school environment and applying those feelings to insects. Notably, some who initially believed that simple observation was sufficient to foster perspective-taking reconsidered their views after listening to peers and began to emphasize the importance of embodied and expressive activities, such as dramatization, to support deeper understanding.

During Sessions 12 and 13, pre-service teachers developed lesson plans for the first time. Many plans set learning objectives related to imagining insects' feelings and designing appropriate rearing environments. The plans frequently incorporated experiential learning methods valued in LES, including simulated environments, role-play, and prediction activities. By creating

worksheets and anticipating children's responses, they repeatedly revised their lesson plans, reflecting on the alignment between learning goals, activities, and the intended perspective-taking.

In the final sessions (14 and 15), pre-service teachers evaluated and presented their lesson plans and reflected on the broader educational significance of animal care. Discussions highlighted the necessity of teachers intentionally designing activities that prompt children to think from an insect's perspective, while also cautioning against the imposition of fixed interpretations regarding an insect's feelings. They further explored the continuity between LES and science education, noting that the perspectives and skills cultivated through insect care, such as comparison, prediction, and respect for living environments, could be transferred to later science learning. These reflections indicate that pre-service teachers not only deepened their understanding of perspective-taking but also began to situate animal care within broader educational goals, including coexistence between nature and humans.

Analysis Of Questionnaires

The following excerpts (Table 2) from the questionnaires further illustrate pre-service teachers' understanding of the significance of "thinking from the animal's perspective" in animal care education. The qualitative analysis focused on identifying recurring ideas and patterns across pre-service teachers' free-response answers through repeated reading and comparison of responses.

Table 2. Emerging Themes from the Questionnaire Analysis

Theme	Example Quotes
Empathy and Perspective-Taking	• "It is crucial to design lessons that enable children to consider the needs of animals from the animal's perspective." • "It is important to encourage children to step into the shoes of animals." • "Through animal care activities, children can begin to think from the standpoint of living beings different from themselves." • "In LES, it is important to engage with various feelings, including those of oneself, others, and animals, without assuming a single correct answer."
Recognizing the Value of Life	• "It is also crucial to help children understand that animals, like humans, have lives that deserve to be valued and protected." • "I believe it is important for children to understand that animals, like humans, have lives and must be treated with care." • "By learning about the preciousness of life, children's attitudes toward animals may change."
Shifting from an Anthropocentric to a Biocentric Perspective	• "This can lead to a more life-centred and ecological perspective, allowing children to empathize not only with animals but with all living beings." • "This can help them shift from a human-centred viewpoint to an animal-centred viewpoint, leading to a deeper understanding of the value of life." • "By considering animals' feelings from multiple perspectives, children can shift from self-centred thinking to a life-centred way of thinking." • "Children need to recognize that animals play roles in nature and that these roles are connected to human life."
Fostering Responsible Behaviour	• "They may become more careful in their handling of animals and more likely to return them to their natural habitats after observation." • "Children may begin to handle animals more gently and return insects to their original environments after observation."

	• "Understanding the differences between natural environments and rearing cases can encourage children to act responsibly toward animals." • "It is important to care for animals responsibly by providing environments suited to their specific needs."

Analysis of the post-intervention questionnaires indicated that 83.3% (20 out of 24) of the pre-service teachers explicitly stated that incorporating "thinking from the animal's perspective" was crucial in LES animal care lessons. Further analysis of these 20 responses revealed that the majority (66.7%, or 16 pre-service teachers) associated this approach with raising children's awareness of life and fostering an attitude of respect for all living beings. They highlighted that encouraging children to consider the animal's perspective could lead to a deeper understanding of the value of life, promoting a shift from an anthropocentric viewpoint to a more biocentric perspective. The percentages reported here are used to indicate the relative prevalence of these themes among pre-service teachers and to complement the qualitative interpretation, rather than to provide statistical generalization. This suggests that the intervention successfully enabled pre-service teachers to understand the pedagogical value of "thinking from the animal's perspective" within LES.

Reflection in Lesson Plans

This understanding was further reflected in the lesson plans developed by the pre-service teachers. Many of these plans incorporated activities specifically designed to encourage children to empathize with animals. These lesson plans were examined to explore how the understandings expressed in the questionnaire responses were translated into concrete instructional ideas, with attention to features that appeared across multiple pre-service teachers' plans. Examples include having children enter a cardboard box designed to represent a rearing case to encourage them to imagine the feelings of an insect within, and role-playing activities where children take on the roles of both the "carer" (human) and the "cared for" (insect) to promote a deeper understanding of both perspectives. These findings demonstrate that the intervention was effective in not only enhancing pre-service teachers' theoretical understanding of "thinking from the animal's perspective" but also in equipping them with practical strategies to incorporate this approach into their future teaching. The emphasis on empathy and respect for life aligns with the broader aims of LES and reflects a growing recognition of the importance of fostering these values in primary education.

Discussion

Implications Of Key Findings

This research aimed to develop and implement a teaching intervention within a mandatory "Living Environment Studies" course for pre-service teachers to enhance their understanding of the significance of "thinking from the animal's perspective" in animal care. The findings suggest that the intervention was successful in achieving this aim. The majority of the pre-service teachers (83.3%) understood the importance of incorporating "thinking from the animal's perspective" in LES animal care lessons. Furthermore, most of them (66.7%) understood this pedagogical approach as a means to cultivate children's awareness of life and foster an attitude of respect for all living beings.

This positive outcome can be attributed to the design of the intervention, which provided opportunities for pre-service teachers to actively engage with the concept. By developing lesson plans and discussing the rationale behind "thinking from the animal's perspective," they were able to grapple with key questions, such as:

- What are the core goals of animal care education in LES?
- What does it mean to think from an animal's perspective?
- How can this approach be effectively incorporated into LES lessons?

This process of active engagement and reflection appears to have been crucial in deepening pre-service teachers understanding of the significance of this pedagogical approach. While previous studies in LES have highlighted the importance of children's experiential learning with animals, the present study extends this line of research by demonstrating how pre-service teachers can be supported in intentionally designing animal care lessons that foreground animals' perspectives as an educational goal. The intervention successfully highlighted the potential of "thinking from the animal's perspective" to not only enhance children's understanding of animal care but also to foster broader values such as empathy, respect for life, and a biocentric worldview.

