Part 16 / Strand 16

In-Service Science Teacher Education And Professional Development

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Continuing professional development of science teachers, including in-service science teacher education programmes and policies, teachers as lifelong learners, strategies and methods for teaching science, innovation and reform in professional development, evaluation of professional development practices, reflective practice, teachers as researchers, and action research.

Sub-themes:

1) Continuing Professional Development Strategies for Science Teachers
2) Reflective Practice and Teacher Research in Science Education
3) Evaluating the Impact of In-service Teacher Training
4) Lifelong Learning and Career Development for Science Teachers

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Strand 16: In-Service Science Teacher Education And Professional Development

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Introduction

The papers gathered in strand 16 address one of the central challenges currently facing science education: how to support teachers' professional learning in a period marked simultaneously by ecological urgency, rapid digital transformation, and growing demands for more equitable, interdisciplinary and socially relevant science education. The ESERA 2025 conference themes of sustainability and digital advances are therefore not peripheral to this collection; they form a central axis around which many of the contributions are organised. Sustainability is approached not only as scientific content to be taught, but also as a multidimensional educational orientation involving values, systems thinking, future-oriented reasoning, responsible action, nature connectedness and socio-environmental engagement. Digital advances, in turn, are considered not merely as tools to be adopted, but as developments that reshape the conditions, practices and purposes of science teaching, raising questions of teacher competence, professional identity, equity, accessibility, ethical use, pedagogical quality and institutional support.

The strand "In-service Science Teacher Education and Professional Development" focuses on the continuing professional learning of science teachers and science teacher educators across different educational levels, institutional settings and national contexts. It encompasses in-service teacher education programmes and policies, teachers as lifelong learners, professional development models, innovation and reform in science teaching, reflective practice, teachers as researchers, lesson study, action research, professional learning communities, and the evaluation of professional development practices. At its core, the strand is concerned with how teachers learn, how they transform their knowledge, beliefs, practices and identities, and how professional development can be designed so that it is meaningful, sustainable and connected to the realities of classrooms, schools and wider educational systems.

Taken together, the contributions show a field that is moving beyond short, decontextualised training events towards richer, more situated forms of professional learning. Across the papers, professional development is frequently conceptualised as collaborative, inquiry-oriented, design-based and practice-embedded. Teachers are positioned not simply as recipients of expert knowledge, but as active interpreters, designers, facilitators, reflective practitioners and co-constructors of innovation. This is visible in studies centred on lesson study, professional learning communities, design-based research, co-design, out-of-school laboratories, teacher learning communities, classroom implementation cycles and reflective inquiry. The emphasis falls on the dynamic relationship between professional development design and teachers' actual possibilities for action in specific school, curricular, technological and cultural contexts.

Several major thematic clusters emerge across the strand. One concerns sustainability and socio-environmental education, including professional development for sustainability competences, climate-change education, nature connection, aesthetic engagement with the natural world, and interdisciplinary STEM or STEAM approaches to complex real-world problems. A second cluster addresses digitalisation and emerging technologies, including ICT-related professional

development, interactive experimental videos, adaptive gamification, artificial intelligence and ChatGPT-supported teacher learning, digital inequalities, and the use of digital tools in laboratory and inquiry contexts. A third cluster focuses on teacher knowledge, beliefs, self-efficacy, professional identity and competencies, showing how professional learning involves cognitive, affective, epistemic and practical dimensions. A fourth cluster examines organisational and systemic conditions for sustainable professional development, including transfer pathways, scaling-up, professional learning networks, institutional routines, resources, time, leadership, policy support and cross-institutional collaboration.

The most prevalent trend across the papers is the search for professional development models that are both pedagogically ambitious and practically viable. Many contributions recognise that teachers are expected to address complex and rapidly changing demands, but often do so under constraints of time, resources, curriculum structure, assessment regimes and uneven institutional support. Consequently, the question is no longer only what teachers need to learn, but how professional learning opportunities can be organised so that they are coherent, sustained, context-sensitive and capable of supporting actual classroom change. Another strong trend is the integration of content, pedagogy and technology, particularly through approaches aligned with TPACK and related frameworks. Digital innovation is treated as productive when it is connected to disciplinary learning, inquiry, experimentation, feedback, inclusion and student agency, rather than when it is used as an isolated technical add-on.

A further trend is the broadening of science teacher professional development towards interdisciplinarity and societal relevance. Integrated STEM and STEAM, sustainability education, climate education and real-world problem solving require teachers to cross disciplinary boundaries, work collaboratively, tolerate uncertainty and develop new professional identities. The papers also reveal a growing concern with equity and accessibility: digital inequalities, inclusive STEAM environments, access to technological infrastructure, and the need to avoid reinforcing existing divides all appear as important issues. Finally, there is a clear methodological tendency towards research designs that make professional learning processes visible, including qualitative case studies, mixed-methods evaluations, systematic reviews, design-based research, lesson study analysis, reflective journals, observations, interviews, surveys and studies linking teacher learning to student outcomes.

Within the wider field of science education research, this set of papers contributes to a more complex understanding of teacher professional development as a systemic, relational and transformative process. It reinforces the idea that improving science education depends not only on producing new curricula, technologies or resources, but on understanding the conditions under which teachers appropriate, adapt, question and sustain innovation. The strand also strengthens the connection between science teacher education research and current educational challenges: preparing learners for sustainability, supporting scientifically informed action, responding critically to digital transformation, and developing inclusive, practice-based and evidence-informed forms of professional learning. In this sense, the collection illustrates a mature and evolving field, attentive both to the micro-processes of teacher learning and to the broader institutional, technological and societal conditions that shape science education today.

Section: Continuing Professional Development Strategies For Science Teachers

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Digital Inequalities In The Context Of Teaching And Learning Of Science And Technology In Secondary School

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In Quebec, since the implementation of the Education Reform, the teaching and learning of science and technology (S&T) at the secondary level has raised several questions. Initially, developing the interdisciplinary component proved challenging, and adolescents' motivation towards this pairing of disciplines, despite concrete focus, has not improved. Additionally, the place of digital technology in the classroom can no longer be ignored, as digital inequalities negatively impact S&T teaching and learning. Furthermore, access to digital technology varies significantly between educational institutions.

In 2015, the Organisation for Economic Co-operation and Development came out in favor of access to digital technology in the school environment. Digital inequalities are then considered a complex problem arising from an authentic situation in the school environment, mobilizing different resources in an imperfectly predictable and difficult to break down function.

To describe the problem of digital inequalities in the school environment, a research initiative involving university researchers and school stakeholders was realised between 2022 and 2024. Led by a facilitator, a group was mobilized to address the problem of digital inequalities. This article explores the meeting dynamics (5 meetings) and the facilitator's role (convene, observe, reflect, act and harvest) in solution co-creation.

The facilitation role can be effectively undertaken by science teachers, enabling them to bridge digital gaps and enhance the teaching of science to secondary school students. This approach empowers educators to integrate interdisciplinary and technological elements into their pedagogy more effectively.

Keywords: Facilitation, U theory, digital inequalities

Introduction

The purpose of this text is to identify and describe the role of facilitator agents in the context of the activities of a co-creation group that is inspired by design thinking and is part of a living laboratory. Thus, participants from various fields, occupying different professional functions and expressing sometimes divergent opinions participate in the co-development of solutions to counter digital inequalities in science and technology (S&T) courses at the secondary level (12 to 17 years old). The approach used by the facilitator agent to support the participants and allow the expression of their perceptions of the situation is design thinking. One of the main challenges of the function of facilitator agents, during these meetings of the co-creation group lies in the ability to listen and be open to the expression of divergent opinions. The challenge of facilitating these meetings is to create an environment of trust and respect that encourages participants to express their thoughts and propose solutions that could produce tangible societal repercussions on digital inequalities in the school environment. During the meetings held, in person and remotely, a facilitator led the group's discussions. The role of this person proved to be important, which led the research team associated with the project to take an interest in their actions and posture. It is by taking these conditions into account that the team of researchers decided to look at the professional action of its facilitator agents to describe and validate their potential for the

co-development of solutions. A question also raises the interest of researchers: What is the role of facilitator agents in a co-creation group of a living laboratory in education? The general objective of the project is to establish a living laboratory for innovation in education (LaVIE) in order to co-create, with stakeholders and users, innovative solutions that promote the adaptation of educational and pedagogical practices to combat educational and digital inequalities exacerbated by the pandemic.

Indeed, although digital inequalities in the school context are recognized and manifest in the manner in which courses are delivered and learning is generated, particularly in S&T teaching where the abstract side of concepts is often dominant, the complexity of the situation precludes a single, simple solution to this problem. That is, the problem is one with no possible definitive resolution (Rittel and Webber, 1973).

Conceptual Framework

According to Stewart and Sampsa (2008), facilitation is defined as the provision of opportunities for various actors affected by a social problem. For them, these opportunities include the provision of information, the establishment of connections, and the allocation of resources. The purpose of these opportunities is to enable these actors to identify and implement remedies for the social problem. Johnson (2018) adds to this definition that the facilitator is a person whose responsibility in research is to help teams conduct and learn innovation work from ongoing projects, without however directing or managing the work themselves.

Facilitation emerged in the early 1960s in the United States. During this decade, there were major debates against the Vietnam War, racism and poverty (Gauthier, Bibaud & Roy-Baillargeon, 2011). Twenty years later, it is mainly returning in the environmental protection and sustainable development awareness movements (Doelle & Sinclair 2006). In this context, facilitation responds to a need for modifications and accommodations of social objectives.

"The term facilitation can be approached in two ways: either interchangeably with the notions of mediation, conciliation and consultation or comparatively with mediation and negotiation." (Gauthier et al., 2011) Facilitation is oriented towards prevention where the discussion methods are fair and open. It contributes through its logistics to the proper conduct of meetings. It promotes active listening and the identification of opportunities for consensus between participants (Dorcey and McDaniels, 2001). Through public debate, it helps to raise awareness among participants so that they can increase their involvement and better coordinate their actions with their community (Thomassian, 2009).

An important part of the facilitators' task is to guide participants toward an agreement by creating a climate of trust and transparency that is conducive to verbalizing needs, sharing information, and analysing all proposed options in order to identify and develop an integrated, equitable, and sustainable solution to the problem under study (Beuret 2006; Milburn 2006). The interactive dimension of facilitation involves seeking an agreement. It is directed toward transforming the conflict by establishing a dialogue between project participants. The interactive dimension also leads them to change their perceptions of the situation and develop an openness to negotiation. Facilitation thus contributes to improving collective understanding of the issues, empowering the parties, and managing emotions (de Carlo 2004a). Balancing emotions is achieved by setting limits on interactions between participants. Facilitation thus generates avenues for compromise or solutions on the relevance of the project in order to facilitate integration into its environment. Therefore, facilitation through its function with participants is oriented towards i) collective decision-making (de Carlo 2004a and 2004b; Kaufman 2009), ii) the ability to prevent conflicts, iii) the social acceptability of projects (Karjalainen & Järvikoski 2010; Peltonen & Sairinen 2010,

and iv) the manifestation of collective intelligence and social cohesion (Fortin, 2009; Kaufman 2009). In addition, being a facilitator agent implies understanding a problem in order to determine its limits and constraints (Glen, Suciu & Baughn 2014). This is manifested by the ability to frame and reframe the problematic situation from different angles, from microscopic and macroscopic levels, and this, at all stages of the targeted project. Framing is linked to the development of critical thinking. It consists of undoing the unconscious biases generated by life experiences, appropriating systems of thought, understanding the main ideas which guide the choices and opinions of the participants.

The objective of the meetings was twofold: first, to assist educational stakeholders and participants in comprehending the issue of digital inequalities in the school environment, with a particular focus on science and technology education, and second, to facilitate the conception and evaluation of innovative solutions.. The support or action of educational stakeholders in the face of digital inequalities constitutes a lever. Facilitators also prevent situations of tension by promoting interaction between the different stakeholders so that they produce common solutions while having initially expressed divergent interests and opinions (Dorcey and McDaniels 2001; de Carlo (2004a); Pereira, Drimie, Zgambo & Biggs (2020)) the primary responsibility of the facilitator lies in their ability to adequately interpret the meaning of the words of the different stakeholders so that it is understood by all and used as a basis in the development of a new social message.

Duhigg (2024) mentions that when a discussion group feels positively guided and respected by a facilitator, few participants are aware of the real influence it has on the evolution of their thinking and their membership in the group. The facilitator then plays an essential role in sharing thoughts and in the evolution of opinions on the situation of digital inequalities.

Design Thinking

Design thinking, centred on the human, requires taking a step back from actions in order to ensure an optimal understanding of the problem to be addressed by the participants, before focusing on the solutions to be explored. In addition, this approach implies, in its implementation, that the shared reflections take into account the experience of the participants. For Brown & Wyatt (2010) a research project conducted according to the design thinking approach is made up of several stages where each is linked to an objective, results and diagrams. Furthermore, these stages do not necessarily occur successively; they can coexist in their implementation.

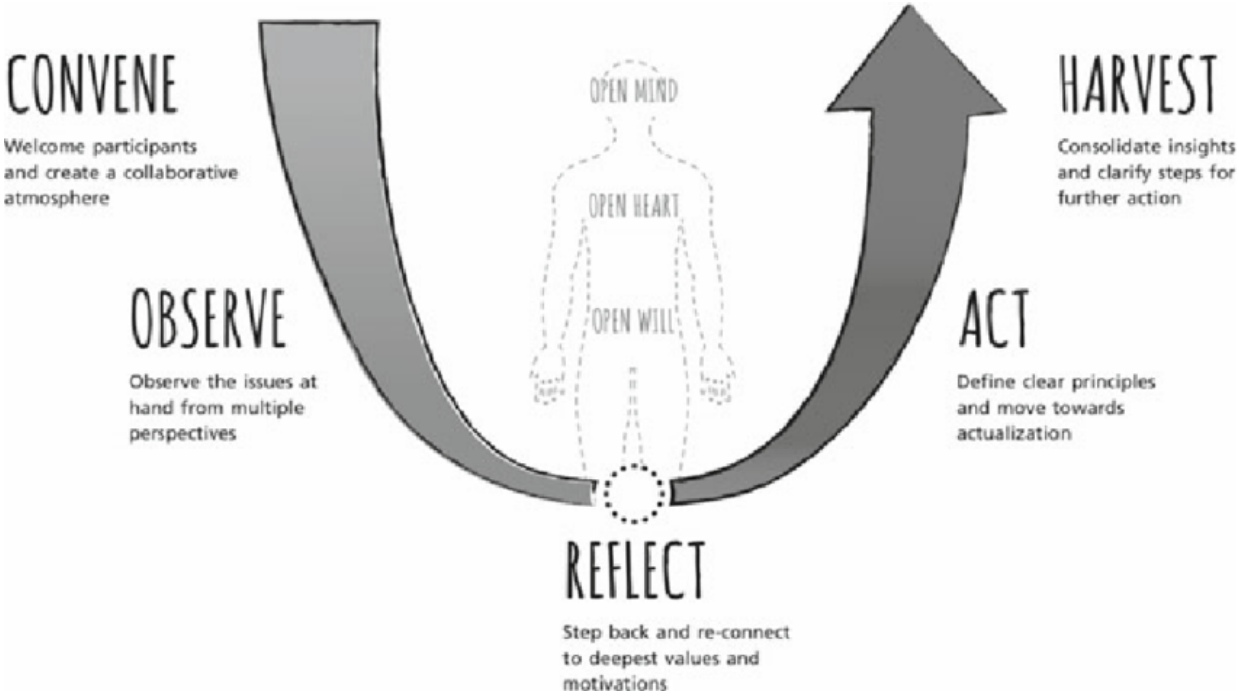
The design thinking model, as used for the project, is made up of two phases and six stages. The phases represent the problem space and the solution space. The steps in the problem space phase, for their part, require defining the problem, understanding it by consulting the people who experience and know it, and then, if necessary, redefining it more precisely. The subsequent step in the process is to envision multiple solutions, prototype them, make them tangible, and test them with the intended users. This method is called collaborative because all participants must be involved in the process.