Future Directions

Building on the findings and limitations of this study, two key areas for future development were identified:

1. Incorporating the concept of coexistence between nature and humans: While this study focused on fostering empathy towards animals, it is important to expand this concept to encompass a broader understanding of the interconnectedness between humans, animals, and the natural world (Matsumoto & Noda, 2009). Future interventions could explore ways to incorporate this concept of coexistence into LES animal care lessons, thereby encouraging pre-service teachers to consider the relationship between wildlife and humans, as well as the impact of human actions on the environment.
2. Exploring the connection between animal care in LES and science education: This study primarily focused on the role of animal care within LES. However, the values of respecting life and understanding living beings are also central to science education. Future interventions could explore the connection between animal care in LES and science, helping pre-service teachers design learning experiences that build a foundation for future scientific exploration while fostering ethical considerations regarding animals and the natural world.

By addressing these areas for future development, this research can contribute to more holistic and effective animal care in Japanese primary schools, fostering in children a deep understanding of and respect for animals and the environment. These efforts may also help pre-service teachers translate the pedagogical principles of LES into broader educational practices.

Limitations

This study has several limitations that should be considered when interpreting the findings. First, the pre-service teachers were drawn from a single private women's university in Japan, and the sample size was relatively small. Therefore, the findings cannot be readily generalized to all pre-service teachers or teacher education contexts. Second, the study relied primarily on self-reported data collected through a post-intervention questionnaire. Although the questionnaire was designed to encourage reflective and descriptive responses, the findings represent pre-service teachers' perceived learning rather than direct evidence of changes in teaching practice or long-term instructional outcomes. In addition, because no pre-intervention questionnaire was administered, it was not possible to quantitatively compare changes in pre-service teachers' understanding before and after the intervention. Third, all qualitative data were analysed by a single researcher. While a transparent and systematic analytic procedure was employed to enhance the trustworthiness of the analysis, alternative interpretations of the data may be possible.

Future studies could strengthen analytic rigor by involving multiple researchers or employing additional validation strategies, such as member checking or inter-rater discussion.

Finally, this study focused on pre-service teachers' understanding immediately following the completion of the course, including the instructional intervention. As a result, it did not examine how this understanding may develop over time or be enacted in actual classroom practice. Longitudinal research following pre-service teachers into their teaching careers would provide further insight into the sustained impact of learning to "think from the animal's perspective" in animal care.

Note

This paper is an expanded and revised version of part of the author's doctoral dissertation.

Acknowledgement

The author would like to express sincere gratitude to all those who cooperated in this research, as well as to the colleagues who provided invaluable guidance and support. This study was supported by JSPS KAKENHI Grant Number 24KK0048.

References

Fujisaki, A. (2002). Owners' understanding of their pets' internal states. *The Japanese Journal of Developmental Psychology*, 13(2), 109–121. (in Japanese)

Fujisaki, A. (2004). Children's experience of taking care of rabbits and understanding of "animal mind." *The Japanese Journal of Developmental Psychology*, 15(1), 40–51. (in Japanese)

Matsumoto, M., & Noda, A. (2009). A study about education of life esteem in the life environment studies. *Journal of the Faculty of Education, Ehime University*: *Educational Sciences*, 58, 1–9. (in Japanese)

Miyazono, M., & Miyagawa, T. (2012). The lecture and activities on animal breeding in the teaching method of living environment studies. *Bulletin of the Faculty of Education, Niigata University, Humanities and Social Sciences Edition*, 5(1), 1-9. (in Japanese)

Ministry of Education, Culture, Sports, Science and Technology [MEXT]. (2018). *Elementary school teaching guide for the course of study: Living environment studies*. Tokyo: Tokyo Shoseki. (in Japanese)

Nakajima, Y. (2021). The role and current status of animals in school education. *Psychology World*, 92, 9–12. (in Japanese)

Onodera, K., & Fujii, H. (2023). Young children's perspectives on thinking from the standpoint of insects. *Journal of Research in Science Education*, 64(1), 63–72. (In Japanese)

Saiki, H. & Tuchiya, Y. (2012). The influence of breeding and observing the insects on elementary school student's consciousness: regarding the emma cricket "*teleogryllus emma*" and the white cabbage butterfly "*pieris rapae* crucivora." *Journal of Research in Science Education*, 52(3), 77-87. (in Japanese)

Saito, C., & Yoshimura, T. (2023). A study of issues related to "raising animals" in elementary school living environment studies. *Bulletin of Miyagi University of Education*, 57, 53-66. (in Japanese)

Science Council of Japan, Committee on Agricultural Sciences, Subcommittee on Applied Entomology. (2011). *Report: The role that insect science should play and the necessity of its promotion*. (in Japanese). Retrieved from https://www.scj.go.jp/ja/info/kohyo/pdf/kohyo-21-h130-1.pdf

Suzuki, T. (2006). A study of the breeding activity about teaching methods for subjects of human life and living. *Bulletin of the Faculty of Education*, *Chiba University*, 54, 93-98. (in Japanese)

Yamada, H. (2012). Personification as the social emotional behaviours in human and animal interactions. *Japanese Journal of Animal Psychology*, 62(1), 41-47. (in Japanese)

Yamashita, K. & Shuto, T. (2008). Effect of Children's Relations with Insects on Their Social Development. *Journal of Saitama University*, *Faculty of Education*, 57(2), 105-121. (in Japanese)

EUROPEAN SCIENCE EDUCATION RESEARCH ASSOCIATION ESERA 2025 Copenhagen

Exploring The Attention Dimension Of Plant Awareness Through Drawing: From Stereotypes To Detailed Observations

Marcia Eugenio-Gozalbo[1], Inés Ortega-Cubero[1] and Rafael Suárez-López[2]
[1]Faculty of Education of Soria, University of Valladolid, Spain
[2]Faculty of Education, University of Salamanca, Spain

The construct 'plant awareness' emphasizes the importance of improving individuals' understanding, appreciation, and attention towards plants. This study explores the role of naturalistic drawing as a strategy to foster plant awareness, focusing on how pre-service teachers represent plants graphically without instruction. Both drawings and text notes were qualitatively analysed through the constant comparison method to classify them into conceptual categories (drawings) and based on information richness (text notes). We observed that students often struggle with representing the volume of plants -especially of those with dense foliage-, and that they tend to use stereotypes to represent plant parts and even whole plants, thus avoiding drawing difficulties. A main identified barrier was plant elements' overlapping, a trait that was not adequately captured in most drawings, which can be attributed to the natural evolution of graphic expression in most adult population lacking art training. Our findings support the idea that drawing is a useful strategy to promote observation and attention towards plants. However, instruction should focus on certain aspects that are particularly challenging for learners, so initial barriers can be overcome, and the observations of plant structures and traits can be refined.