Methodology

The authors Pearson et al. (2018) and Scharmer (2016, 2009) proposed a modelling of the change process through reflection and sharing of perceptions. The goal of this model is to present an evolving sequence of meetings (in workshops) in order to lead participants to design a common solution to improve a situation that has become socially difficult. Called the U theory, this model is used as a co-design tool. It is easy to understand for the facilitators and provides essential time for individual reflection followed by sharing. It thus marks the duration of the different stages of

the meetings. According to Pearson (2021), the stability and predictability of this framework contribute to facilitating the engagement of the participants. The U theory explicitly aims to open up spaces of possibilities.

Figure 1. Theory U The Theory U process of co-sensing and co-creating[1].



The application of the Pearson et al. model. (2018) can be summed up in five stages: a) the gathering (convene) where a climate of collaboration is created, b) the observation (observe) of the different facets of the problem to be solved, c) the reflection (reflect) on the values and principles inherent in the problem and the motivation of the actors to modify elements, d) the action (act) redefine the principles retained and update e) the harvest (harvest) clarification and consolidation of the possible stages to be put in place.

To analyse the meetings held between 2022 and 2024, based on these stages, their content was transcribed in verbatim form. A sequenced thematic analysis was applied to part of the verbatims (4 pages of verbatim from the first meeting) by the authors of the text. After this exercise conducted independently, an inter-judge validation meeting was held to consolidate the analysis grid. Subsequently, an author analysed all of the identified verbatims.

The Results

The facilitator's professional actions, including her invitation to engage in the discussion and her openness to diverse opinions, fostered an environment conducive to the expression of individual perspectives while respecting the divergent ideas of others. The quality of her facilitation made it possible to define the constitutive parameters of digital inequalities, information whose nature is linked to the professional status of the different participants and the relationship they have with the use of digital technology.

The U-model appeared operational and can be used as a tool for the expression and analysis of design thinking in the context of the living laboratory. The five stages of the U-model were

[1] Source: Pearson et al. (2018) as adapted from Scharmer (2009) Creative Commons Attribution 4.0 International

manifested. However, nuances must be made, particularly on the succession of stages in an iteration (back and forth) where several stages of the model are likely to manifest themselves during the same meeting. It should be mentioned that the different stages of the model are associated with reflections and the expression of these reflections. In addition, everyone has their own way of creating links between the comments made by the participants and the realities as they perceive them on digital inequalities in the school environment.

The facilitation role can be effectively undertaken by science teachers, enabling them to bridge digital gaps and enhance the teaching of science to secondary school students. This approach empowers educators to integrate interdisciplinary and technological elements into their pedagogy more effectively.

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Adaptive Gamification In Primary Science Education: Teacher Implementation

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Implementing adaptive gamification in science education, supported by teacher training, is vital to enhance students' engagement and learning. This study examined how teachers trained in a TPASK-based program integrated and utilized an adaptive gamification application in teaching science concepts related to the water cycle with 3rd-grade students. using observational checklists. This study examines the training of teachers regarding the use of an adaptive gamification application, in the teaching of science education concepts in elementary education. The main point of interest was collecting first-hand data on the degree of effective utilization and pedagogical integration of the adaptive gamification environment by in-service teachers. The data were collected through the use of observational checklists based on the TPASK dimensions after the implementation. Results revealed two teacher profiles based on TPASK proficiency and diverse application strategies. The findings highlight the potential of such practices in early and primary education and emphasize the need for teacher training to utilize adaptive learning digital application and ongoing support to address implementation challenges.

Keywords: Adaptive education, Teacher implementation, TPASK framework, motivational aspects, science education

Theoretical Framework

In recent years, due to new challenges and demands, education has been in a process of reconfiguration, especially after the coronavirus period (Shehaj, 2022). In general, the role of the teacher has changed over the years, as the teacher is now expected to provide strategic support to students to help them become self-directed learners (UNESCO, 2008). However, this requires the redefinition of teachers' professional skills (Torrance & Forde, 2017) and the enhancement of their training to enable and facilitate the development of essential skills such as collaboration, critical thinking, problem-solving, scientific and digital literacy in today's world (Dede, 2010; Torrance & Forde, 2017). Enabling students to acquire modern skills such as scientific and digital literacy requires teachers to use and/or create appropriate classroom scenarios that inspire, motivate, and engage students in learning (Mee et al., 2020). One of the current trends that is attracting the interest and attention of teachers and students alike is that of gamification (Statti & Torres, 2020).

Several researchers have focused on applying gamification in science education due to its familiarity with students (Kalogiannakis et al., 2021). Additionally, it can facilitate the development of scientific thinking (Tsai, 2018), and it is compatible with scientific theories, methods, and learning strategies related to the teaching of science concepts (Tsai, 2018). Providing motivation and enjoyment is not common to all people, so there is a need to understand the characteristics and techniques responsible, taking into account the different needs, values, and interests of each individual (Böckle et al., 2017). Adaptive gamification, i.e. the adaptation of different gaming mechanisms and features based on each learner's actions, preferences, and characteristics, is a rapidly developing method that enhances the traditional gamification approach (Klock et al., 2020). Inherently, it is a more personalized, learner-centred method of teaching, using a specific set of elements that respond to the characteristics of each learner.

However, although teachers recognize the value of technology, they often fail to use it as a learning tool (UNESCO, 2017). Therefore, in order for teachers to be able to effectively integrate ICT in education in the context of new pedagogical changes, they should be exposed to new models and trained to apply them (Zourmpakis et al., 2022).

Furthermore, a training program following the Technological Pedagogical Science Knowledge (TPASK) model as a design framework (Jimoyiannis, 2010) has been developed to train teachers to effectively teach science concepts using an adaptive gamification environment in authentic classroom settings. The present study aims to investigate the extent to which practicing teachers use adaptive gamification environments to teach science relating to the water cycle, following their participation in a training program designed according to the TPASK model.

Consequently, after the in-service teachers conducted the instructional implementation and analysed the observational checklists and motivational questionnaires of the students, we will respond to the following research question:

RQ: What is the degree of effective utilization and pedagogical integration of adaptive gamification environments in science teaching by practicing teachers?

The Adaptive Gamification Application: “The Water Cycle”

For the needs of this study, the adaptive gamification application “The Water Cycle” was created. This open-world role-play simulation was built with the Unity3D engine. The theoretical framework that the application was based was Self-Determination Theory (SDT) and Marczewski’s Hexad typology, allowing dynamic tailoring game elements and mechanics to each student’s needs and motivational priorities. More specifically, upon entry, students complete a 24-item questionnaire to identify their dominant player type (e.g., Philanthropist, Achiever, Socializer) but also their two more adjacent ones. Based on this profile, the system configures the game environment by activating specific game mechanics that align with the user's main type, while also incorporating elements from their two adjacent types traits to ensure a balanced experience (Zourmpakis et al., 2023).

The application further personalized the educational process by integrating two distinct pedagogical strategies: Problem-Based Learning (PBL) and Inquiry-Based Learning (IBL). The PBL approach focused more on narrative driven mystery where students act as detective assistants. On the other hand, IBL positions them as university research assistants focused on structured experimentation, limiting the story side. To maintain engagement, a continuous adaptation mechanism monitors student progress and feedback through in-game dialogues, in order to adjust difficulty and provide real-time scaffolding if necessary, ensuring the learning curve remains appropriate for each user.

Methods & Context

The main interest of this study was to investigate how teachers will integrate and utilize the adaptive gamification application after completing a professional training program based on the TPASK methodology.

This study was conducted in a Mediterranean country in southwestern Europe. Data were collected using observation checklists by the researcher. The educational application included 5 teaching hours, one to prepare the students to use the application and one for each of the 4 scientific concepts taught, coagulation, melting, evaporation, and boiling. Overall, 6 in-service elementary 3rd grade teachers participated in this study. The implementation took place in their school's computer labs. Data were collected using observation checklists by the researcher. An observation checklist was completed for each teaching session. The researcher was present during

these sessions to observe, fill the observation checklist and provide technical support only when strictly necessary (e.g., if students found "bugs" or ways to break the game boundaries), ensuring the teachers remained the primary facilitators. The observation checklists were analysed qualitatively. Additionally, this research followed all formal national and international rules for ethics in research, including obtaining written consent from parents and from students.

Albeit the small sample of teachers, we followed a semi-experimental design with a convenience sample, following a robust ethical protocol through the following:

(a) observational checklists were checked by external researchers to verify clarity and connection to the TPASK model

(b) to ensure the validity of this study, all data could be accessed and reviewed by external researchers

(c) data were analysed through the use of ATLAS.ti software.

This approach allowed for first-hand data collection where teachers' interaction with students occurred naturally, as opposed to relying on secondary reports that could be obtained through interviews. The process involved completing an observation method which involved having a comprehensive checklist with detailed explanations in each TPASK domain, providing a thorough description of each teaching case. In addition, increasing student motivation is the direct purpose of gamification. Thus, it was deemed necessary also to measure student motivation in order to be able to ascertain whether the practical application is influenced by student motivation.

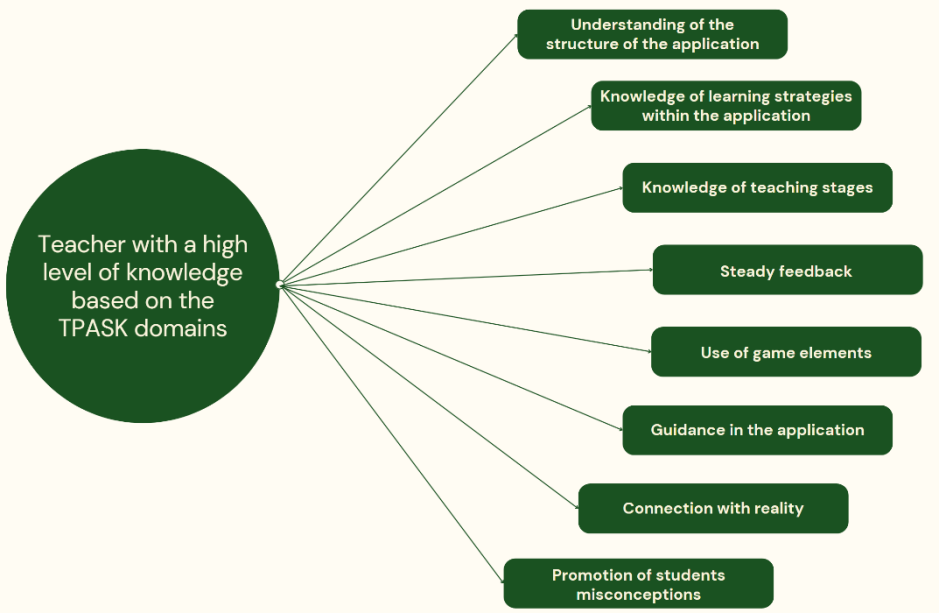
Findings

Based on our findings two main categories of teachers were identified. The primary criterion for this categorization was the actual utilization of the application during teaching, as the effective pedagogical integration of technology is the ultimate goal of the TPASK framework.

The first type, which consisted of half the sample size, appeared to have considerable knowledge of the application. applied appropriate teaching strategies, and incorporated game elements to enhance student motivation. To be more specific, these teachers demonstrated a comprehensive understanding of the structure of the application and were well-prepared, possessing specific knowledge of the learning strategies embedded within the software and how to identify them. They applied appropriate teaching strategies and knew the specific teaching stages required to help students at every step. Moreover, they were distinguished by their ability to relate the application to reality and to support students' conceptual understanding by highlighting alternative conceptions and guiding them toward conceptual change. An important factor of their teaching was their provision of steady feedback during experiments and review discussions. Furthermore, they consistently incorporated game elements and mechanics to enhance student motivation and engagement.

However, their performance was not high from the start, as almost all had some initial difficulties in the first lesson implementation, but showed gradual improvement, especially in areas such as guidance within the application and the integration of gamified elements. Also, even though they showed high levels of TPASK knowledge, they faced some difficulties with technical issues that came up during the lesson implementation in all lessons.

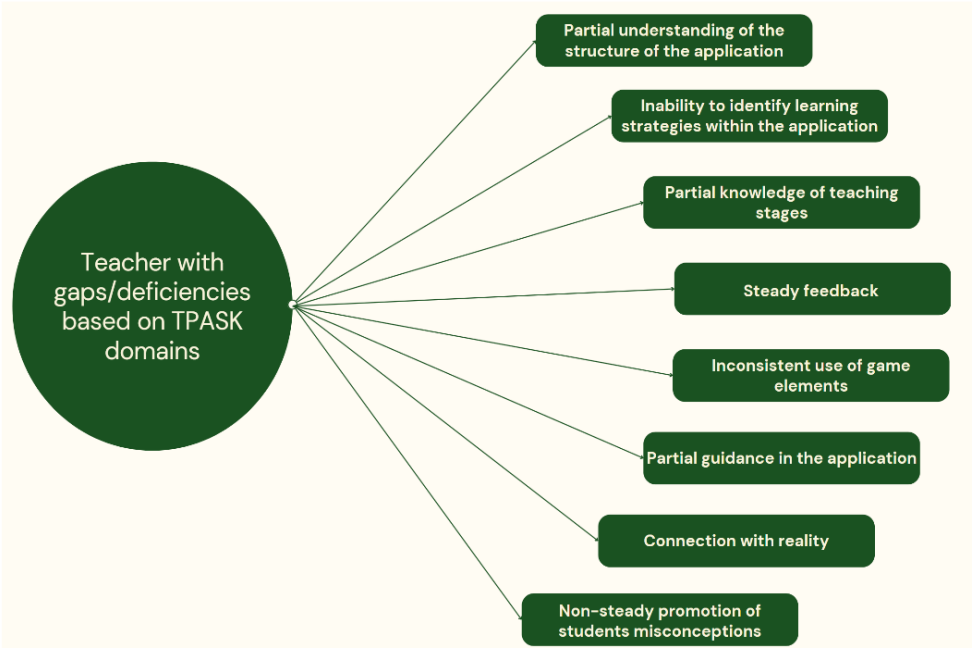
Figure 1. The specific characteristics of type 1: Teacher with a high level of knowledge based on the TPASK domains.



The second type included the rest of the sample size and showed deficiencies in the preparation and use of the app, as well as in the management of learning strategies. This group was characterized by a partial understanding of the application's structure and a lack of full integration of the scientific inquiry process through the digital tool.

In particular, although they made an effort to support students, they exhibited an inability to identify specific learning strategies within the application and had only partial knowledge of the necessary teaching stages. They struggled with linking technological knowledge with pedagogical and scientific knowledge, resulting in a failure to consistently integrate experiments and game elements into the educational process. Despite these gaps, they did attempt to provide steady feedback to students during the explanation of phenomena. However, their promotion of student misconceptions and reflection was non-steady and inconsistent. They also had similar problems in solving technical issues and reported more significant concerns regarding time constraints and classroom management.

Figure 2. The specific characteristics of type 2: Teacher with gap/deficiencies based on TPASK domains.



Importance

The findings of this study, though they can't be generalized due to the small sample, show the importance of training teachers in the use of adaptive gamification environments through specialized professional development programs based on the TPACK framework, particularly adapted for teaching science education (TPASK) and applying it practice. Additionally, based on students' engagement during the implementation, of it can be suggested that applying adaptive gamification environments in teaching can have a positive impact on students' motivation, even in cases where the teacher shows deficiencies regarding implementation. This could become clearer later with the analysis of the students' motivational questionnaire and teachers interviews in a later stage. Integrating technologies into education through TPASK requires balanced knowledge and skills development, with a focus on practical application and reducing the complexity of tools (Rochintaniawati et al., 2018).

Taking into account the role of the teacher in the learning process and their impact on students' learning experiences, especially when integrating technological tools into teaching (Kalogiannakis et al., 2021), it is important to design and provide appropriate training programs for current and future teachers. Based on the differentiations found from the utilization of classroom instruction (teacher types), we propose the creation of education/training programs where teachers' training is tailored based on their specific characteristics and needs. Additionally, the advantages of adaptive environments are not limited to primary and secondary education.

In addition, we propose the use of methodologies that are specialized both in the content of teaching and in the integration of technologies in teaching. By its nature, TPACK requires pedagogical methods and technologies tailored to specific topics (Voogt et al., 2013). Each subject has specific characteristics (e.g. learning strategies), which are sometimes specific to that subject (Jimoyiannis, 2010). Also, each technological tool has different capabilities and weaknesses. Treating technological tools in a generic way may result in not offering appropriate guidelines to improve teachers' professional development based on their abilities and weaknesses (Hsu et al., 2015). Creating a personalized learning system driven by the TPACK methodology would facilitate teachers' professional development (Chaipidech et al., 2022), while combining it with gamification could enhance their motivation and engagement.

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Developing Sustainable Professionalization Programs For STEM Teachers By Systematically Reflecting On Transfer Pathways

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Digitalization offers great potential for teaching and learning. To unfold this potential and support pre- and in-service teachers as well as students in schools to develop the competences needed for teaching and learning in a culture shaped by the digital transformation, a statewide program was initiated in the German federal state of Schleswig-Holstein. The program aims at developing and implementing innovative support structures on a personal, material and systemic level, thus addressing multiple target groups with the ultimate goal to implement the program at scale throughout the state. With its long-term orientation, its integration of all phases of teacher education and its approach to institutionalize the collaboration between the different institutions involved in teacher education, the program offers unique opportunities to systematically investigate transfer processes. Research in this field shows that enabling successful transfer is challenging - and often fails - because of the complex nature of factors influencing it. This paper will present findings from a systematic analysis of transfer pathways within the program based on a process model that accounts for the complexity of the program, conditions and interactions, using STEM subjects as an example. It will show the models' potential for the monitoring and synoptic reflection of transfer processes in large-scale intervention programs that can not only feed back into the program but may contribute to a better understanding of transfer in education in general.

Keywords: transfer processes, digitalization, teacher professionalization

Introduction And Background

Today's personal, social, and professional lives are shaped by digitalization (Stalder, 2016). Living in a culture of digital transformation is also affecting teaching and learning in many ways. Digital media have the potential to support teaching and learning processes and promote the acquisition of subject-specific and interdisciplinary competences and skills. At the same time, however, if you look e.g. at the opportunities arising from the use of artificial intelligence (AI) and big data, the subjects and disciplines themselves are changing as a result of increasing digitalization. From the perspective of important cross-cutting issues such as inclusion, heterogeneity and differentiation, or assessment, digital media enable new approaches of support for and design of learning processes. They pose, however, also challenges with generative AI being a prominent example: It opens up new possibilities for individual, formative support through intelligent tutoring and automated feedback systems, but at the same time poses challenges for traditional learning and examination formats. Moreover, thinking e.g. of fake news, it brings new aspects into traditional classroom instruction that need to be addressed. Ultimately, living in a culture of digital transformation requires digital and media-related skills, the acquisition of which is a cross-cutting task to which all subjects and disciplines must contribute (Redecker, 2017). Consequently, digital transformation also requires innovative formats for education and the way that we teach and learn. This does not only include the content or formats but also the conditions and actors that shape educational (systems).

However, across countries and educational systems, it can be observed that sustainably bringing educational innovations into practice is a widespread challenge leading to a limited impact of educational research on schools and teaching practice (e.g., Penuel et al., 2020). Research in this area faces the additional challenge that the process of "bringing into practice" incorporates not only different phases ranging from the development of an innovation, to its implementation, dissemination, and scaling-up, but also different concepts such as e.g. research-practice partnerships or teacher professionalization (e.g., Schrader et al., 2020). However, throughout different research fields these aspects and concepts are not consistently defined (e.g., implementation processes, innovations in school, school improvement, knowledge transfer) and sometimes used synonymously. In the last years, in the German-speaking literature, most of these aspects and research fields are summarized under the term transfer (e.g., Schrader et al., 2020). Therefore, in this contribution, we try to unify these existing aspects and constructs and define the interplay of development, implementation, and scaling-up as transfer processes.

Due to the great importance of transfer processes for the transformation of education, research in this area has increased over the last years. In a review study, Schrader and colleagues (2020) investigated factors supporting or hindering such transfer processes with a specific focus on the implementation phase. In total, they found 194 factors that are either related to the intervention itself (e.g., quality of material, fit to existing curricula) or the social environment of the learners (e.g., support, acceptance) as well as to institutional and organizational (e.g., autonomy, support, cooperation) or personal conditions (e.g., beliefs, self-efficacy). In their research, the authors used a utilization of learning opportunities model that allows not only for looking at different levels of context factors but also for taking the role of the target group as the ultimate user of transfer endeavors into account – a perspective often neglected in existing transfer models. One reason for this might be that for a long time a unidirectional understanding of transfer – with research being the provider and practice being the recipient – prevailed (e.g., Penuel et al., 2021; Tseng, 2012). More recent approaches, however, advocate for understanding transfer as bi-directional or co-constructive processes in which actors from research and practice bring in their respective expertise and collaboratively work together to enable educational transformation (Farley-Ripple et al., 2018; Penuel et al., 2021). Investigations in this field, however, are still scarce which might be due to a lack of models allowing to investigate this kind of transfer processes.

The growing importance of transfer within educational research is also reflected in educational policy and practice. Over the last years, a number of projects that explicitly aim at supporting transfer processes (in Germany e.g. the project lernen:digital[2]) have been funded. However, these projects often face the challenge that they are of limited duration. The successful transfer of innovations, though, requires longer time spans due its complexity but also a certain inertia of educational systems (e.g. Otto, Bieber, & Heinrich, 2019).

In this contribution, we present an investigation of bi-directional and co-constructive transfer processes in a long-term, statewide program aiming at the sustainable professionalization of teachers for teaching and learning in a culture shaped by the digital transformation. The findings from this investigation can make an important contribution to the development of sustainable programs for the transformation of education.

A Statewide Program For Fostering Digital Competences As A Context For Investigating Transfer Processes

As a response to the increasing demand by schools, teachers and teacher educators for support in addressing the challenges of the digital transformation but also harnessing its potential for

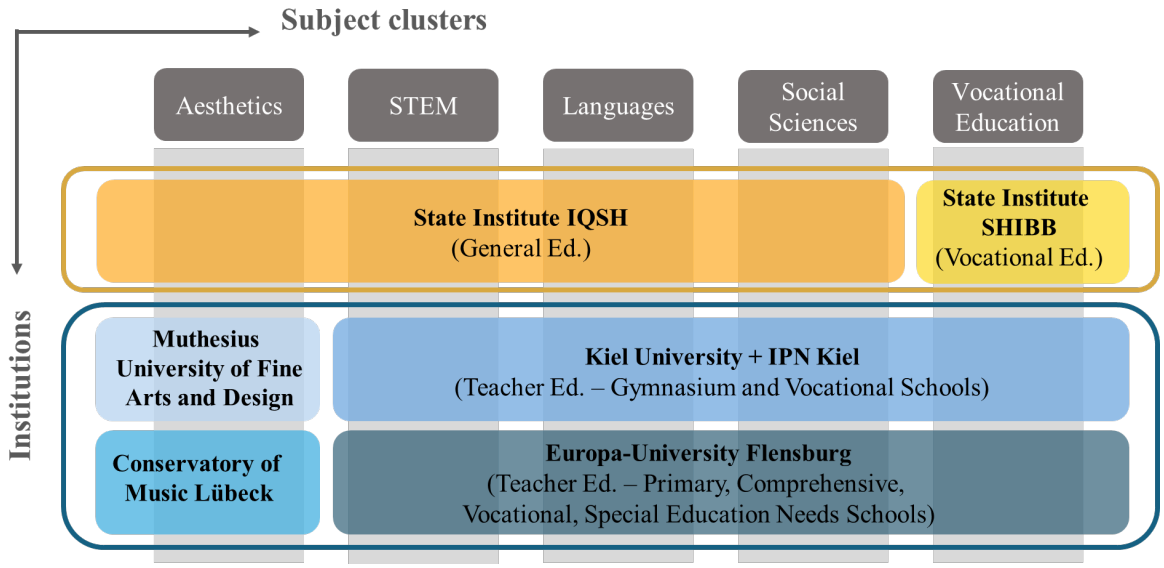
[2] https://lernen.digital/

enhancing student learning, a statewide program was established in the German federal state of Schleswig-Holstein. The program *Zukunft Schule im digitalen Zeitalter* (*Future School in the digital age*) aims at sustainably promoting the competence development of students and pre- and in-service teachers through a future-oriented approach to the potentials and challenges of an increasingly digitalized living and working environment. For addressing these aims, it

- … is conceptualized as a long-term, permanent support and intervention project,
- … addresses all subjects and all phases of teacher education (university/phase 1, teacher training/phase 2 ("Vorbereitungsdienst (VD)"), TPD/phase 3) and, ultimately, the competences of students, and
- … brings together all institutions involved in teacher education, namely the four universities offering teacher education programs in Schleswig-Holstein, the IPN Leibniz-Institute for Science and Mathematics Education, the two state institutes (for general and vocational education) responsible for VD and TPD and the Schleswig-Holstein Ministry of Education.

The program focuses on fostering general digital competences (such as media and technological competences) as well as subject-specific (e.g., the potential of microcontrollers in science education) and transdisciplinary competences (e.g., education for sustainable development). This is reflected in its organizational structure that builds upon two pillars. The media competence pillar consists of four regional media labs and media consultants who offer school counseling and TPD activities regionally in the different state districts. Within the subject cluster pillar, teacher educators at the state institutes (called *Regional Subject Consultants, RSC*) and the universities (called *Educational Engineers, EE*) collaboratively develop and implement support activities for pre- and in-service teachers in five subject clusters, thus bringing together expertise and perspectives from research and practice (see Figure 1).

Figure 1. Research-practice collaboration within the organizational structure of the state program.



Their activities include e.g. university, TPD and self-study courses; school development days; lecture series; exhibitions; digital work shadowing; OER teaching and learning materials or courses for teacher trainers but also supporting curriculum development at schools and universities.

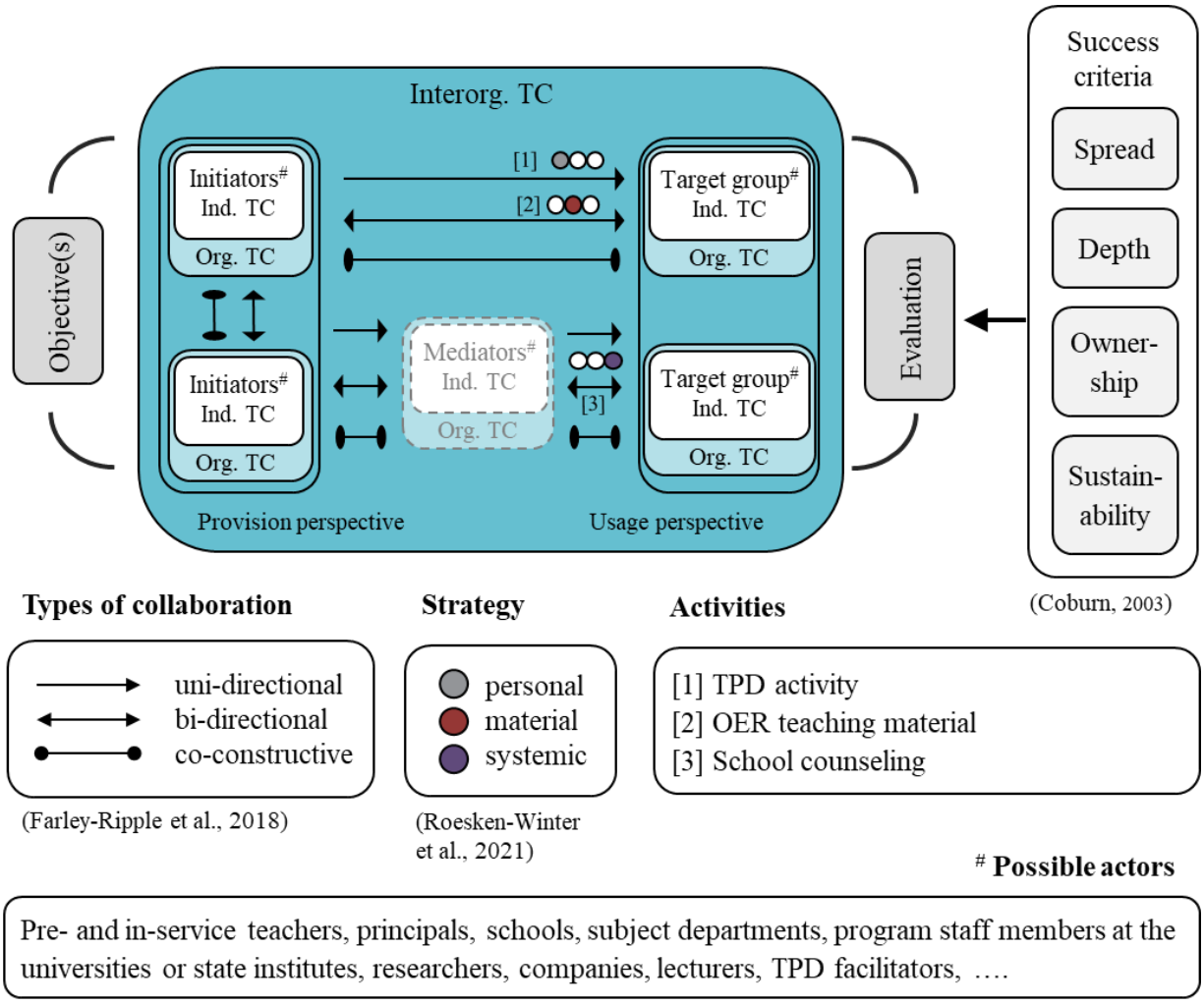
The concept and structure of the state program thus not only address the challenges and opportunities of the digital transformation but explicitly acknowledges what is known about

successful transfer. It thus provides promising conditions for investigating transfer processes with a specific focus on bi-directional and co-constructive collaboration.

A Model To Monitor And Reflect On Transfer In Projects

The model presented in this section (see Figure 2) understands transfer initiatives as projects with a clear focus on transfer (flerlage et al., in press). While building on existing models of transfer, this model differs in its explicit focus on the processes and actors involved, allowing for the identification and pursuit of specific transfer pathways tailored to project goals. With this focus, the model is particularly suited for monitoring and reflecting on transfer in complex large-scale projects, in which many contributors with potentially different goals are involved.

Figure 2: Model For The Systematic Reflection On Transfer (Adapted From Flerlage Et Al., In Press).



Note: TC = Transfer Conditions, Interorg. = Interorganizational, Org. = Organizational, Ind. = Individual

The model represents transfer scenarios within a project as structured around three core elements: the definition of objectives (left grey box in Figure 2), the transfer process (big blue box in figure 2), and the evaluation of outcomes (right grey box in Figure 2). It can be used to investigate various pathways leading from the objective to the outcome. Larger projects as the presented state program may consist of multiple interrelated transfer scenarios including various pathways from the defined objective to the outcome. The evaluation of outcomes related to the objectives is conducted using suitable indicators, which may conclude the transfer scenario or function as an intermediate checkpoint to inform adjustments to objectives, actor involvement, and/or strategy.

A key feature of the model is its focus on the actors involved. From a provision perspective, transfer processes are set up by initiators, while from a usage perspective, they address specific target groups. Mediators may also be involved to facilitate the process. Actors can be individuals, groups, or institutions within educational contexts, such as teachers, principals, students, TPD facilitators, subject departments, researchers, companies, or schools. Importantly, actors can assume different roles depending on the transfer process, for example as initiators, mediators, or target groups. While initiators and target groups are essential components of any transfer process, the inclusion of mediators depends on the specific objectives and design of the transfer process. The actions of all actors are shaped by individual, organizational, and interorganizational conditions. Individual conditions include beliefs, motivation, self-efficacy, and competencies. Organizational conditions encompass factors such as institutional size, available resources, and incentive structures. Inter-organizational conditions involve aspects such as frequency of contact, trust, mutual recognition of expertise, and geographic or cultural proximity, all of which can influence collaboration and transfer effectiveness (Schrader et al. 2020, 27 f.).