Keywords: attention, naturalistic drawing, plant awareness, pre-service teachers

Introduction

The term 'plant blindness' (Wandersee & Schusler, 1999) describes how people tend to overlook plants. Since then, reversing this phenomenon has become a major goal of biological education. A recent conceptualization links 'plant awareness disparity' to a lack of attention, interest, positive attitudes, and knowledge about plants (Parsley, 2020). Pany et al. (2022) proposed using 'plant awareness' instead, emphasizing positive engagement. Recently, this theoretical construct was defined as "a multidimensional construct that reflects the level of an individuals' perception, understanding, and valuation of plants" (Dünser et al., 2024).

A key challenge in fostering plant awareness is enhancing individuals' attention to plants. One effective strategy to improve plant awareness could be promoting their observation through drawing (Eugenio-Gozalbo & Ortega-Cubero, 2022). Drawing deepens scientific understanding by stimulating intense observation and aiding effective data recording for subsequent study (Katz, 2017). Several theoretical frameworks address the role of drawing in learning. Dual coding theory states that integrating verbal and non-verbal information facilitates the construction of a coherent mental representation and recall (Paivio, 2014). The later theory of generative learning considers that drawing connects previous knowledge with new content, contributing to building mental models and enhancing understanding and recall (Fiorella & Mayer, 2016). However, drawing is a difficult task for many people, requiring spatial abilities that are hard to develop, and is time-consuming and cognitively demanding (Fiorella & Zhang, 2018).

Classical treatises on children's drawing emphasize that children tend to place each element in drawings in its own space, avoiding overlap. Objects in front of another are usually drawn next to, rather than partially overlapping, each other (Lowenfeld & Brittain, 2008; Martínez, 2004; Matthews, 2002). This trait persists in adults who have not advanced beyond the developmental

stages of childhood graphic language, which applies to most people. It leads to unconscious resistance, causing moments of creative block during demanding drawing exercises. To avoid this, most people use stereotypes—simple images as communicative symbols. The tree stereotype is particularly widespread, often depicted with a rectangular trunk supporting a rounded or fan-shaped canopy spread out on a single plane (Parini, 2002). Stereotypes are typically drawn with firm, inexpressive lines. Parini (2002) recommends using 'trembling, sharp, unpredictable, piercing, curved, or tortuous lines, or inventing one's own' to effectively depict different types of plants, emphasizing that these strokes 'are highly appealing for overcoming stereotypical representations' (p. 188).

In this research, we aimed at posing a naturalistic drawing exercise to pre-service teachers (PSTs) to be conducted without any artistical or biological instruction; to unveil the difficulties they faced in drawing and perceiving plant structure and traits. The exercise was conducted outdoors, with students free to choose any plant specimen, as we were also interested in such choices themselves.

Materials And Methods

The study involved third-year 39 PSTs in the compulsory subject 'Natural Sciences', of the Degree in Pre-School Education at the Faculty of Education of Soria (University of Valladolid, Spain). A teaching-learning sequence designed to promote plant awareness, published elsewhere (Eugenio-Gozalbo et al., 2024), combined artistic and scientific activities, both theoretical and practical, some conducted outdoors at an organic garden. The artistic part focused on observation-based drawing, particularly botanical illustration, to help students understand plant morphology, thus laying the foundation for effective learning of basic plant classification. One of the initial activities of such sequence was the naturalistic drawing exercise, whose results are presented here.

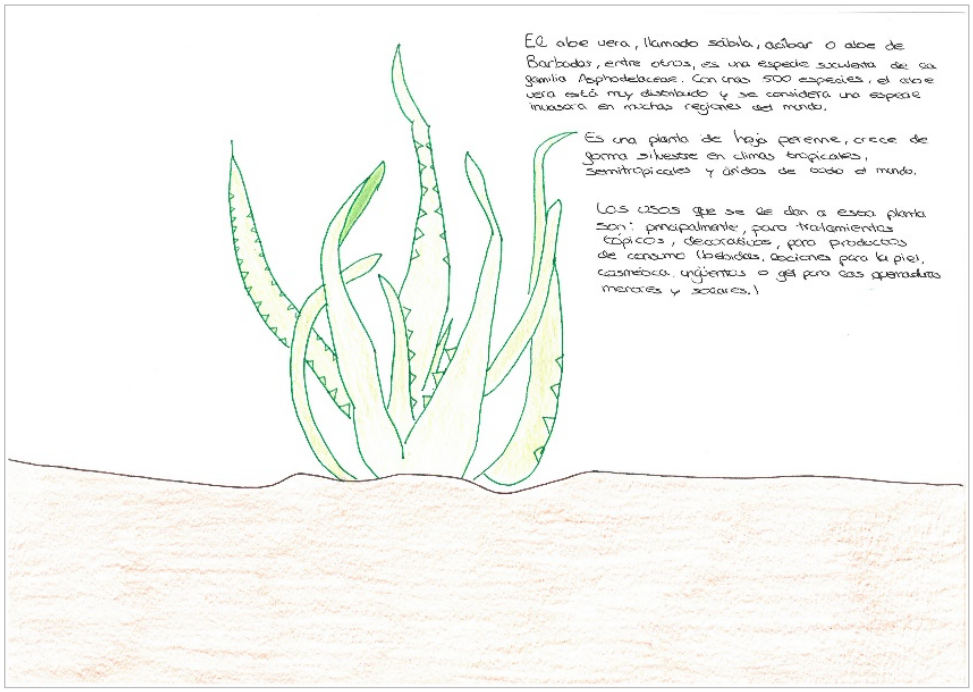
Students' drawings and text notes were qualitatively analysed by two researchers using Grounded Theory, through the constant comparison method. This approach involved systematically and iteratively examining the sample to identify emerging categories and subcategories of graphic representations, rather than using predefined classifications. The drawings were analysed together to detect recurring patterns and establish a more robust categorization. Text notes were categorised into three complexity levels (low, medium and high), based on the type and richness of information. The final categorization was reached through consensus between the researchers, who discussed all cases, particularly those with ambiguities.

Results

Drawing Analysis

Of the 39 drawings analysed, most students chose to depict trees (23), followed by herbaceous plants (12), and shrubs (4). A strong preference for flowering plants was observed, with 28 drawings featuring plants with flowers and only 11 without. Thus, trees were the plant form most frequently drawn, with 17 featuring flowers. Almond trees (Prunus dulcis) dominated this category, with 15 representations, while a pear tree (Pyrus communis) and a cherry tree (Prunus avium) were also included. The remaining six tree drawings depicted non-flowering species. Shrubs were less common, with an equal distribution between flowering and non-flowering species. Herbaceous plants accounted for 12 drawings, nine of which had flowers. Notably, three students selected Aloe vera, likely due to its simple appearance, though its thick, sculptural leaves posed unexpected challenges in conveying the sense of volume (Figure 1).

Figure 1. Example of an *Aloe vera* drawing with an inaccurate three-dimensional representation.



Students faced significant difficulties in tree representation, often lacking spatial awareness, resulting in flat, fan-like depictions with all elements displayed on the same plane (Figure 2). When drawing trunks, eight students failed to depict the gradual tapering of trunks, creating structures that widened and narrowed arbitrarily. In contrast, nine students correctly showed this transition, with six achieving a sense of volume. However, three avoided the challenge by focusing on small details like branches or saplings. Non-flowering trees exhibited similar issues, with half of the students' making distortions. For canopies, three students struggled to convey volume, instead outlining individual elements uniformly, thus avoiding overlapping. This approach resulted in rigid, repetitive patterns, reinforcing the flat, schematic nature of their drawings. Some added excessive leaves to conceal structural difficulties, as seen in an olive tree drawing. Few students included trunk textures, with only four drawings (poplar, olive, cherry, and almond trees) showing this detail. Similarly, leaf details were rare, appearing in a few cases (holm oak, two olive trees, one cherry, and one pear tree). Notably, the absence of leaves in almond trees at the time of observation likely influenced this.

A clear correlation between the quality of trunk and flower representations was observed. PSTs who depicted tree structures well also rendered flowers more accurately. The biggest challenge was capturing petal perspective, especially in non-frontal views, where some petals appear smaller. Six students successfully created recognizable flowers (five almond flowers, one pear flower), with most belonging to the group that achieved better tree representations. Common difficulties included simplification or exaggeration of petal shapes, the latter indicating effort despite inaccuracies. A strong example of expressive floral drawing was an almond flower drawing (Figure 3), where she used a loose, irregular stroke to capture petal fragility. When depicting flowers in tree canopies, students tended to repeat the same graphic symbol uniformly instead of creating texture, further reinforcing the fan-like canopy representation (see Figure 2).

Figure 2. Example of an almond tree (*Prunus dulcis*) representation in a single plane.

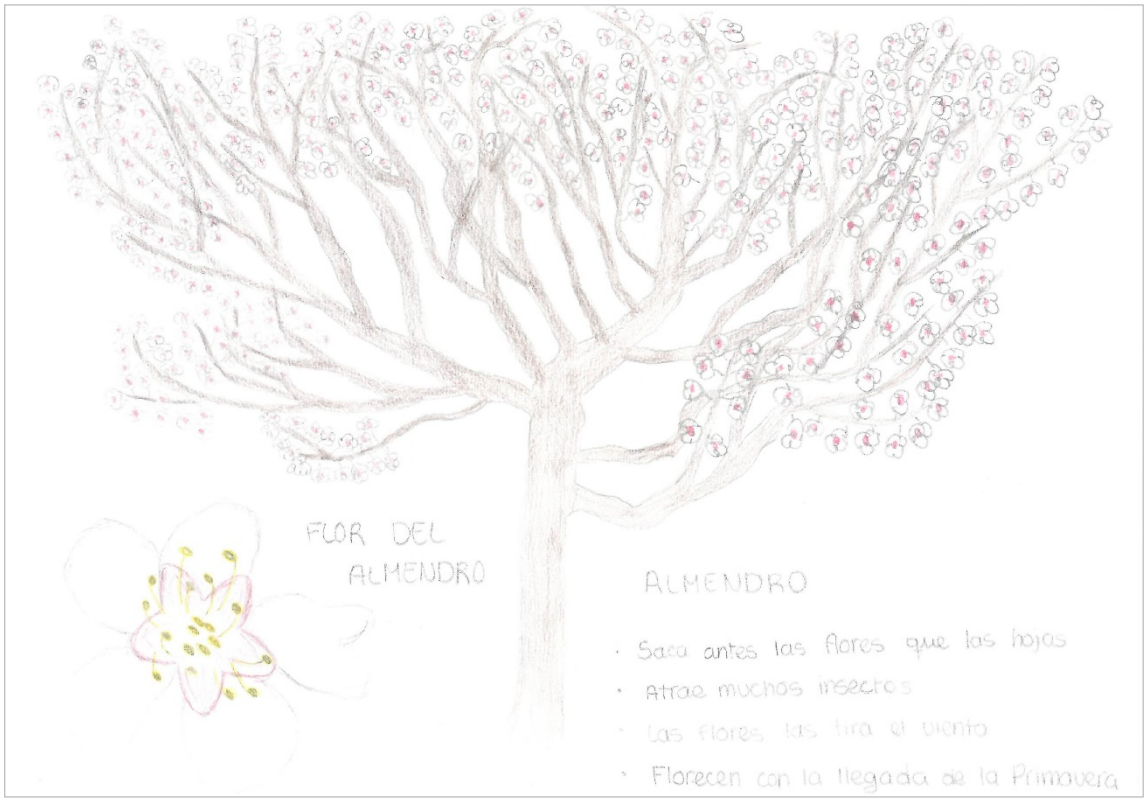
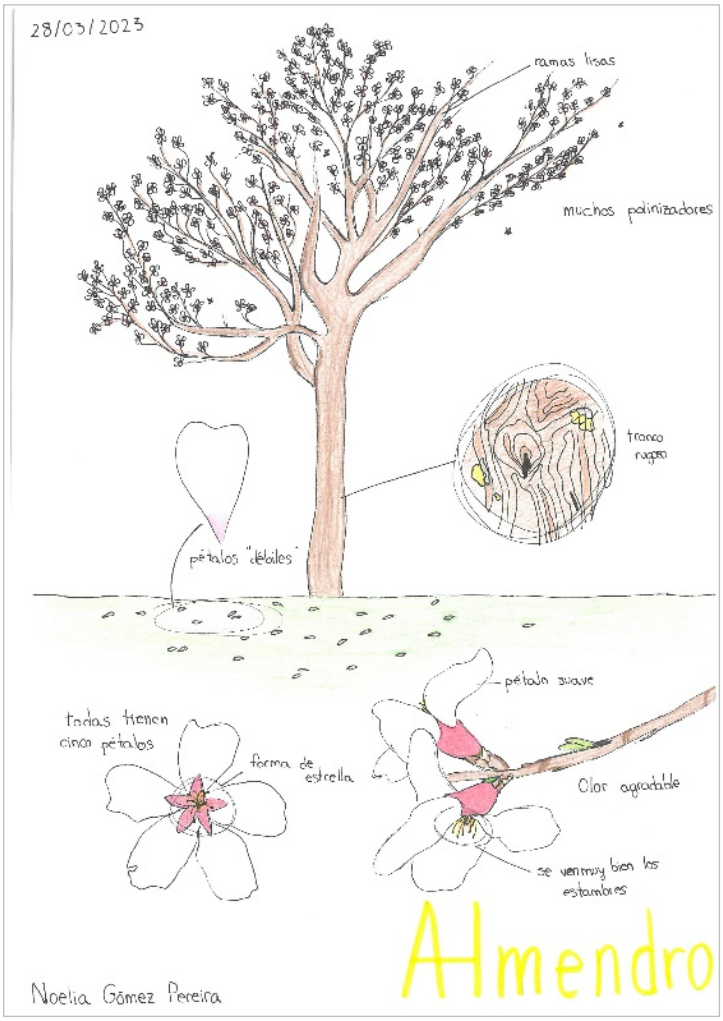