The model also accounts for the variety of collaboration forms between actors. Depending on the objectives pursued, collaboration may be uni-directional, bi-directional, or co-constructive (Farley-Ripple, et al., 2018). Furthermore, different transfer strategies can be applied individually or in combination, including personal strategies (e.g., professional development activities), material strategies (e.g., provision of teaching materials), and systemic strategies (e.g., development of policy or strategy documents; Roesken-Winter et al., 2021). These strategies and forms of collaboration may vary across actors within a single transfer process, allowing objectives to be pursued through tailored combinations of approaches.

Finally, the model supports the systematic evaluation of transfer outcomes through goal-aligned indicators. For example, the four criteria proposed by Coburn (2003) can be used: reach (the involvement of multiple institutions and actors), depth (changes in beliefs and practices), ownership (identification with and responsibility for the transfer product), and sustainability (continuation beyond initial funding phases). These criteria provide a flexible foundation for operationalizing indicators that are adapted to the objectives of each transfer initiative.

Overall, the model's strength lies in its flexibility, capturing the dynamics of actors, collaboration forms, and transfer strategies across different phases of transfer processes. Rather than depicting prototypical processes, it provides a framework for the systematic analysis and of diverse transfer initiatives within a project. In this way, it supports both the scientific analysis and the informed design and optimization of transfer processes in educational research and practice.

Investigating Transfer Pathways

The complex conceptualization of the state program and its broad and all-encompassing overarching objectives provide opportunities but also challenges for transfer, among others, the multitude of formats, content, target groups, strategies and actors. To counteract this complexity and make beliefs about expected effects, decisions and related actions visible, the model presented in the previous paragraph is used to exemplarily map, describe and analyse different transfer scenarios – and the corresponding transfer pathways – pursued within the program. The underlying assumption is that looking into the specific transfer pathways from a program perspective will not only provide insights into objectives, beliefs and how these influence the decision for e.g. specific target groups, contents or formats, but also into the nature of interactions that hinder or support transfer at different stages of the process. On the individual level, visualizing one's own cooperations, formats, target group(s), etc. and explicitly describing objectives and outcomes of different transfer scenarios might support and lead to a more strategic and reflective process of planning one's own work. Thus, applying the model in the program

potentially serves two purposes: 1) giving an overview about different transfer pathways within specific transfer scenarios already “implemented” for further systematic and strategic decisions and, by fostering self-reflection, 2) acting as a systematic tool for planning and reflecting on transfer scenarios in a more holistic way.

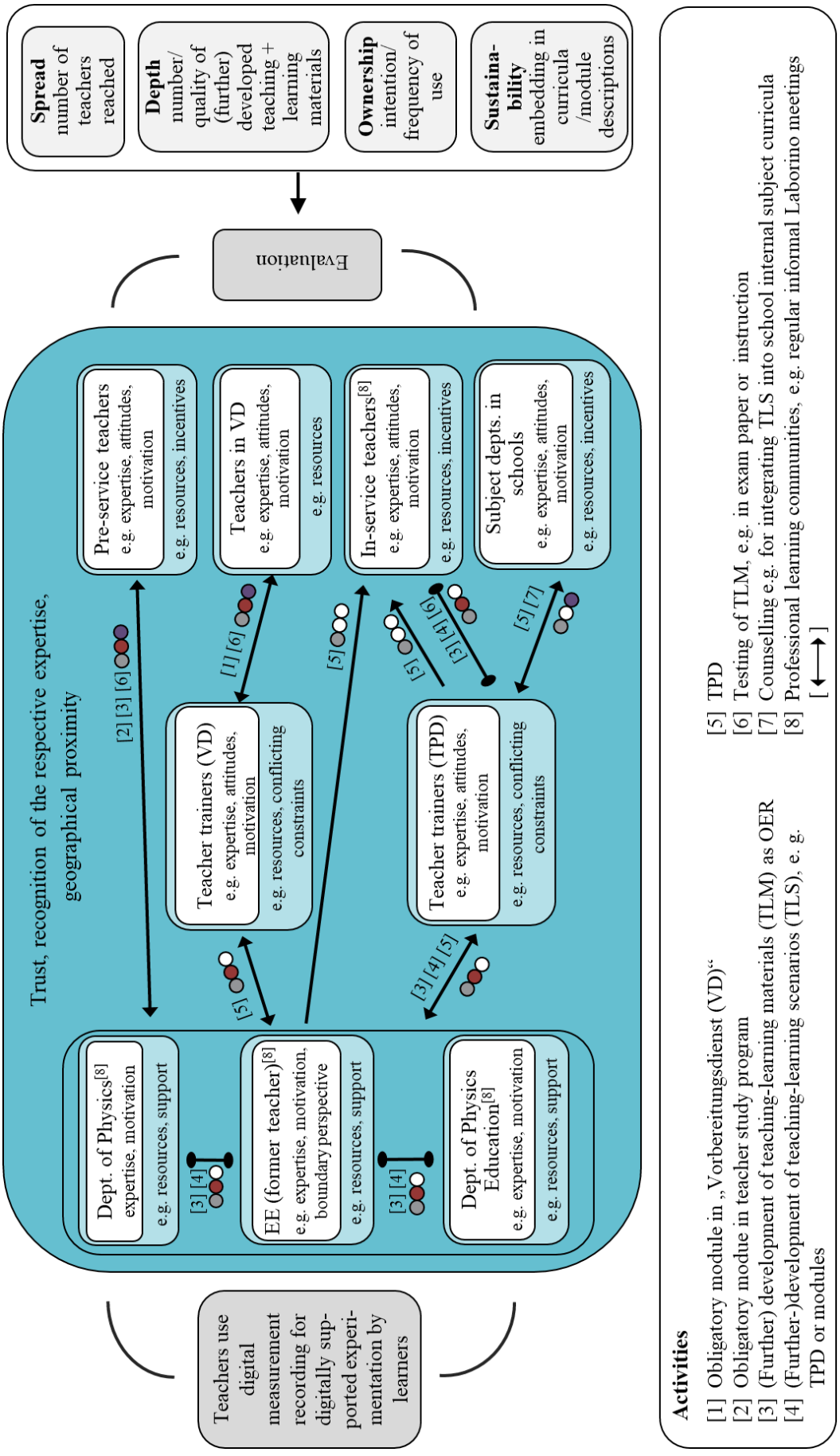
To address these purposes, the model was presented to the program staff working in the five subject clusters. Thereafter, they were asked to use it to describe and visualize examples of transfer pathways within one or two transfer scenarios from their clusters. The resulting graphical representations were then discussed with two of the authors and, if necessary, revised. In addition, the providers of the examples were asked about their experience of working with the model and their feedback was collected.

In the following, one example of a transfer scenario from the stem subject cluster including various pathways will be described in detail to illustrate the analysis approach and the work with the model. The example was chosen because it represents a rather complex scenario initiative, thus showing the potential of the model to visualize complex transfer pathways including several target groups such as pre- and in-service teachers.

Example Of A STEM Transfer Scenario

The chosen example is from the field of physics education (see Figure 3) and acknowledges the potential of digital measurement recording for science teaching and learning (e.g. Abdiakhmetova et al., 2024; Papadimitropoulos, & Pavlatou, 2023). The overall objective is to increase teachers’ use of these systems in student experiments. To support teachers in developing the necessary competences, beliefs and attitudes to reach this objective, a transfer process integrating different actors from all phases of teacher education is used. This not only enables a coherent acquisition of competences but also acknowledges that beliefs tend to be robust and difficult to change (e.g. Tillema, 1998; Fives & Buehl, 2015). With the Educational Engineer acting as the central initiator, researchers and educators from physics and physics education co-constructively develop teaching and learning materials and scenarios. In order to provide teachers with the necessary digital measurement technology, a digital sensor box was developed and is made available as an open educational resource. Its further development is an important part of the co-constructive transfer process. The teaching and learning materials form the foundation for subsequent support measures for pre- and in-service teachers (e.g. modules in the teacher study program or TPD courses) but also for teacher trainers working at the state institute or at schools in teacher training and TPD. In the context of the model, these teacher trainers act as mediators between the initiators and specific target groups. Introducing mediators in the transfer process allows to increase the spread by using them as multipliers but also contributes to the other indicators of successful transfer, e.g. by embedding the topic as an obligatory module into VD (increasing sustainability) or by counselling subject departments in schools (increasing ownership). In addition to these formal learning opportunities, the transfer process also incorporates professional learning communities as informal settings to encourage and support collaboration and exchange among teachers and between research and practice. As far as transfer conditions are concerned, from an individual perspective expertise and motivation play an important role. However, the expertise of the respective actors differs. On the initiators' side, researchers in the physics department contribute primarily technical and physics-specific expertise to the development and use of digital measuring devices as open educational resources, while researchers in the department of physics education contribute expertise in systematic integration into teaching and lesson plans. On the user side, in-service teachers contribute their expertise and experience to the co-constructive process, sharing what has worked well in their teaching and what is still needed.

Figure 3. Exemplary transfer scenario from physics education (for legend see Figure 2).



From an organizational perspective available resources, possible incentives and support are important transfer conditions. At the interorganizational level, the success of the transfer process depends on trust and appreciation of the respective expertise and perspective; it is supported by

a spatial proximity, e.g. all initiators and institutions involved are located in the same city and the teacher trainers are working regionally with schools and teachers in VD.

Conclusion: Challenges And Opportunities Of Working With The Model In The Program

Reaching the objectives of the state program requires successful transfer. The overarching aim of looking at transfer through the lens of the presented model thus is to support transfer at the program level by systematically analysing the different transfer scenarios that are pursued. Applying the model to examples from the STEM cluster but also across subject clusters showed the model's potential to systematically describe, analyse, and reflect on transfer pathways of varying complexity ranging from processes involving multiple initiators, target groups, collaborations and formats to simple ones like e.g. the development and implementation of a single module within a teacher education program. The graphical representations thereby visualize important factors influencing transfer like e.g. individual and organizational conditions, types of collaboration and transfer strategies as well as criteria to evaluate whether the outcomes are in line with the objectives. For example, it can be observed that truly co-constructive collaboration (Farley-Ripple, et al., 2018) is rare but is supported if contributors have the same subject background. Moreover, initiators usually pursue more than one transfer strategy to reach their objectives; they often combine material and personal strategies but yet seldom address the systematic level (Roesken-Winter et al., 2021). Overall, it became obvious that a lack of learning scenarios addressing the systematic level exists (e.g., teach-the-trainer workshops, multipliers, professional learning communities) which might give hints for strategic management and planning in the future.

In terms of evaluation and effects of transfer scenarios it can be observed that working with and discussing the model enables the visualization of the criteria and measurements of effects that are actually applied (Coburn, 2003). However, it also became obvious that an important target group stated in the program's objectives, namely school students, is only very seldom directly addressed by support measures. These focus almost entirely on pre- and in-service teachers as well as teacher educators in all phases of teacher education assuming that supporting and professionalizing these groups will have a positive effect on student learning.

Working with the (science) educators in the state program on describing and reflecting on transfer pathways related to the support measures they are developing and implementing revealed challenges but also opportunities at different levels. From a transfer perspective, formulating objectives in a way that they can guide a transfer process proved to be vary daring. Objectives tended to be very broad (e.g., fostering digital competences or supporting collaboration) or format- rather than content-related (e.g., developing a TPD activity or support). In addition, only limited attention was paid to evaluation criteria leading to the use of standard questionnaires that were often not aligned with the stated objectives and transfer getting confused with related concepts like effective TPD or the development of teachers' professional competence. Looking at challenges related to the specific use of the model, a tendency could be observed to report only on complex processes and consider any type of collaboration as co-constructive. The analysis, however, also revealed that the initiators of support activities often focus on the development and implementation of a specific format rather than regarding it as a transfer scenario and seldom included ideas for scaling up. Working with the model and trying to apply it to their own work, however, made them aware of this, thus making the model a valuable resource for self-reflection at an individual level, too.

Outlook

Overall, it can be summarized that applying the transfer process model to the program has been helpful in two ways. From a program point of view, analysing transfer through the lens of the model enables the investigation and visualization of transfer pathways that lead from an objective, over transfer processes of various complexity to outcomes. At an individual level, the contributors considered the model very valuable in guiding and structuring their work because it encourages and supports self-reflection. However, the model might not only be helpful in retrospective. It could also be used as a planning tool to guide transfer initiatives and design effective and detailed scenarios when initiating new projects or programs (Ward, 2019).

These first results are exemplary and have to be supported by further analyses in order to learn from comparing the different transfer scenarios and address questions like: How do objectives align with target group, content and formats? What beliefs exist regarding expected and expectable effects and how do these influence the decision for specific transfer pathways? What are individual and group-specific conditions for successful transfer of individual support measures? Moreover, additional analyses like e.g. social network analyses could provide information whether the collaboration structure envisioned in the conceptualization of the program – and in parts visualized in the transfer pathways – is reflected in the resulting networks. Answering these questions may not only feed back into the program to inform its further development but may also provide valuable insights for similar projects and programs and enhance the existing knowledge base on transfer.

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Professional Development In Out-Of-School Learning Environments To Promote Teachers' ICT Skills – How Can We Scale-Up Our Best Practice Examples?

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Research shows that teachers need to feel a degree of instructional autonomy, i.e., a sense of ownership, and self-efficacy to implement reform-based instructional practices learned in professional development (PD) courses. Certainly, PD has been shown to be crucial for teacher professionalisation and engagement. Criteria for effective PD, such as content-focused, collaboration, or activity-based approaches, have been elaborated. However, there is a great deal of variation between countries in how PD is organised, what topics are offered, who participates (voluntarily) and what the outcomes regarding teachers' (Information and Communication Technology, ICT) skills are. Accordingly, it is challenging to empirically identify what works best in PD courses, i.e., to identify examples of best practice that work in and for different teaching and school contexts. Our current Ministry-funded research and development project LFB-Labs-digital focuses on Science, Technology, Engineering, and Mathematics out-of-school laboratories as spaces for PD in teachers' ICT skills. Therefore, good practice within PD is being identified through questionnaires, interviews, and observations. We see great potential in a cross-country exchange of good, next and ideally best practices to improve PD provision. In this exploratory seminar, we discussed with international PD providers and researchers what examples of best practice look like, what data and criteria are used to identify them, how evidence-based approaches can be scaled up and implemented in different countries, and what recommendations can be derived for PD providers, researchers, and policymakers. To structure the exchange, we applied the placemat method, in which participants recorded and reflected their ideas and experiences.

Keywords: professional development, teacher education, digital learning

Introduction

Professional development (PD) is a central component of teachers' professional learning and an important lever for improving teaching and learning in schools (Drossel & Eickelmann, 2017; Priebe et al., 2019). In recent years, expectations on PD have further increased, particularly with regard to supporting teachers in responding to ongoing digitalisation and changing educational demands (Kultusministerkonferenz, 2020; European Commission, 2021; West & Leary, 2024). Although a growing body of research has outlined characteristics of effective PD (e.g. Desimone & Garet, 2015), its specific design and implementation continue to vary widely across educational systems, institutions, and national contexts. As a result, practices that are considered successful in one setting are often difficult to transfer to another.

This contribution is situated within this field of tension between established research knowledge and context-specific practice. It draws on an international exploratory seminar that brought together researchers, professional development providers, and practitioners from Germany and the United States. The exploratory seminar offered an opportunity for shared reflection on PD

focusing on teachers' ICT-related competences and on the conditions under which good or best practices can be meaningfully adapted and disseminated. By examining different perspectives and experiences, we seek to illuminate challenges and opportunities related to scaling PD across diverse educational contexts.

Theory And State Of Research

Beyond supporting individual growth, PD plays a central role in school and instructional development and ultimately affects the quality of student learning opportunities (Kultusministerkonferenz, 2020; European Commission, 2021; West & Leary, 2024). Against this backdrop, research has identified several core features that contribute to the effectiveness of PD initiatives. For example, Desimone and Garet (2015) highlight content focus, active learning, coherence, sustained duration, and collective participation as central criteria. Similarly, Lipowsky and Rzejak (2021) propose an adapted offer-and-use model, which outlines ten features of effective PD, including the quality of instructional design, the organisation of learning activities, and the professional expertise of the facilitators. These frameworks emphasise that PD must go beyond isolated workshops and be embedded in sustained, collaborative, and practice-oriented formats.

However, there is still considerable variation in how PD is structured and delivered across countries and even within regions of the same country (OECD, 2020). This includes differences in the topics addressed, the degree of voluntary participation, the resources allocated, and the resulting outcomes for teachers and students. Such diversity poses challenges for identifying universally applicable best practices for PD, as their success often depends on local educational traditions, systemic conditions, and teacher needs (Hayes et al., 2025). Recent studies also stress the importance of organisational factors, such as school culture and leadership support, alongside teachers' individual characteristics for successful PD implementation (Beavers, 2009; Hayes et al., 2025).

A key area of current concern is the integration of digital technologies into teaching and thus into PD. Despite investments in digital infrastructure, the actual use of information and communication technology (ICT) in classrooms remains limited (Eickelmann et al., 2024, Gil-Flores et al., 2017). This highlights the importance of PD that not only strengthens teachers' ICT skills but also supports the development of digital pedagogical competence, as described by frameworks such as TPACK (Mishra & Koehler, 2006) and DigCompEdu (Redecker, 2017). PD programmes in this field must enable teachers to critically reflect on their own beliefs about digitalisation, integrate technological tools meaningfully with subject content and pedagogy, and prepare students for participation in a digitally mediated world (Ertmer et al., 2012; Vogelsang et al., 2019).

Out-of-school learning environments, such as out-of-school labs, provide a promising yet under-explored context for teacher PD. Traditionally designed for students, these laboratories, often located at universities or research centres, offer authentic insights into scientific practice and experimentation (Kirchhoff et al., 2023). More recently, they have also been used as spaces for teacher learning, including the development of ICT-related skills (Martens et al., 2022; Martens & Schwarzer, 2023). Preliminary results of our joint project *LFB-Labs-digital* (see Kirchhoff, Schwedler et al., 2024) highlight the importance of collaboration and sufficient PD duration, while challenges remain regarding sustainable implementation and broad participation (Lüsse et al., 2025), which aligns with international findings (Popova et al., 2022).

Aim And Subject Matter Of The Exploratory Seminar

Despite the findings of several recent studies, the question of how to scale-up and generalise good practices remains a pressing concern. The diversity of educational contexts in different countries necessitates a careful consideration of how best practices can be adapted to meet the unique needs of different teacher populations. For example, PD programmes designed for urban schools with access to advanced technological infrastructure may not be directly applicable to rural schools with limited resources. Similarly, cultural differences in teaching philosophies and student-teacher dynamics must be accounted for when designing and implementing PD initiatives.

Given these complexities, a cross-country exchange of best practices was conducted within the exploratory seminar as a means of improving PD provision internationally. The aim was to provide an overview of PD practices for teachers' ICT skills across different countries, with a particular focus on identifying and scaling up best practice examples, while also establishing international collaborations to evaluate and disseminate these practices. The key question was: How can we scale-up our best practice examples in PD?

Figure 1. Overview of the placemat and the guiding questions within that was used in the exploratory seminar. The questions were enlarged for better readability.

In the exploratory seminar several interrelated themes were examined: the identification of best practice in PD from a cross-country perspective, the data and criteria used to identify best practice, strategies for scaling and adapting successful approaches across contexts, and recommendations for PD courses. Participants were asked to share specific examples of best practice, to reflect on the influence of policy guidelines, and to discuss how research evidence can be balanced with practitioners' experience. The exploratory seminar also considered factors contributing to successful scaling, including both achievements and challenges, and examined recommendations from multiple perspectives: for PD providers, on combining evidence-based approaches with practical classroom applicability; for researchers, on suitable designs and methods to capture long-term impact; for policymakers, on structural and financial conditions required to sustain PD; and across all roles, on fostering effective collaboration.

We used the placemat method enabling participants to individually record and reflect their ideas and contribute to a collective dialogue around these guiding themes (Figure 1). The placemat method is a cooperative learning strategy with a graphical layout, implemented in this context in groups of four. It first allows for the individual documentation of participants' ideas, solution approaches, and responses to a given question, and subsequently supports the negotiation and recording of shared group results, which are then discussed with the whole group.

To structure and enrich the exchange, the seminar followed four main steps.

1. Collecting Individual Thoughts: Each wrote their own experiences and perspectives
2. regarding the guiding questions into the placemat while rotating the placemat after each round (5 min).
3. **Breakout Group Discussions:** Participants discussed in smaller groups the general conditions, data collection, criteria, and evidence regarding best practice PD examples.
4. **Group Reports and Open Discussion:** The group results were summarised and compared in a plenary discussion, allowing for reflection on similarities and differences across contexts.
5. **Conclusion and Follow-Up Plans:** The seminar concluded with outlining next steps, including the definition of work packages, future seminars or workshops, and potential collaborative projects.

Results Of The Exploratory Seminar

The following section presents the results from the group discussions within two groups, which were documented using the placemat method. Participants (N =8) from Germany and the United States took part, providing a comparative perspective on the topics discussed. Due to the focus of the participants on PD in general, it was not possible in this case to compare experiences regarding teacher PD in out-of-school labs or with a focus on teachers' ICT skills in different countries.

Defining Best Practice In International PD

The discussions emphasized several recurring elements that contribute to defining best practice in PD from a cross-country perspective. Clarity and structure were identified as essential characteristics ("clear program", "clear guidelines", participants group 1). Programmes with clear guidelines enable teachers and school leaders to estimate the required workload and time commitment, thereby increasing feasibility at the school level. In contrast, the absence of sufficient hands-on opportunities was noted as a weakness in many PD formats. Opportunities for dialogue among teachers, students, and school leadership were considered necessary to ensure relevance and applicability in practice ("have conversations with teachers, students, and head of school", participant group 2). A second theme concerned the transferability of international examples ("International examples must be translated to a common language, what sometimes is difficult to achieve", "They [PD] depend on national/regional learning objectives", participants group 2). Participants highlighted the challenge of translating practices into a common conceptual and linguistic framework, particularly when aligning them with diverse national and regional learning objectives. The consideration of teachers' needs emerged as another defining feature of best practice ("Ask teacher what they need/expect for these PD courses → hands on + practical material", participant group 2). Effective PD should be designed in consultation with teachers, incorporating hands-on activities, practical materials (including possibilities for borrowing resources), and systematic evaluation through mixed methods. The integration of digital tools was also considered important. PD initiatives should prepare participants to work with a range of devices and hardware. At the same time, policy guidelines were often perceived as insufficiently

supportive, with limited autonomy reported as a barrier ("policy guidelines did not help; too much top dow[n], too less autonomy"; "I generally find policy to be limiting", participants group 2). In several cases, practitioners chose to move beyond restrictive policy frameworks in order to pursue what they considered most effective. Another point was the role of collaborative structures and action research in large-scale PD projects ("In a very large PD project we developed three different collaboration groups and did Action Research. Each group had a unique facilitator and PI. Each had a slightly different focus depending on their [teachers'] interest", participant group 1). Establishing multiple working groups with differentiated focuses, supported by targeted facilitation, was seen as a productive strategy for accommodating diverse professional interests while ensuring sustained engagement.

Data And Criteria For Identifying Best Practice

Concerning the data and criteria used to identify best practice in PD from a cross-country perspective, participants emphasized the importance of engaging in conversations about plans and results, collaborative planning between teachers and researchers, and producing practically oriented publications. School visits were highlighted as valuable opportunities to experience local practices firsthand and understand the contextual possibilities ("learn from practitioners + listen to them", participant group 1; "visit schools to experience their work and their possibilities", participant group 2). A crucial starting point, according to participants, is the practitioner's own experience, which helps to establish initial expectations while also introducing them to new models and approaches. Collaborative approaches, such as design-based research, were seen as effective ways to share ideas, experiences, and evidence ("development of a shared views", "compare actions and research", participant group 1). Mixed methods – including interviews and questionnaires – were recommended to compare evidence with practitioner experience. The development of a shared understanding and the comparison of action research with research-based interventions were also highlighted as important strategies ("I include classroom teachers in the design, implementation, and assessment process. This is done through Participatory Action Research, Collaborative Action Research, and a lot of formative Assessment/Evaluation", participant group 1)", participant group 1). In addition, participants stressed the need to include classroom teachers in the design, implementation, and evaluation of professional development. This is often achieved through participatory, collaborative action research and formative assessment, using research instruments not only to collect data but also as reflective tools for teacher learning.

Scaling And Adapting Best Practice Across Contexts

Regarding scaling and adapting best practice across different contexts, participants noted that dissemination rarely happens directly; instead, it is often carried out through multiple platforms, including digital networks, websites, and professional development institutes ("I suppose that dissemination through several platforms (web, network, institute of PD) could be positive", participant group 2). Therefore, the idea of a best practice handbook or "how-to" guide, combining digital and analog formats for both providers and researchers, was suggested and discussed within the exploratory seminar as a potential tool. German participants emphasized the challenge of coordinating communication with a larger number of participants and schools, particularly when crossing regional or federal boundaries with differing curricula for PD ("Expanded to more schools – lead to higher time commitment of coaches. Also, more organization", participant group 1). Effective communication was highlighted by all participants as essential to ensure that both practitioners and researchers feel acknowledged and heard. Commitment from PD providers and additional organizational support were also seen as necessary, alongside collaboration with specific teachers (find a way to have a good conversation

to make sure that both (providers and researchers) feel ‘good and heard’”, participant group 2). Teachers can act as multipliers, engaging their colleagues at their own schools. Long-term cooperation with laboratory schools was described as particularly effective, often yielding more substantial outcomes than initially expected, despite the understanding that teachers have a mind of their own.

Recommendations And Take-Away Of Own PD Courses

As last aspect, recommendations and key takeaways for designing effective PD courses were discussed. Regarding the role of PD providers, participants suggested using design-based research in collaboration with teachers, visiting schools to gain firsthand experience, and including assessments on specific topics as well as sufficient time for reflection. For researchers, longitudinal and cross-sectional studies as well as mixed-methods approaches were recommended to gain deeper insights, with a particular emphasis on qualitative research. From a policy perspective, participants highlighted the need for sufficient funding, clear communication, blended formats combining digital and in-person elements, and overall commitment to make PD feasible and sustainable. It was noted that in the United States, teachers are often paid for participating in PD programmes, which appears to serve as a strong incentive for engagement. Participants discussed that implementing a similar approach in Germany could likewise enhance participation, but can hardly be implemented in the current system as PD is seen in Germany as part of the duties of a teacher. Across all roles, effective collaboration was seen as essential, with participants emphasizing discussion and action on equal footing. Inviting policymakers to PD courses was also suggested to strengthen mutual understanding and engagement. Additional recommendations included involving various stakeholders, integrating action and community action research, providing coaching throughout the planning and implementation phases, conducting interview-based studies, designing programmes with sufficient duration, establishing long-term cooperation, and ensuring ongoing communication (e.g., “programmes with enough ‘time’ might impact sustainability”, “long lasting cooperations”, participants group 2).

Discussion And Conclusion

The results of the exploratory seminar indicate that the dissemination of PD is a non-linear process that depends on structural clarity, participatory design, and sustained communication. PD programs with transparent structures regarding workload, time commitment and outcomes are more likely to be taken up and disseminated at the school level, whereas formats lacking hands-on components limit practical transfer. Hereby, the results underline former results in the context of teacher PD (Drossel & Eickelmann, 2017; Lüsse et al., 2025; Lipowsky & Rzejak, 2021).

The dissemination of PD content across contexts requires careful adaptation rather than direct replication. The discussions between participants from the United States and Germany have shown that national best practices cannot be replicated in other countries but must be translated into shared conceptual and linguistic frameworks and aligned with local curricula, policy conditions, and teachers’ needs. By doing so, this might be a chance to improve policies regarding teacher PD in different countries.

Teachers play a key role as multipliers in the dissemination process. PD initiatives that actively involve teachers in design, implementation and evaluation (e.g. through participatory action research or design-based research) support sustainable dissemination within and across schools. Collaborative working structures and long-term partnerships with schools further strengthen ownership and professional learning communities.

Dissemination typically occurs through multiple channels, including digital networks, institutional platforms, professional development institutes and school visits. Hybrid

dissemination tools, such as digital and print-based best practice guides, can support both practitioners and researchers. Effective communication across platforms is essential to ensure engagement and recognition of all stakeholders.

Finally, sustainable dissemination depends on supportive organizational and policy frameworks, including adequate funding, institutional commitment, and blended PD formats. Incentives for participation – as described by the participants from the United States in contrast to the opportunities in Germany where PD are part of the job as teacher – and ongoing collaboration among teachers, PD providers, researchers, and policymakers are crucial for ensuring that PD content is not only disseminated but also sustained over time. This exploratory seminar facilitated a cross-country exchange about individual experiences in the context of teacher PD. As it was not possible in this case to compare experiences regarding teacher PD in out-of-school labs or with a focus on teachers' ICT skills in different countries, further exchange or research would be of interest.

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Understanding In-Service Stem Teacher Professional Development Needs: A Literature Review

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As the global demand and importance for up-to-date STEM professionals increases, STEM education should flexibly follow the trends. One mechanism, how STEM teachers can stay up to date with changes in the STEM field is in-service teacher professional development (PD). In the last decades, there have been numerous reports about various STEM teacher PD solutions in various contexts. Also, the number of publications regarded STEM teacher PD needs is growing, therefore the present study aims to provide an overview of the complexity of this topic. As a result, a systematic study was carried out to identify STEM PD teacher needs both in terms of PD contents and approaches to PD. The selected 17 peer-reviewed publications were published between 2010 and 2024 in Scopus, Web of Science, and EBSCOhost databases. A comprehensive review of these empirical articles produced a total of 16 subthemes under the main PD content and approach themes.

The results exhibited that the dominant STEM teacher PD needs in terms of contents are the use of ICT in STEM teaching and learning and the teacher's deeper understanding of STEM subject contents; in terms of PD approaches – practice-based PD and systemic support. Finally, several recommendations for STEM PD sustainability and future research references are presented.

Keywords: STEM, In-service teacher professional development

Introduction

In-service STEM teacher professional development (PD) is a cornerstone for fostering high-quality STEM education. As scientific knowledge and instructional methodologies advance, it is crucial that practising STEM teachers continuously enhance their content knowledge, pedagogical skills, and practical classroom strategies. Effective professional development experiences not only support teacher growth but also translate into enriched learning environments for students and enhanced student results – the goal of STEM education (Surahman & Wang, 2023). Several scholars agree that recognizing and addressing in-service STEM teacher PD needs is central to designing meaningful PD programs, as adults learn according to their needs. Still, often the STEM teacher PD is built top-down – the contents and approaches to teacher learning within PD are dictated by higher authorities (Cooper et al., 2020). The investigation of various teacher PD needs has been ongoing for some time in research articles as well as in international studies (i.e., OCED TALIS), still to this date there is an empirical gap about the in-service STEM teacher PD needs. At the same time, the perspective from which teacher PD needs are defined (and simultaneously the teacher PD needs definitions) vary.

Conducting a literature review in this area is vital for several reasons. First, it provides a comprehensive overview of existing research, enabling educators, policymakers, and PD providers to discern models and strategies for in-service STEM teacher PD. Second, it can help to identify persistent gaps and future research avenues.

Aim Of The Study

The study aims to investigate the intricacies of in-service STEM teacher PD needs (in terms of PD contents and approaches), which can guide further research and practice development. More particular, we aim to answer the following research questions:

RQ1: From what perspectives (teacher, school leader, policymaker etc.) are in-service STEM teachers' professional development needs addressed and how are they defined in recent studies?

RQ2: What are the in-service STEM teacher needs in terms of PD contents and approaches?

It is worth mentioning, that in the present review, the authors themselves do not define what STEM teacher PD needs are; we aim to obtain an overarching view about STEM teacher PD needs, the definitions and perspectives from which STEM teacher PD needs are defined.