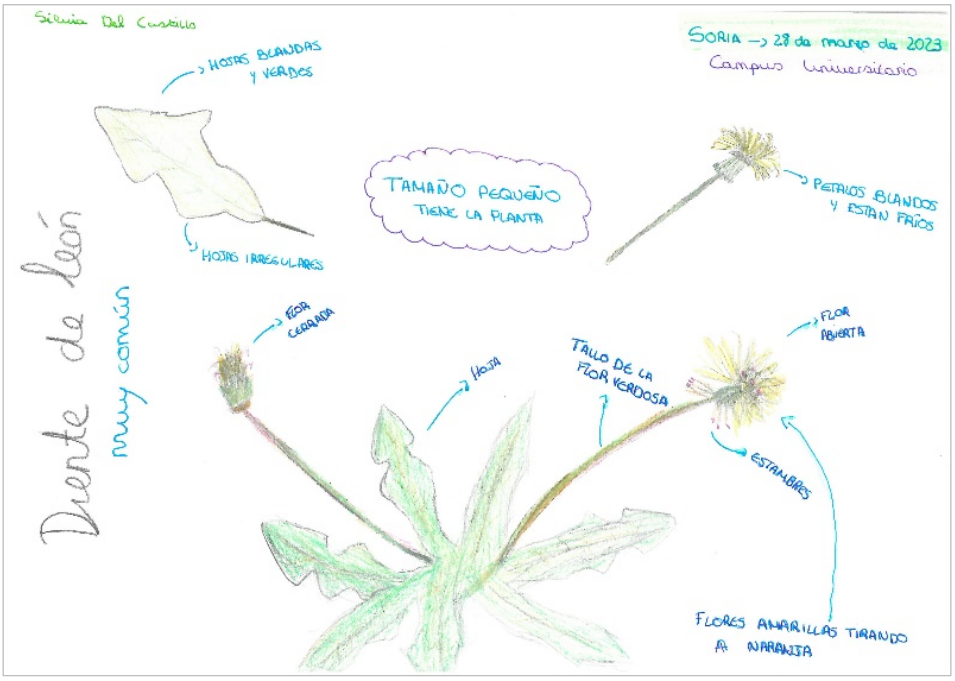
Figure 3. Example of an accurate representation of an almond flower (*Prunus dulcis*).



Students also encountered similar difficulties in representing volume with herbaceous plants, particularly tulips and *Aloe vera*, struggling to distinguish spatial relationships. In Asteraceae,

such as *Taraxacum* sp. and *Bellis perennis*, basal rosettes were depicted as undifferentiated masses rather than distinct leaves (Figure 4). Overall, students found it challenging to represent depth and spatial layering, indicating a broader struggle with volume perception in plant drawing.

Figure 4. Example of an inaccurate representation of a basal rosette.



Text Notes Analysis

Students' textual descriptions categorized at the low level (7 cases) typically reflected personal opinions or inaccurate observations, such as noting ‘much resistance’ or ‘irregular petals’ in the case of forget-me-not flowers (*Myosotis* sp.). This level also included information copied from the internet, such as descriptions of absent *Aloe vera* flowers. At the medium level (15 cases), students provided more concise and accurate labels. These included simple descriptions consisting of one or two adjectives (4 cases), such as “dark green stem,” or more specific, yet general, observations (11) like “petals flying in the wind” and “presence of many pollinators,” particularly for almond trees. While these descriptions lacked the richness found in higher-level texts, they still reflected the students' direct observations and were more consistent. The high level (10) included the most detailed and accurate descriptions. One student provided a long passage that described both the plant's context and its features, indicating a thorough awareness of the plant's environment. Other nine students used text notes that correspond to sensory details, such as the ‘lighter brown branches’ or ‘yellow stamens with anthers.’ In some cases, students acknowledged the limitations of their drawings and supplemented their observations with additional information.

Discussion And Conclusions

Students’ naturalistic drawings often focused on trees and flowering plants, likely influenced by their aesthetic appeal rather than other criteria. A minority chose specimens seemingly easier to draw, such as Aloe vera. In general, capturing the volume of plants proved challenging, as it was easier to depict the linear, less dense structure of herbaceous plants (with few leaves and one or more long stems, but not overlapping). This difficulty arises from the conflict between vegetal density, which is not a solid mass of leaves, and the tendency to avoid overlapping in graphic representation (Lowenfeld & Brittain, 2008; Martínez, 2004; Matthews, 2002). Thus, drawing details was easier than depicting the whole plant.

To address this challenge, it is important to provide students with strategies that focus on capturing the essence of plant forms, particularly volume and density. Emphasizing observation techniques that focus on textures, light, and shadow can help represent complex plant structures, including dense leaves or branches (Parini, 2002). Encouraging practice in both detailed and holistic representations will help them balance the intricate features of plants with their overall form. This approach encourages students to notice, reflect on, and appreciate plant morphology and complexity, ultimately improving plant awareness (Eugenio-Gozalbo et al., 2024).

Further discussion and research should address how drawing exercises can be effectively integrated into plant biology education to enhance students' observation skills. One key area of research is how to support students in moving beyond stereotypical representations of plants. Additionally, assessing the effectiveness of these educational strategies remains an important aspect for further development. The poster session will feature visual examples of the results, with an interactive component inviting participants to discuss these questions and exploring how drawing can serve as a valuable tool for improving plant awareness.

References

Dünser, B., Möller, A., Anđić, B., Lampert, P., Bergmann-Gering, A., & Pany, P. (2024). (Re) growing plant awareness: A Delphi study. *Plants, People, Planet*. https://doi.org/10.1002/ppp3.10617

Eugenio-Gozalbo, M., & Ortega-Cubero, I. (2022). Drawing our garden's insects: A didactic sequence to improve pre-service teachers' knowledge and appreciation of insect diversity. *Journal of Biological Education, 58*(3), 512–529. https://doi.org/10.1080/00219266.2022.2081243

Eugenio-Gozalbo, M., Ortega-Cubero, I., & Suárez-López, R. (2024). Mind maps for eliciting and assessing plant awareness: A preliminary study on pre-service teachers. *Plants, People, Planet*. https://doi.org/10.1002/ppp3.10605

Fiorella, L., and R. E. Mayer. 2016. Eight Ways to Promote Generative Learning. *Educational Psychology Review, 28*(4), 717–741. https://doi.org/10.1007/s10648-015-9348-9

Katz, E., Ed. 2017. *Drawing for Science Education: An International Perspective*. Sense Publishers.

Lowenfeld, V. & Brittain, W. L. (2008). *Desarrollo de la capacidad intelectual y creativa*. Madrid: Síntesis.

Martínez García, L. M. (2004). *Arte y símbolo en la infancia: un cambio de mirada*. Barcelona: Octaedro.

Matthews, J. (2002). *El arte de la infancia y la adolescencia: la construcción del significado*. Paidós.

Paivio, A. 2014. Intelligence, Dual Coding Theory, and the Brain. *Intelligence 47*, 141–158. https://doi.org/10.1016/j.intell.2014.09.002.

Pany, P., Meier, F. D., Dünser, B., Yanagida, T., Kiehn, M., & Möller, A. (2022). Measuring students' plant awareness: A prerequisite for effective botany education. *Journal of Biological Education, 58*(5), 1103–1116. https://doi.org/10.1080/00219266.2022.2159491

Parini, P. (2002). *Los recorridos de la mirada: Del estereotipo a la creatividad*. Paidós.

Parsley, K. M. (2020). Plant awareness disparity: A case for renaming plant blindness. *Plants, People, Planet, 2*(6), 598–601. https://doi.org/10.1002/ppp3.10153

Wandersee, J. H., & Schussler, E. E. (1999). Preventing Plant Blindness. *The American Biology Teacher, 61*(2), 82–86. https://doi.org/10.2307/4450624

EUROPEAN SCIENCE EDUCATION RESEARCH ASSOCIATION ESERA 2025 Copenhagen

Agile In Academia: Assessing Scrum's Potential For University Teaching

Dirk Brockmann-Behnsen
Leibniz University Hannover, Germany

This study explores the integration of the Scrum concept into university-level teacher training, specifically within a physics teaching internship preparatory course at Leibniz University Hannover. Originally developed for agile software development, Scrum promotes self-directed learning and iterative improvement, aligning well with modern educational approaches. The study investigates the effectiveness of Scrum in fostering pre-service teachers' competence development through a structured, team-based lesson planning process. A longitudinal study was conducted to examine changes in students' competence self-assessment. Data were collected at three points: before the preparatory course, after the course, and after the following school internship. Results indicate a significant increase in competence self-assessment during the course, attributed to the iterative, feedback-driven structure of Scrum. However, a stagnation or slight decline was observed during the school internship, likely due to real-world challenges in lesson implementation. Findings suggest that Scrum is a viable framework for teacher education, enhancing competence development through structured teamwork and reflective practice.

Keywords: Pre-Service Teacher Education, Professional Development, Learning Environments

Theoretical Framework

At the Physics Working Group at Leibniz University Hannover, students train to become secondary school teachers, with the module "Physics Teaching Internship" ("Fachpraktikum") playing a key role in their preparation. This module consists of a preparatory course at the university (1.5 hours per week over 14 weeks) and a five-week internship at grammar or vocational schools. The course aims to develop practical teaching competences through both subject-specific and pedagogical training. It encourages students to explore professional teaching approaches and to critically reflect on their actions based on educational research.

Previously, the preparatory course followed a traditional, lecturer-led format, focusing on lesson planning and execution. However, in the winter semester of 2022/2023, a paradigm shift toward more student-centred learning was implemented. Research indicates that self-directed learning enhances intrinsic motivation (Dignath & Büttner, 2008; Stone, Deci, & Ryan, 2009). This principle is integral to the Scrum methodology (Schwaber & Sutherland, 2020), which originates from agile software development, but is now used in many other areas. In the school sector, it was first adopted by Willy Wijnands in the Netherlands in 2011 as "eduScrum".

In the revised course format, students work in teams of three to five, with one member serving as team captain responsible for coordinating the group's workflow. Teams create lesson plans on assigned topics within three course sessions. They organize their tasks using a backlog, a tabular overview that lists specific work steps and tracks progress via mobile graphical elements. Completed lesson plans are uploaded to an online platform, where they undergo peer review. This review process provides critical feedback, which students use to refine their lesson plans. Regular team discussions allow members to assess their collaboration, identify strengths and weaknesses, and make improvements. This iterative approach ensures continuous enhancement of lesson plans and contributes to the development of a cohesive teaching unit.

The effectiveness of this Scrum implementation in academic teaching is investigated in an accompanying study, which examines its impact on student competences. The study already found that Scrum was well-suited for university-level education. Students particularly valued the small team structure and the lecturer's advisory role (Brockmann-Behnsen, 2024).

This report specifically examines the development of the students' competence self-assessment during the preparatory course and the internship. Competence, as a theoretical construct, is complex and lacks a universal definition (Weinert, 2001, p. 46). One relevant framework is "action competence", which includes problem-solving skills, critical thinking, social skills, and domain-specific strategies. In the school context, the German Conference of Ministers of Education and Cultural Affairs (Kultusministerkonferenz, 2004) defines key competence areas as *"teaching"* (instructional design, learning facilitation, differentiation, etc.), *"educating"* (values education, social development, conflict management, etc.), *"assessing"* (diagnostic assessment, performance evaluation, feedback, etc.) and *"innovating"* (professional development, reflective practice, school improvement, etc.). These domains are the focus of the current study on the effectiveness of Scrum-based learning in teacher training.

Research Questions

As the competence self-assessment is to be examined during the preparatory course and internship, a longitudinal study is appropriate. The research questions therefore focus on the developmental stages occurring throughout these two phases:

[Q1] How does the students' competence self-assessment represented by the above-mentioned areas 'teaching', 'educating', 'assessing' and 'innovating' change during the preparatory course?

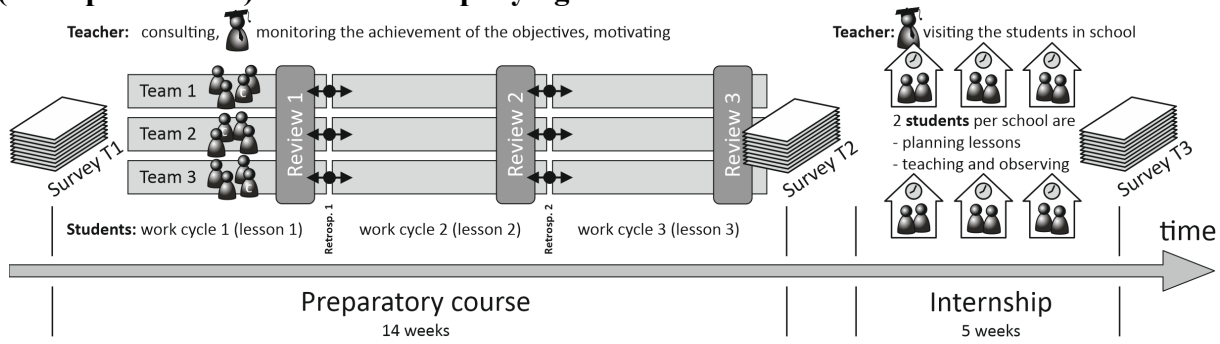
[Q2] How does the students' competence self-assessment change during the school internship?