Method

This study investigates the PD and training needs of in-service STEM teachers through a systematic literature review guided by the PRISMA checklist (Moher et al., 2009). The review followed key stages: (a) eligibility and exclusion criteria, (b) identification review, (c) screening, (d) eligibility, and (e) data abstraction and analysis. The process began with identifying relevant keywords and creating search strings for Scopus, Web of Science, EBSCOhost, and Google Scholar, as detailed in Table 1. Articles were then screened based on inclusion and exclusion criteria (Table 2), with automatic sorting functions used to streamline the process. The overall selection process is illustrated in the PRISMA flow diagram (Figure 1). Out of 85 initially screened papers, 43 articles were assessed for eligibility, and 21 were excluded for reasons such as including both pre-service and in-service teacher participants or lacking direct relevance to STEM PD needs. The final selection of studies was critically analysed to synthesize key findings, ensuring a rigorous and focused review aligned with PRISMA principles.

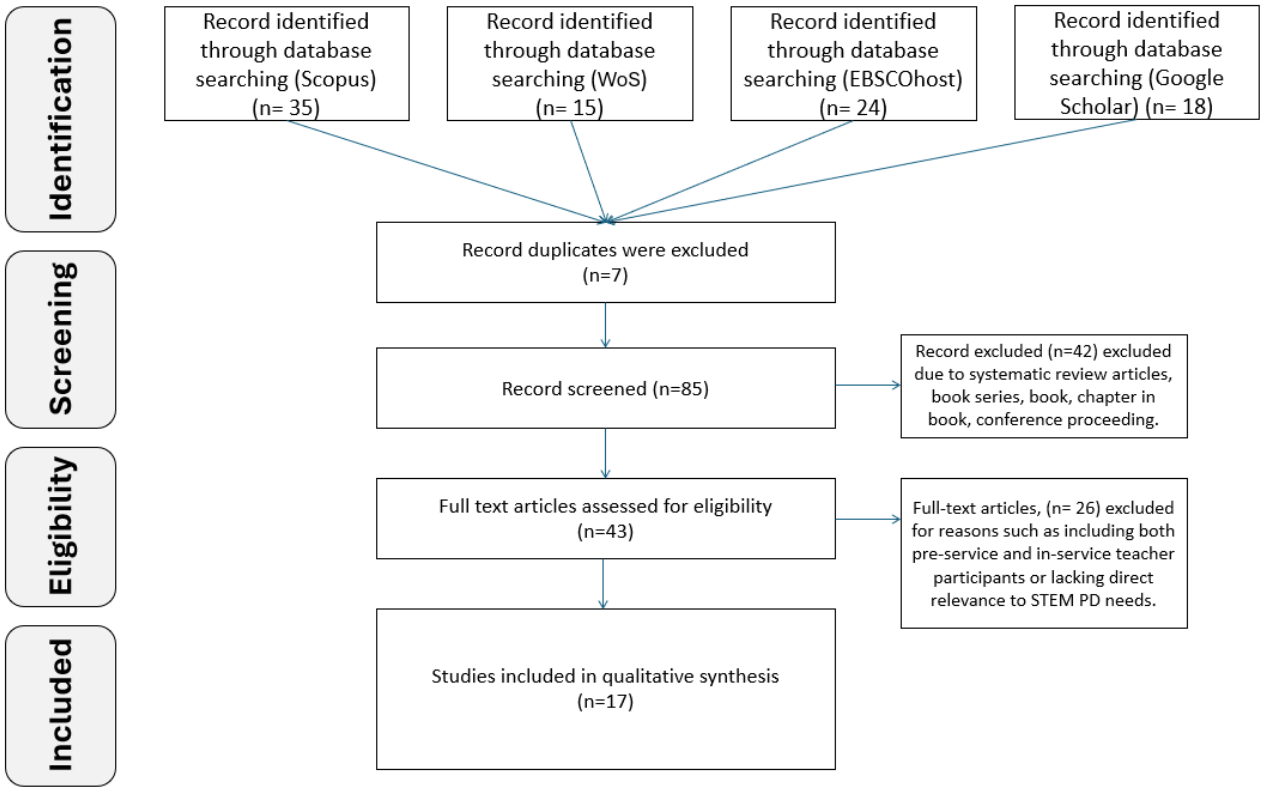
Table 1. Strings used during the search.

Databases	Search String
Scopus	TITLE-ABS-KEY(('STEM professional development' OR 'teacher professional development') AND ('In-service teacher' OR 'PD needs' OR 'Teacher needs' OR 'Teacher training needs'))
WoS	TS=(('STEM professional development' OR 'teacher professional development') AND ('In-service teacher' OR 'PD needs' OR 'Teacher needs' OR 'Teacher training needs'))
EBSCOhost	(('STEM professional development' OR 'teacher professional development') AND ('In-service teacher' OR 'PD needs' OR 'Teacher needs' OR 'Teacher training needs'))
Google Scholar	"STEM professional development" OR "teacher professional development" AND "In-service teacher" OR "PD needs" OR "Teacher needs" OR "Teacher training needs"

Table 2. The inclusion and exclusion criteria.

Inclusion Criteria	Exclusion Criteria
Studies focusing on in-service STEM teachers (science, technology, engineering, and mathematics).	Studies focusing on pre-service teachers or teacher candidates.
Articles that explicitly address professional development needs or teacher training needs.	Articles that do not explicitly mention STEM disciplines.
Peer-reviewed journal articles, conference papers, and reputable reports published in the last 15 years (2010-2025).	Opinion pieces, editorials, and non-peer-reviewed sources.
Research was conducted in diverse educational contexts, including primary, and secondary contexts.	Studies published in languages other than English (due to resource constraints).
Studies employing qualitative, quantitative, or mixed methods approaches.	

Figure 1. PRISMA flow diagram.



Findings

The reviewed studies span multiple continents, providing a comprehensive view of in-service STEM teacher PD needs. The research was conducted across North America (USA), Europe (Lithuania, Northern Ireland, Greece, Portugal, and Germany), and Asia (Taiwan, Malaysia, Turkey, Israel, and the Philippines), showcasing diverse educational contexts and priorities. Sample sizes ranged widely, from small-scale studies with as few as 5 participants in Lithuania to extensive surveys involving up to 4,957 teachers in the USA, offering both localized insights and broader comparative analyses. The studies employed various research methodologies,

including quantitative, qualitative, and mixed methods approaches. Quantitative studies, such as those conducted in the USA, utilized structured questionnaires for systematic data collection. Mixed methods approaches, combining surveys and interviews, were used in studies from Taiwan, Malaysia, and the Philippines, enabling both statistical analysis and nuanced qualitative insights. Meanwhile, qualitative methods, including case studies, interviews, and teacher reflections, were prominent in studies from Israel, Turkey, and Greece, offering a deeper contextual understanding of PD needs. This methodological diversity enriches the overall findings and highlights the complexity of STEM teacher PD globally.

In terms of in-service STEM teacher PD needs definitions, only one of the reviewed studies (Zakaria & Daud, 2009) included a definition of needs (still not in the context of STEM teacher professional development needs): “need is defined in terms of want or preferences of an individual or a group of people. Need in this context is seen as a want (which implies interest or motivation), felt by an individual or group to eliminate a lack (Queeney, 1995).” Nevertheless, many of the reviewed studies include the perspective from which STEM teacher PD needs are viewed. For example, the study by Shernoff et al. (2017) includes the perspective in the study research questions: “What are the greatest challenges [for STEM teachers] to effectively implement integrated approaches to STEM education? What supports would be most helpful to overcome these challenges?”. Overall, all of the reviewed studies view STEM teacher PD needs from the teacher's perspective and define STEM teacher PD needs as challenges that STEM teachers face in their practice.

In the table below the identified 16 subthemes under the two main themes: 1) STEM teacher PD content and 2) approach needs are outlined.

Table 3. The themes and subthemes of in-Service STEM teacher PD needs identified in the present review (For the list of references of the reviewed articles, please use this LINK).

Publications	PD approach needs							PD content needs							
	Short PD	F2F	School-based	Practice-based	Systematic support	Ready-to-use materials	Collaborative	Reflective	ICT	Inquiry-based learning	A deeper understanding of the contents	Problem-solving in STEM lesson	Classroom management	Student collaboration	Assessment	Real-world issues
Zakaria & Daud (2009)									x		x	x	x			
Oztay et al. (2022)				x	x				x	x	x			x		
Shernoff et al. (2017)				x	x				x		x	x			x	
Lai (2021)				x	x											
Herro & Quigley (2017)				x	x											
Even-Zahav et al. (2022)							x	x								
McElearney et al. (2019)				x		x	x									

Chin et al. (2022)													x		x			x				x		
Burke et al. (2022)													x					x						
Chen et al. (2021)			x			x							x		x		x					x		
Sadler et al. (2018)	x	x						x					x				x							x
Akgunduz & Mesutoglu (2021)													x											x
Juskeviciene et al. (2024)								x		x														
Spyropulo & Kameas (2020)											x							x		x				
Hasim et al. (2022)			x		x			x					x	x		x								
Costa et al. (2022)						x		x								x								
Owens et al. (2018)	x	x	x					x		x		x	x				x							x
Buscher (2022)													x					x						
Kang et al. (2021)					x								x											
Zhang (2015)														x		x						x		

Discussion

All the research articles view teacher-perceived needs and are based on teacher opinions. There is a lack of studies, where PD needs are viewed from other perspectives (school leaders, external experts).

There are noticeable similarities between the results of this review and the large-scale OECD TALIS 2018 survey (OECD, 2019), which identified teacher PD needs on a large scale: use of ICT in lessons; assessment; and classroom management are some aspects which converge and are STEM teachers' top priorities in terms of PD content needs. Teaching students with special needs differs - none of the reviewed articles in the present research, still it is one of the top needs in OECD TALIS. A deeper understanding of STEM concepts could be highlighted as a unique PD need for STEM teachers. The rationale for such a need is clear - as few of the reviewed studies uncover – STEM teachers are usually specialists in one of the STEM subjects. When STEM is taught as an integrated subject it is objective to lack knowledge about other aspects.

Systemic support, ready-to-use materials and practice-based approaches are the top PD needs from the perspective of PD approaches; such needs appear not only in small-scale qualitative studies but also in large-scale quantitative studies.

There aren’t a lot of differences between the PD needs of STEM teachers in countries from various regions. For example, studies by Oztay in Turkey (Oztay et al., 2022) and Shernoff in the

USA (Shernoff et al., 2017) outline quite similar STEM teacher PD needs both in terms of approaches and contents. This could be possibly explained by the comparatively recent popularity of integrated STEM worldwide.

Acknowledgement

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Aesthetic Learning Processes In Science Education – Cultivating Empathy And Curiosity For Nature In Primary And Middle School Science

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This paper examines how Danish primary and middle school science teachers can develop and implement aesthetic learning processes to foster students' empathy and curiosity for nature. The study focuses on integrating authentic macro photography and observational drawing within a science-didactic framework that encompasses Education for Sustainable Development (ESD), the Danish concept of "naturdannelse", i.e. nature connectedness. By incorporating these visual tools, teachers can create engaging science lessons that deepen students' understanding of natural phenomena and promote sustainable development. Data collected from both in-service and pre-service teacher training programs demonstrates the effectiveness of these didactic approaches in engaging both teachers and students.

Keywords: professional development, student engagement, sustainability

Introduction

Research indicates that children develop deeper understanding and retention of natural phenomena when they engage with them through sensory experiences (Shouse et al., 2007; Zinkernagel 2017, 2022). However, studies also show a declining trend in curiosity and empathy for nature (Shouse et al., 2007), an observation supported by our experiences as teacher educators at the University College of Copenhagen. While direct contact with nature is crucial for fostering curiosity, this presents a challenge given the limited weekly hours allocated to science lessons in Danish public schools (Bentsen & Jensen, 2012).

This work contributes to Education for Sustainable Development (ESD, e.g. UNESCO 2017) by exploring how aesthetic engagement with nature might foster the emotional connection and curiosity that underpin environmental care and stewardship. To address the constraint of limited classroom time and foster students' curiosity and engagement with nature, we propose bringing nature into the classroom' through the use of macro photographs and aesthetic learning processes. This paper presents our work incorporating instructor-captured photographs and observational drawing activities in pre-service and in-service teacher education. This approach aligns with outdoor didactics theory by complementing classroom teaching with indoor nature experiences (Jordet, 2002). This method provides teachers with didactic tools that promote student co-ownership and engagement, potentially leading to increased motivation and stronger connections to nature (Jordet 2002; Bentsen & Jensen, 2012).

Photographs and observational drawings serve as powerful tools for creating aesthetic experiences of nature in science education. Visual representations help students grasp complex concepts while creating engaging learning experiences (Alenezi, 2015; Andersen, 2022). By using authentic macro photographs and guiding students through iterative observational drawing and discussion, teachers facilitate direct engagement with scientific phenomena through nature's aesthetics. This approach enables students to develop deeper connections with their subjects of observation while enhancing their understanding of nature's complexity and biodiversity – essential foundations for sustainable development (Zinkernagel, 2017, 2022).

Methodology

Our methodological approach is grounded in Iskov's (2020) concept of "det dobbeltdidaktiske blik", i.e.. the double didactic lens and the pedagogic principle of modelling. This framework emphasizes the importance of having teachers experience learning activities as learners themselves, while also reflecting on how to implement these activities in their own teaching practice. By engaging teachers in the same type of aesthetic learning processes which they later can be expected to facilitate with their students, we as teacher educators create opportunities for both experiential learning and pedagogic (didactic) reflection.

The study reported here was conducted at the University College of Copenhagen (Københavns Professionshøjskole, KP), which offers both pre-service teacher education and in-service professional development programs. Pre-service teachers at KP complete a four-year bachelor's degree in teaching, with those specializing in science education receiving comprehensive training in both scientific content and pedagogic/didactic approaches. The in-service program offers already practicing teachers the opportunity to become science supervisors through a professional development degree which combines two modules focusing on pedagogical knowledge and research with three science education courses and a final independently determined capstone project.

In one of the in-service modules, we introduced macro-photography in science teaching implementing the double didactic lens. Participants first experienced the learning process as students by examining authentic macro photographs of insects, flowers, and other natural subjects. These photographs were taken by one of the authors, who is a successful amateur photographer, highlighting subjects such as local flora and fauna. Using these photographs as models, in-service teachers were then asked to create detailed observational drawings of the organisms (Figure1). The process included peer feedback sessions and refining their drawings based on the feedback received. This was followed by presentations of their work to the whole class, with a subsequent reflection session, shifting to the teacher perspective. In the reflection session, participants engaged in whole-class discussions analysing the pedagogic potential of this approach. The lesson finished with time allotted for the in-service teachers to plan implementation of the approach in their own practice.

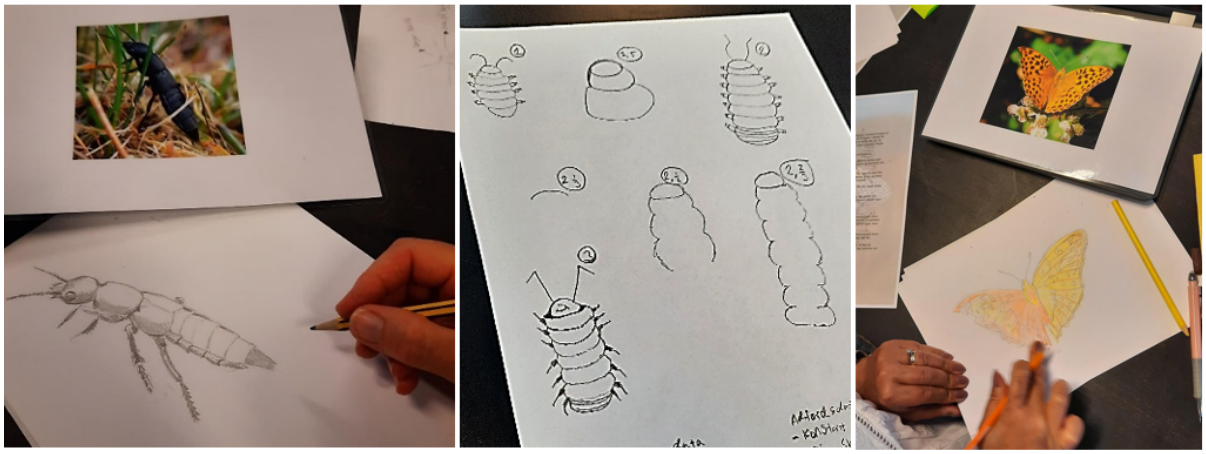
The lesson described for in-service teachers above was replicated with in-service teachers participating in a NAFA (Danish Academy of Science Education) project and with two cohorts of pre-service teachers in their first and third years of study, maintaining the dual focus (the double didactic lens) on personal experience and professional application.