Hypotheses:
It is to be expected that the competence self-assessment will improve during the preparatory course, as the iterative, incremental approach of the Scrum concept leads to a noticeable improvement in the lesson planning and corresponding feedback. During the block internship in the schools, on the other hand, students often experience that a good lesson plan does not necessarily lead to a good lesson. It can therefore be assumed that during this phase the competence self-assessment does not increase further or even decreases.

Methodology

Since the study is intended to examine the students' competence self-assessment in the course of the preparatory course and the internship, three measurement points were determined at which written surveys were conducted with the participants: at the beginning of the preparatory course (T1), between the preparatory course and the school internship (T2) and at the end of the internship (T3). Figure 1 provides an overview of the overall course of the module. In the preparatory course, the participants were introduced to the Scrum concept and then worked within the framework of this concept. The aim of this phase was to learn professional lesson planning. These skills were then applied during the block internship in a real school context. The scientific investigations reported in this article focus on effects of this innovative approach onto the students' competence self-assessment. Therefore, the research results presented here refer to the measurement points T1 vs. T2 and T2 vs. T3 respectively.

Figure 1: Overview of the courses in the "Physics Teaching Internship" module ('Fachpraktikum') and the accompanying research.



Instrument

The survey instrument consists of three questionnaires, which are used at the respective measurement times T1, T2 and T3 (see table 1). Scales from the KLiP study (Gröschner, & Schmitt, 2012; Gröschner, Schmitt, & Seidel, 2013) were used for all three measurement points to analyse the students' competence self-assessment. The items formulated there are based on the above-mentioned educational science standards of the German Conference of Ministers for Education. Six to eleven items each relate to the four areas of competence that are important for teacher professionalization: *"teaching"*, *"educating"*, *"assessing"* and *"innovating"*. The competence self-assessment is inquired by a seven-point Likert scale ("1" corresponds to "not at all competent", "7" corresponds to "fully competent"). The items are introduced by: "The teacher is capable of ..." ("Die Lehrperson kann …"). The Likert scale formulation and the initial sentence are intended to prevent the students' overestimation of their competences and tendencies towards socially desired response behaviour (see Gröschner et al., 2013, p. 81). In order to examine the development of the participants' competence self-assessment during the preparatory course (research question [Q1]) and during the block internship (research question [Q2]), the results from the questionnaires of the survey are used at points in time T1 vs. T2 and T2 vs. T3 respectively. The central tendencies of the two pairs of data sets were examined using Wilcoxon sign rank tests.

Sample

The sample consists of N = 39 students from courses in the summer semester 2023, winter semester 2023/2024, summer semester 2024 and winter semester 2024/2025; complete data was available from 32 participants (82% cohort utilization). The course participants were on average M = 24,13 (SD = 1,87) years old. The age ranges from 22 to 30 years. The reduced sample includes 24 males, 7 female and one with diverse gender. All of them are enrolled in the course of study for a teaching degree at grammar schools.

Results

Table 1 shows the median values (M) and interquartile ranges (IQR) of the students' competence self-assessments in the four areas "teaching", "educating", "assessing" and "innovating" at the three survey times. Cronbach's α was determined to examine the internal consistency of the scales. For the areas "teaching", "educating" and "assessing" the competence self-assessment increase is significant ($p < 0{,}001$) in between timepoints T1 and T2 with median increases of 1. Between timepoints T2 and T3 only the area of 'teaching' shows a significant increase in competence ($p < 0{,}01$).

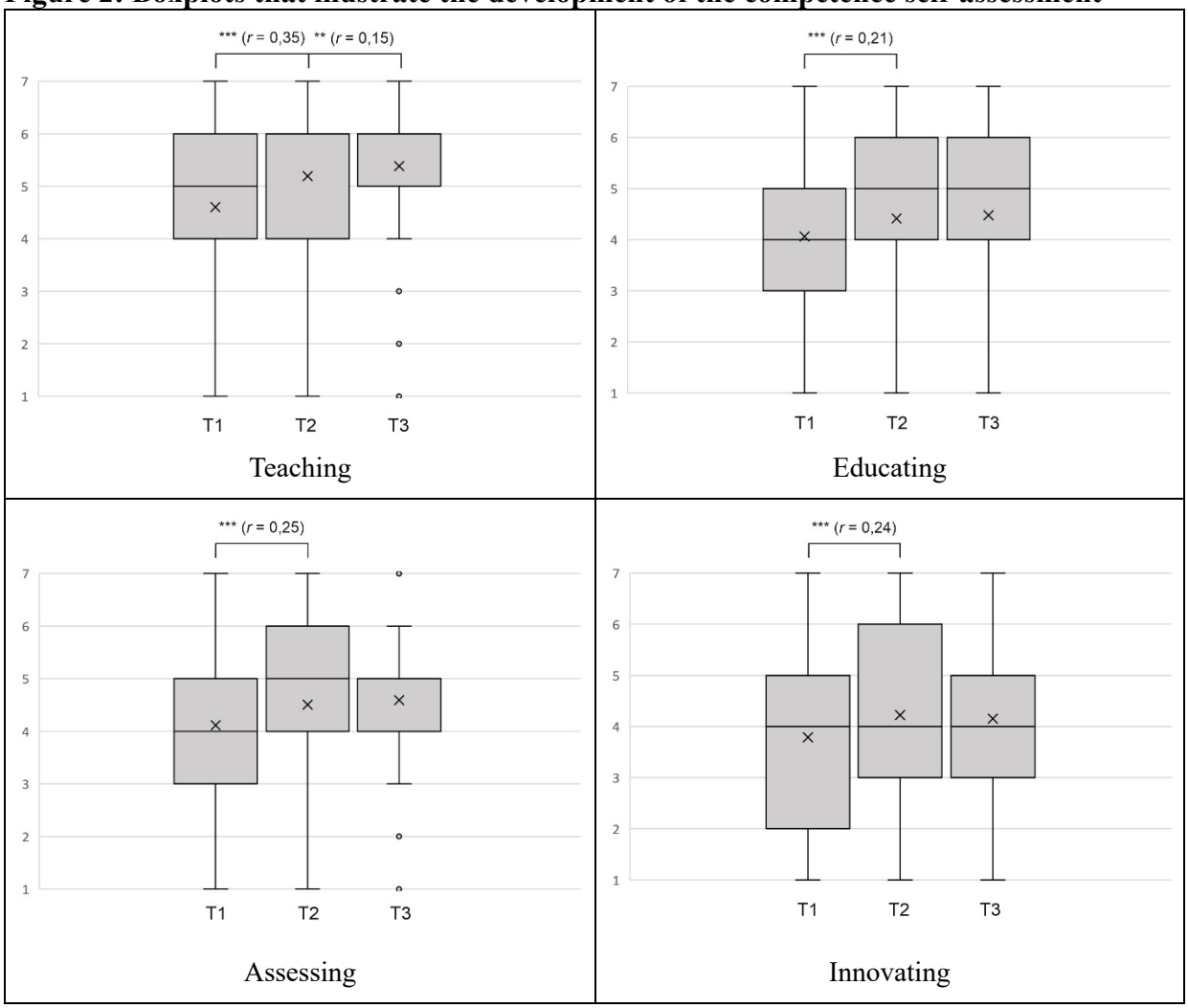
Figure 2 shows the distributions of the students' responses as box plots. The increase in self-assessments of competence between the time points T1 and T2 and the stagnation or decline

between the time points T2 and T3 can clearly be seen. The determination of the effect sizes shows small effects for all areas between the time points T1 and T2 (Pearson's r [0.21; 0.35]) and also a small effect for the ‘Teaching’ area between the time points T2 and T3 (r = 0.15).

		T1		T2		T3	
Scale	Items	*α*	*M (IQR)*	*α*	*M (IQR)*	*α*	*M (IQR)*
Teaching	11	0,82	5 (2)	0,85	6 (2)	0,86	6 (1)
Educating	9	0,76	4 (2)	0,89	5 (2)	0,81	5 (2)
Assessing	7	0,74	4 (2)	0,85	5 (2)	0,82	5 (1)
Innovating	6	0,81	4 (2,5)	0,78	4 (3)	0,87	4 (2)

Table 1: Results and statistical values for the competence self-assessment scales.

Figure 2: Boxplots that illustrate the development of the competence self-assessment



Discussion

Testing innovative concepts is of great importance for research in university teaching. The iterative and student-led approach of Scrum is a very innovative concept. It is therefore an important finding that this concept led to significant increases in the students' competence self-assessment in three of the four scales analysed during the preparatory course. This was to be expected, as the students experience themselves as very effective when working in small teams and generally receive a lot of praise and constructive feedback in the regular reviews. Due to the high frequency of the work loops, they also experience a rapid improvement in their lesson planning. This apparently also leads to an increase in self-perceived competence. It is interesting that the increase in competence self-assessment does not only refer to the area of *“teaching”*,

which is particularly addressed in the preparatory course, but is apparently also transferred to the areas of *"educating"* and *"assessing"*. It is unexpected that the preparatory seminar on the Scrum methodology does not have a significant impact on "innovation", as this methodology places particular emphasis on regular introspection and reflection with the aim of optimisation.

The stagnation or decline in the self-assessment of competences during the practical phase following the preparatory course is noteworthy. Here, the students are no longer in the familiar surroundings of their teams and the academic environment but have to implement their lesson plans into the reality of the school. They learn that not every lesson plan that is promising in theory will prove successful in everyday school life. This experience obviously manifests itself in a decline in self-assessment of competence. In this context, it is interesting to note that Gröschner et al. (2013), who developed the questionnaire used here to investigate the self-assessment of competences during a practical semester, came to different conclusions. There, the self-assessment of competence increases with the degree of perceived learning support during the practical phase. The practical phase described here does not extend over an entire semester, but only over a period of five weeks. For organisational reasons, it is also only possible to visit the students once during this time. It can be assumed that the learning support is therefore perceived as rather low. There is clear potential for improvement in this regard, particularly with respect to the duration of the practical phase. Empirical studies, such as those by Gröscher et al., demonstrate that an extended practical semester can be highly effective when accompanied by structured and high-quality supervision. In the study presented here, lesson plans were regularly reviewed and refined through systematic, collaborative critique within the preparatory seminar. Extending this iterative process into the practical phase would allow for continuous further development of instructional design. Such sustained optimisation of teaching practice is likely not only to enhance instructional quality but also to positively influence students' self-perceived teaching competence.

References

Brockmann-Behnsen, D. (2024). Teaching Internship Preparation on The Next Level – A Scrum-Based Concept for The Preparatory Seminar. Kaya, G., Sardag, M., & Donmez, I. (Hrsg.) (2024). *Proceedings Book Series-V of the ESERA 2023 Conference. Connecting Science Education with Cultural Heritage*, Strand number (co-ed. K. Gokhan, M. Sardag & I. Donmez), (222–230). Cappadocia, Türkiye. Nobel Bilimsel Eserler.

Gröschner, A., & Schmitt, C. (2012). Kompetenz im Praktikum? Entwicklung eines Instruments zur Erfassung von Kompetenzeinschätzungen und Ergebnisse einer Befragung von Lehramtsstudierenden im betreuten Blockpraktikum. *Lehrerbildung auf dem Prüfstand 2012*, *5*(2), 112–128.

Gröschner, A., Schmitt, C., & Seidel, T. (2013). Veränderung subjektiver Kompetenzeinschätzungen von Lehramtsstudierenden im Praxissemester. *Zeitschrift für Pädagogische Psychologie*, *27*(1-2), 77–86.

Kultusministerkonferenz (2004). Standards für die Lehrerbildung: Bildungswissenschaften. (https://www.kmk.org/fileadmin/veroeffentlichungen_beschluesse/2004/2004_12_16-Standards-Lehrerbildung.pdf,26.01.2026)

Schwaber, K., & Sutherland, J. (2020). *The Scrum Guide The Definitive Guide to Scrum: The Rules of the Game*. (https://scrumguides.org/docs/scrumguide/v2020/2020-Scrum-Guide-US.pdf, 26.07.2023)

Stone, D. N., Deci, E. L., & Ryan, R. M. (2009). Beyond talk: creating autonomous motivation through self-determination theory. *Journal of General Management*, *34*(3), 75–91. doi/pdf/10.1177/030630700903400305

Weinert, F. E. (2001). Concept of Competence: A Conceptual Clarification. Rychen, D. S., & Salganik, L. H. (Eds.): *Defining and Selecting Key Competencies*. Hogrefe & Huber Publishers