Data

This paper draws on practitioner inquiry conducted within teacher education courses at the University College of Copenhagen. As course instructors, we implemented the macro photography and observational drawing approach described above with both pre-service teachers (1st and 3rd year cohorts) and in-service teachers within the context of the science supervisor program and NAFA´s professional development. Following their experience with these activities, some participating pre- and in-service teachers chose to implement similar approaches and were observed in their own classrooms (in grades ranging from Kindergarden to year -6, with students aged approximately 6-12).

Data presented here includes observations from our own teaching, teachers' created artifacts, and feedback collected through classroom discussions with pre- and in-service teachers. Figure 1 below shows examples of teachers' observational drawings.

Figure 1. Teachers´ observational drawings.



The subsequent classroom implementations provided additional observational data, including students' drawings and unstructured reflections with the participating teachers. Figure 2 below shows examples of observational drawings made by students and students, taking their own photos of insects found near their school.

Figure 2. Students' Observational Drawings And Taking Photos.

Finally, we conducted a survey-questionnaire with the teachers who implemented the approach with their students. The questionnaire includes four different themes according to our research interest in fostering students' empathy and curiosity for nature:

1. Empathy and Affection for Nature
2. Curiosity and Engagement
3. Understanding of and Communication about Natural Phenomena
4. Developing Nature Connectedness

Theory

The theoretical framework integrates multiple perspectives on learning and nature connection (e.g. Shouse et al., 2007). Beginning with aesthetic learning processes, research demonstrates how aesthetic experiences enhance motivation and engagement in science education (Zinkernagel, 2022). Visual learning theory supports the use of photography and drawing in

science education, showing how visual tools facilitate understanding of complex scientific concepts (Alenezi, 2015; Feldman & Lee, 2014).

Studies specifically examining macro photography and observational drawing highlight their effectiveness in fostering creativity and engagement (Antal et al., 2020). This visual approach aligns with the Danish concept of "udeskole" (outdoor education), which emphasizes the importance of bridging indoor and outdoor learning experiences (Jordet 2002; Bentsen & Jensen, 2012).

The Danish Outdoor Council further enriches this framework by identifying five essential dimensions for fostering children's nature connection (Hartmeyer & Præstholm, 2021):

1. Experiential Learning and Sensory Engagement: Macro photography and observational drawing enable detailed sensory interaction with nature in the classroom, allowing students to discover overlooked details and patterns.

2. Cognitive Development and Knowledge Acquisition: The process of careful observation and documentation through drawing promotes scientific investigation skills and deeper understanding of natural phenomena.

3. Emotional Connection and Appreciation: Visual engagement with nature through photographs and drawing cultivates emotional responses and empathy, fostering environmental stewardship.

4. Philosophical Reflection: The documentation process encourages reflection on humanity's role in ecosystems and environmental impact.

5. Material Engagement and Sustainability: Direct engagement with natural subjects through visual observation and documentation creates tangible connections to nature and environmental responsibility.

This theoretical framework supports our approach of using macro photography and observational drawing as tools for ‘bringing the outdoors in;’ when direct outdoor experiences are limited by time constraints, such aesthetic methods provide meaningful alternatives that maintain the essential connection to nature while also developing scientific observation skills.

Results And Findings

Our experiences implementing this approach in teacher education, combined with observations and feedback from teachers who subsequently tried it with their students, revealed patterns at two levels: first, the experiences of pre-service and in-service teachers as they engaged in the observational drawing process themselves; and second, their observations when implementing the approach with their own students in classrooms. Analysis of teachers' observational drawings, reflections, and feedback from course and classroom activities revealed insights about teachers' own learning experiences and patterns within four areas we had identified as central to our research interest: empathy and affection for nature, curiosity and engagement, understanding of and communication about natural phenomena, and developing nature connectedness. Below we present findings from both teacher learning experiences and classroom implementation, demonstrating how the double didactic approach functioned in practice

Teacher Experiences With Observational Drawing

When pre-service and in-service teachers engaged in the macro photography and observational drawing activities as learners, they consistently reported deep immersion in the observation process. As one teacher noted, "I became completely immersed in the task and forgot about time

while working."[3] This absorption appeared to stem from the detailed visual information provided by macro photographs, which revealed features that participants had previously overlooked. One teacher expressed surprise: "I was surprised by how little I actually knew about what the animal looks like."

The extended observation required by drawing facilitated what teachers characterized as slow and deep learning: "Working slowly gave me time to really notice details I would otherwise have missed," one participant reflected. This deliberate pace appeared to transform not only participants' understanding but also their emotional responses to their subjects: "An animal I initially found unpleasant became fascinating to explore."

Teachers acknowledged that the drawing process demanded perseverance, particularly at the outset. However, participants emphasized that success was more about technique than innate ability: "Drawing turned out not to be about talent, but about learning a technique." The scaffolding provided through video demonstrations and peer feedback proved essential, with one teacher noting, "The video and the feedback partner made it easier to get started."

The collaborative dimension emerged as particularly valuable, both for skill development and for generating science-related discussions. Through peer feedback and shared observation, teachers found themselves naturally engaging with scientific concepts and vocabulary. As one participant observed, "Talking about the animal helped me become more confident in using scientific terms." Teachers reflected that experiencing these challenges and discoveries firsthand enhanced their pedagogical understanding of how to implement the approach with their own students.

Student Implementation Findings

When teachers implemented these approaches in their classrooms with students ranging from kindergarten through 6th grade, four key themes emerged that illuminated how the aesthetic learning process functioned across different age groups.

Empathy And Affection For Nature

The most striking finding across multiple classroom implementations was a transformation in students' emotional responses to organisms they previously found unappealing or frightening. One 6th grade teacher observed: "The students saw the beauty of nature. Before, they screamed when they saw a spider in the classroom, but after these lessons, they went looking for spiders in nature and in the vicinity, just to look at them!" This shift from fear to fascination was echoed by another 6th grade teacher who reported being, "surprised that the students became so eager and affected to go out after the class session to find animals they previously found disgusting!"

Teachers attributed this change to the detailed visual access provided by macro photography. A 3rd grade teacher noted that, "especially the macro photos that allowed them to see all the many details up close gave the students enhanced joy and fascination of nature, something I don't usually see daily." The magnified perspective appeared to reveal aesthetic qualities in familiar organisms that students had previously overlooked or dismissed.

Curiosity And Engagement

The combination of viewing macro photographs and creating observational drawings generated sustained student engagement across all age groups. A 4th grade teacher reported that the approach, "created curiosity and motivation for further investigation into butterflies." This motivation extended beyond passive observation to active participation: "When the students were

[3] All teacher quotes have been translated from the original Danish to English by the authors of this article.

sent out, there was great engagement as they thought it was fun to take pictures themselves. The students were very curious when they were out taking pictures. It was very motivating to take pictures themselves."

The drawing process itself facilitated deep concentration, with one 6th grade teacher expressing surprise at observing students, "sit and immerse themselves in drawings of different species," a level of focused attention they had not previously witnessed in their science lessons.

Understanding Of And Communication About Natural Phenomena

Teachers observed that the detailed observation required for accurate drawing supported students' development of more precise descriptions and a need for related scientific vocabulary. A 6th grade teacher noted: "The students were able to name the animals and use technical terms such as horns, wings, hind legs, tail, etc. In addition, they learned to be concrete in their language." The iterative process of observing, drawing, and receiving peer feedback appeared to refine both students' visual discrimination and their ability to articulate what they observed using more appropriate scientific terminology.

Developing Nature Connectedness

Perhaps most significantly for long-term environmental engagement, participating students developed enhanced awareness of local biodiversity and their relationship to nearby nature. A 4th grade teacher reported that her students were, "especially surprised by how many different butterflies there actually were. 'They don't all look alike' – and 'do they really exist here!'." This discovery of diversity in familiar surroundings led to deeper connections: "The pictures opened up the butterfly-world more to the students, as they observed things that require the butterfly to sit still for a longer period of time. They became aware of the diversity, also in appearance. So, it created a desire to learn more about the butterfly."

A 3rd grade teacher emphasized the importance of using students' own nature experiences and photographs: "The students became more aware of what nature is and their local nature... Since it was their own nature-experiences and nature-images that we used, they also had to relate to their own experiences." Multiple teachers reported that students expressed "a desire to continue working with butterflies" and other natural subjects beyond the planned lessons. We see this as a solid foundation for further developing students' empathy and interest in nature.

Discussion And Conclusion

The implementation of macro photography and observational drawing in science education presents both opportunities and challenges that warrant careful consideration. Teacher reflections from both their own learning experiences and classroom implementations consistently highlighted several key requirements for successful practice. First, students require scaffolding and support in developing both observational awareness and drawing skills. As one teacher noted, success is, "not about talent, but about learning a technique." Second, what the teachers characterized as 'slow' and 'deep' learning facilitated by this approach demands dedicated time worth prioritizing even though it may conflict with curriculum pressures and the limited hours allocated to science instruction. Third, teachers need a clear pedagogical framework to guide implementation effectively, particularly in balancing aesthetic engagement with scientific learning objectives. These considerations are not limitations of the approach itself but rather indicate areas where teacher preparation and institutional support are essential for successful implementation.

Despite these implementation requirements, our findings demonstrate significant potential for this approach to address contemporary challenges in science education. While the four areas we

examined were informed by the five dimensions of nature connection identified by the Danish Outdoor Council (Hartmeyer & Præstholm, 2021), our findings validate this theoretical framework as a useful lens for understanding how aesthetic engagement supports nature connection.

The deep immersion and curiosity reported by both teachers and students reflects experiential learning through detailed sensory interaction. The transformation in students' emotional responses, from fear and disgust to fascination and care, embodies emotional connection and appreciation for nature. Students' awareness of local biodiversity and desire to continue exploring represents material engagement with their environment. Notably, several teachers reported students raising questions about ecosystems and biodiversity during the drawing process, touching on the dimension of philosophical reflection about humanity's relationship with nature. Students' use of more precise descriptive language and scientific vocabulary in articulating observations suggests cognitive development and knowledge acquisition. The iterative process of observing, drawing, and discussing appeared to create contexts where more precise language became useful for communication, an observation that warrants further investigation.

The convergence between our findings and established theoretical frameworks suggests that macro photography and observational drawing offer a viable pedagogical strategy for achieving the goals of "naturforbundethed" (in English: nature connectedness) even within the time constraints of contemporary schooling. Where Bentsen and Jensen (2012) and Jordet (2002) emphasize the importance of outdoor education for developing nature connection, our approach demonstrates how carefully selected visual materials can ’bring the outdoors in’, creating meaningful nature experiences when direct outdoor access is limited. The authentic macro photographs function as what we might call ‘windows to nature' providing the detailed, extended observation opportunities that are often difficult to achieve in traditional outdoor settings where organisms are small, mobile, or ephemeral. We believe that through providing such windows to nature in science lessons, students will become more curious and more motived to engage with nature outside the classroom. Teachers’ reflections on students’ wanting to take their own pictures of organisms reflect this.

The effectiveness of aesthetic engagement in generating scientific curiosity aligns with Zinkernagel's (2017, 2022) arguments for the role of aesthetics in science education. Teachers' observations that students discovered beauty in previously feared or ignored organisms suggest that aesthetic appreciation can serve as a gateway to scientific inquiry. This finding has particular relevance for Education for Sustainable Development (ESD), where fostering emotional connection to nature is recognized as foundational for developing environmental care and stewardship. The emotional and cognitive shifts we observed in both teachers and students represent important precursors to the deeper environmental engagement that ESD seeks to cultivate.

Our use of the double didactic approach (Iskov, 2020) in teacher education proved particularly valuable. Teachers who experienced the learning process themselves, engaging with photographs, creating observational drawings, giving and receiving peer feedback, developed both experiential understanding of the approach's power and practical insight into potential student challenges. This embodied knowledge appeared to translate directly into more effective classroom implementation, as evidenced by teachers' reports of increased confidence and their ability to anticipate difficulties and design appropriate scaffolding. The voluntary nature of classroom implementations further underscores teachers' genuine conviction in the value of this approach; those who chose to try it with their students did so based on their own transformative learning experiences.

Our findings across both pre-service and in-service teacher contexts suggest that the approach presented here is viable for teachers at different stages of professional development. These findings point toward broader implications for science teacher education. Traditional science methods courses often emphasize content knowledge and inquiry processes while giving limited attention to aesthetic dimensions of science learning. Our results suggest that explicitly addressing how visual tools and aesthetic experiences can support both affective and cognitive learning goals in science, have a valid place in teacher education programs. This is particularly important given the documented decline in children's connection to nature (Shouse et al., 2007) and the increasing recognition that environmental education must engage both head and heart. The double didactic approach offers a practical model for how teacher educators can prepare future teachers to use aesthetic engagement effectively, not as a supplement to science education, but rather as an integral component.

The success of this approach with students ranging from kindergarten through 6th grade, as reported by teachers across several implementations, suggests its adaptability across developmental stages. While the specific scaffolding varied by age group, with younger students requiring more support and older students capable of more sophisticated scientific engagement, the core process of careful observation, aesthetic appreciation and refining drawings proved engaging across the age range included.

The practitioner inquiry reported here demonstrates that macro photography and observational drawing offer a practical approach for cultivating both scientific understanding and emotional connection to nature within the constraints of contemporary classroom settings. By bringing nature indoors through aesthetic engagement, teachers can address the documented decline in children's nature connection while simultaneously developing essential scientific observation skills. This represents a contribution that aligns with both scientific literacy goals and the Education for Sustainable Development agenda.

While our findings demonstrate the potential of aesthetic learning processes for developing empathy and curiosity for nature, they also reveal opportunities for deeper investigation into how such approaches can support scientific literacy development. Our observations from both lessons with pre- and in-service teachers and with K-6 classrooms suggest significant potential for working more closely with subject-specific language and disciplinary dialogue. Teachers noted that students naturally sought more precise terminology as they attempted to describe and compare their observations. These finding warrants development and further investigation.

We hypothesize that through slow, attentive observation combined with structured collaborative discussion, learners can be scaffolded from everyday descriptions toward increasingly precise scientific understanding (Heinrich et al., 2024; Polias 2016). The need to accurately represent and communicate about organisms in their drawings appears to create authentic motivation for acquiring scientific vocabulary and engaging with disciplinary explanations. In this way, aesthetic engagement may serve as a dual function: deepening conceptual understanding while simultaneously motivating meaningful scientific communication.

While this practitioner inquiry establishes the viability of using macro photography and observational drawing to cultivate both emotional connection to nature and scientific observation skills, the approach warrants further development in two key areas. First, more systematic investigation is needed to understand how best to leverage aesthetic engagement for sustained nature connectedness and environmental stewardship. Second, future research should examine how this approach can be refined to more intentionally support scientific knowledge and science literacy development. Such investigations, conducted through more structured research designs across diverse educational contexts, will help establish the generalizability of our findings and

develop pedagogical frameworks that maximize the dual potential we have observed: fostering both affective engagement with nature and developing scientific literacy and understandings.

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Empowering STEM Teacher Professional Development Through AI Integration

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Artificial intelligence (AI) has revolutionized education by offering scalable, personalized, and interactive tools for teachers. This study investigates the potential of ChatGPT, an AI-powered platform, to enhance PD for primary school teachers, focusing on improving instruction in spatial ability—a critical skill for success in STEM disciplines. Grounded in constructivist learning theory, spatial cognition theory, and the TPACK framework, the research adopts a design-based research (DBR) approach to iteratively develop and evaluate a ChatGPT-supported PD program. The study utilizes a four-phase methodology: exploratory interviews, program design, classroom implementation, and program evaluation. Teachers integrate ChatGPT to design spatial ability tasks, generate lesson plans, and provide differentiated instruction aligned with STEM curricula. Data collection includes pre- and post-intervention assessments, reflective journals, focus groups, and lesson observations, analysed through the TPACK framework to assess the program's impact on teaching practices and student outcomes. This study highlights the potential of AI to transform teacher PD, offering insights into best practices for integrating AI tools into education while addressing challenges related to ethical use and overreliance. The findings aim to inform future PD initiatives and enhance STEM education at the primary level.

Keywords: Teacher professional development, spatial ability, ChatGPT, STEM

Introduction

Artificial intelligence (AI) is transforming education by offering innovative tools to enhance teaching and learning, particularly in professional development (PD) for educators. AI-powered platforms like ChatGPT provide unique opportunities to support teachers in designing, implementing, and refining strategies to foster critical skills such as spatial ability. Spatial ability—the capacity to visualize and manipulate objects in space—is a foundational skill for success in STEM disciplines, as it underpins problem-solving and conceptual understanding in subjects like mathematics, physics, and engineering (Uttal et al., 2013). Developing these skills in primary education is crucial, as early spatial reasoning correlates strongly with later academic achievement in STEM fields (Newcombe, 2010). Professional development plays a pivotal role in equipping teachers with the knowledge and tools needed to integrate spatial skills into their classroom practices effectively. Traditional PD models, while valuable, often face limitations in scalability, personalization, and real-time applicability. Here, AI emerges as a game-changer. Tools like ChatGPT can personalize PD experiences by tailoring content to individual teacher needs, providing immediate feedback, and generating diverse examples and instructional strategies (Holmes et al., 2022). Additionally, the accessibility of AI-driven PD solutions makes advanced methodologies more attainable for teachers, especially in under-resourced settings, ultimately enhancing both teaching practices and student outcomes. This study explores how AI can bridge gaps in traditional PD models, focusing on its potential to revolutionize the teaching of spatial ability in primary education. Still, every AI solution has its limitations and also can produce insufficient and/or biased answers.

Theoretical Framework

This study draws on two important frameworks for teaching & learning: the spatial cognition theory, and the TPACK framework. Spatial cognition theory (Uttal et al., 2013) underscores the malleability of spatial skills and their significance for STEM success. This study leverages these principles to enhance students' spatial skills through targeted teacher PD. The TPACK framework (Mishra & Koehler, 2006) integrates technology, pedagogy, and content knowledge, guiding the use of ChatGPT to align spatial skills strategies with STEM curricula. Grounded in design-based research (DBR) (Anderson & Shattuck, 2012), this study emphasizes iterative cycles to refine AI-supported PD, ensuring both theoretical rigour and practical relevance.

Aim Of The Study

The study aims to investigate the use of ChatGPT in enhancing PD for primary school teachers to improve spatial ability instruction. To achieve this, the study addresses the following objectives:

1. Investigate how ChatGPT can support teacher PD in improving spatial ability in STEM lessons.
2. Identify teachers' perceptions, challenges, and opportunities when integrating AI tools like ChatGPT into their PD.
3. Assess the effectiveness of ChatGPT-assisted PD compared to traditional PD methods.

Method

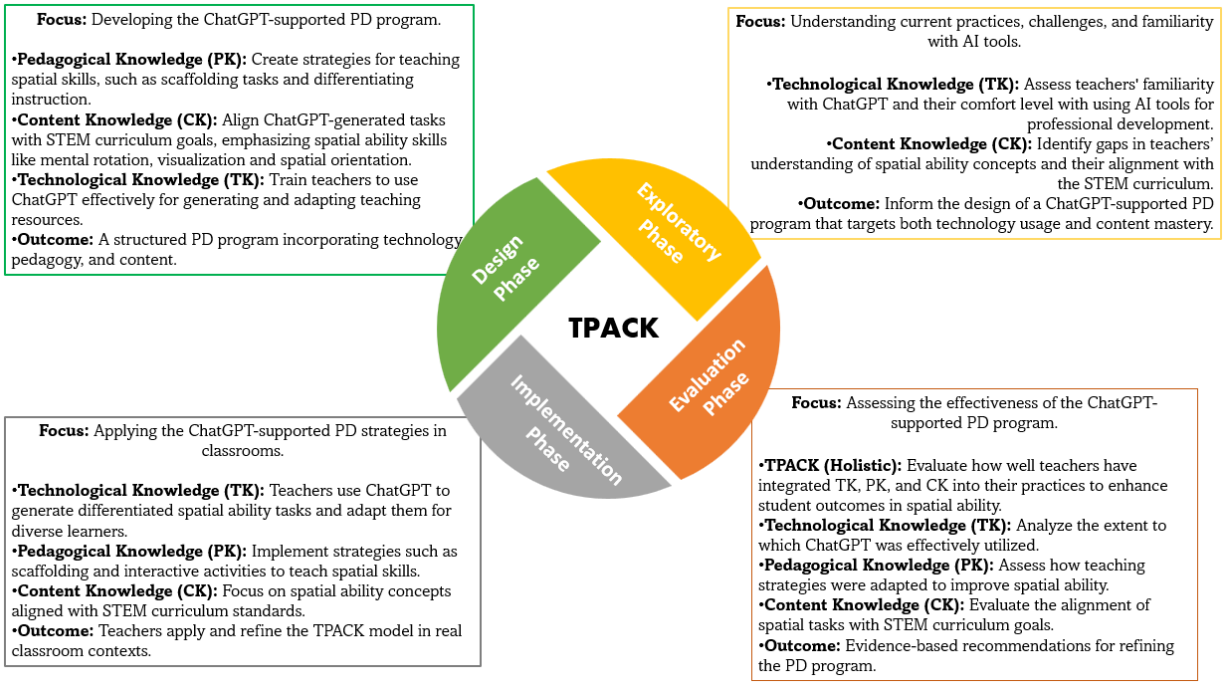
This study adopts a DBR approach, grounded in the TPACK and spatial cognition frameworks, to iteratively develop and evaluate a ChatGPT-supported PD program for primary school STEM teachers. The integration of ChatGPT serves as both a technological scaffold and a tool for aligning pedagogical strategies with spatial reasoning content. The DBR approach enables the refinement of the intervention through cycles of design, implementation, and reflection, ensuring both practical relevance and theoretical rigour (Anderson & Shattuck, 2012). The study involves 15 primary school teachers, selected through purposive sampling, who have diverse levels of experience in teaching STEM subjects. Their students (ages 8–10) are indirectly involved, with pre-and post-intervention assessments used to measure the impact of teacher PD on student spatial ability.

Phases Of Research

The study is structured into four key phases. In the exploratory phase, semi-structured interviews with teachers are conducted to understand their current practices, challenges, and familiarity with AI tools in their PD practices. These insights inform the design of a ChatGPT-supported PD program aligned with the TPACK framework, addressing gaps in technological knowledge (TK), identifying pedagogical strategies (PK) for teaching spatial ability and focusing on specific spatial skills such as mental rotation, spatial visualization and spatial orientation (CK). The intervention design phase involves developing a PD program consisting of workshops to train teachers on ChatGPT use, guided practice for aligning tasks with curriculum goals and adapting them for diverse student needs, and iterative reflections to refine their ChatGPT application. In the implementation phase, teachers integrate ChatGPT-supported strategies into their classrooms over six weeks. ChatGPT is utilized to generate differentiated spatial ability tasks, provide real-time feedback, and enhance lesson plans aligned with STEM curricula and developmental requirements. Finally, in the evaluation phase, both quantitative and qualitative data are collected through pre- and post-intervention tests, reflective journals, focus groups, and lesson

observations. These data are analysed using the TPACK framework to evaluate the integration of ChatGPT into teaching (TK, PK, CK), the alignment of spatial tasks with curriculum goals (TCK, PCK), and the overall effectiveness of ChatGPT in enhancing pedagogy and improving student outcomes (TPK, TPACK). In other words, to ensure that this phased approach ensures a comprehensive and iterative evaluation of the intervention, we set the TPACK elements as criteria for designing an effective STEM teacher PD solution that promotes teaching that supports student spatial ability. Figure 1 provides a visual representation of the DBR phases within the TPACK framework, illustrating how each phase is interconnected and aligned to enhance teacher development and student learning outcomes.

Figure 1. The DBR phases aligned with the TPACK framework, highlighting the integration of technological, pedagogical, and content knowledge in teacher PD for enhancing student's spatial ability.



The table below outlines how the TPACK framework was applied in the design and implementation of the ChatGPT-supported PD program. Each component of TPACK was strategically addressed throughout the various phases of the program's development and execution.

Findings

As this study is currently in its first cycle, findings are not yet available. The intervention is being implemented, and data collection will continue throughout the semester. By the time of the conference, the research will have completed all phases, including data analysis. Preliminary findings are expected to provide insights into how effectively ChatGPT supports teacher professional development for enhancing spatial reasoning skills and its impact on student outcomes. The conference presentation will focus on sharing these findings, discussing key themes from the qualitative data, and presenting implications for practice based on the quantitative results.

Table 1. Research phases aligned with TPACK components as design principles.

Phases	Component	Focus on PD Design	Annotation
Exploratory Phase	TK CK	Understanding current practices, challenges, and familiarity with AI tools.	**Activity:** Semi-structured interviews to assess teachers' current technological and content knowledge levels. **TPACK Focus:** Exploration highlights gaps in TK and CK, laying the groundwork for integrating these with PK in subsequent phases.
Design Phase	PK CK TK	Developing the ChatGPT-supported PD program.	**Activity:** Workshops for training on ChatGPT functionalities (TK), designing scaffolded spatial tasks (PK), and aligning them with curriculum goals (CK). **TPACK Focus:** The design integrates TK, PK, and CK to create a holistic program that fosters spatial reasoning.
Implementation Phase	TK PK CK	Applying the ChatGPT-supported PD strategies in classrooms.	**Activity:** Teachers integrate ChatGPT to design and implement lesson plans, aligning technology and pedagogy with STEM content. **TPACK Focus:** Real-time application of TPACK, enabling iterative refinement of teaching practices.
Evaluation Phase	TPACK (Holistic) TK PK CK	Assessing the effectiveness of the ChatGPT-supported PD program.	**Activity:** Analyse pre-and post-tests, focus groups, and reflective journals to assess TPACK integration. **TPACK Focus:** Evaluation synthesizes insights into how well TK, PK, and CK were integrated to improve teaching and learning outcomes.

Discussion

The TPACK framework, introduced by Mishra and Koehler in 2006, emphasizes the integration of technology, pedagogy, and content knowledge for effective teaching. Several studies have applied the TPACK framework to PD programs, demonstrating its effectiveness in enhancing

teachers' abilities to incorporate technology into their instruction. For instance, Bos (2011) highlights the integration of the TPACK framework in PD for elementary teachers, emphasizing its effectiveness in enhancing teachers' ability to incorporate technology into instruction. Through workshops and guided practice, teachers developed instructional units utilizing Web 2.0 tools and mathematical objects, aligning with TPACK principles. The study demonstrated that such professional development initiatives significantly improved teachers' technological, pedagogical, and content knowledge, enabling more effective technology integration in the classroom.

Moreover, recent studies have explored the integration of ChatGPT into educational settings, highlighting both its potential benefits and challenges. A systematic review by Mai et al. (2024) examined the strengths and weaknesses of using ChatGPT in teaching and learning, discussing opportunities and threats associated with its implementation. Additionally, a study conducted by Gill et al. (2024) analysed ChatGPT's capabilities and its impact on the education sector, identifying potential concerns and challenges. These studies collectively suggest that while ChatGPT can enhance personalized learning and provide immediate feedback, there are concerns regarding academic integrity, potential overreliance, and the need for educators to guide its ethical use.

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Bridging The Gaps In STEAM Education: Voices Of Educators

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STEAM education is widely recognised as a key approach for developing 21st-century skills through the integration of science, technology, engineering, arts, and mathematics. However, its implementation remains challenging due to limited resources, insufficient professional development, and weak systemic support for interdisciplinary teaching. This study, conducted within an EU Horizon project, examines the needs of in-service educators through a large-scale mixed-methods survey involving more than 600 participants from more than 25 countries. The analysis focuses on five areas: preparation, implementation, coordination, collaboration, and professional development. The findings highlight financial constraints, lack of preparation time, and limited training opportunities as major barriers. Educators also emphasised the need for real-world learning, improved technological infrastructure, and assessment approaches aligned with interdisciplinary goals. The study points to the importance of policy support, sustained funding, and structured professional development to enable effective and inclusive STEAM education.

Keywords: STEAM Education, Teachers professional development, teacher perceptions

Introduction

STEAM education integrates multiple disciplines to provide learners with a holistic learning experience that supports the development of 21st-century skills. By integrating science, technology, engineering, the arts, and mathematics (STEAM), STEAM promotes inquiry-driven, project-based, and problem-solving learning activities that reflect real-world challenges (Amanova et al., 2025; Leavy et al., 2023). Research shows that interdisciplinary and experiential learning approaches enhance student engagement and better prepare learners for changing labour market and societal demands (Erol, Erol, & Başaran, 2023; Harris & de Bruin, 2017).

The integration of diverse disciplines within STEAM education responds to the growing need for a workforce capable of combining technical knowledge with creativity, critical thinking, and collaboration. Across Europe, industries increasingly seek professionals with strong digital competences, sustainability awareness, and innovation-oriented problem-solving skills (Colucci et al., 2017). In this context, STEAM education plays a key role in supporting future generations to address complex global challenges, including technological transformation and sustainable development (Yeomans et al., 2025; Yim et al., 2025).

Despite its widely recognised benefits, the effective implementation of STEAM education largely depends on educators' ability to design and deliver interdisciplinary teaching (Spyropoulou, Mathiopoulos & Kameas, 2025). This requires not only subject knowledge but also pedagogical approaches that support collaboration across disciplines, real-world learning, and innovative assessment practices (Firmansyah & Aslan, 2025). However, many education systems continue to prioritise traditional, discipline-based structures, limiting opportunities for integrated teaching and learning.

As a result, educators often face structural, organisational, and professional barriers when attempting to implement STEAM approaches in practice (Ariza, J. Á., & Olatunde-Aiyedun, 2023). Limited access to targeted professional development, lack of institutional support, and insufficient time and resources further constrain their capacity to adopt interdisciplinary methods effectively.

This study aims to identify the specific needs and gaps of in-service teachers in relation to the implementation of STEAM education. By examining current challenges in teachers' preparation, support structures, and working conditions, the study provides evidence-based insights to inform strategies that can strengthen STEAM teaching and learning across Europe.

Methods

For this study, we employed a survey-based approach to gather quantitative and qualitative data on the needs of in-service educators in STEAM education. A structured questionnaire was developed to capture various aspects of educators' experiences, competences, and challenges during the different roles of educators during preparing, design, implementing and coordinating STEAM education projects and activities. The questionnaire was designed based on existing research in STEAM education and the competence framework (Spyropoulou & Kameas, 2024). It included demographic questions, Likert-scale items, and open-ended responses to ensure the following five core dimensions:

- Preparation and Development: Understanding of STEAM foundations, curricular standards, disciplinary content, instructional design strategies, and more.
- Implementation: Needs for resources and support to implement pedagogical strategies, content knowledge of specific STEAM disciplines, instructional time, assessment methods, etc.
- Coordination: Support needs for coordinating and managing the educational process, resource and lab management, handling of students/teachers, and school organization/administration.
- Collaboration and Community Building: How to foster cooperation with other educators, institutions, parents, local communities, and industries.
- Professional Development: Understanding of STEAM instructional practices, student motivation strategies, assessment tools, teamwork techniques, classroom organization, and the use of emerging technologies.

The survey targeted 664 in-service educators from 28 countries. The professional roles of participants varied, with secondary teachers comprising the largest group (45.5%), followed by primary teachers (20.7%), secondary principals/directors/education managers (8.5%), and pre-primary teachers (7.0%). Other roles included vocational school teachers and teacher trainers/adult educators. While the overall survey addressed all five dimensions, this paper concentrates on the first dimension, Preparation and Development. This focus enables a detailed examination of the foundational conditions necessary for effective STEAM education and provides insights into the early-stage challenges educators face in designing and planning interdisciplinary learning experiences.

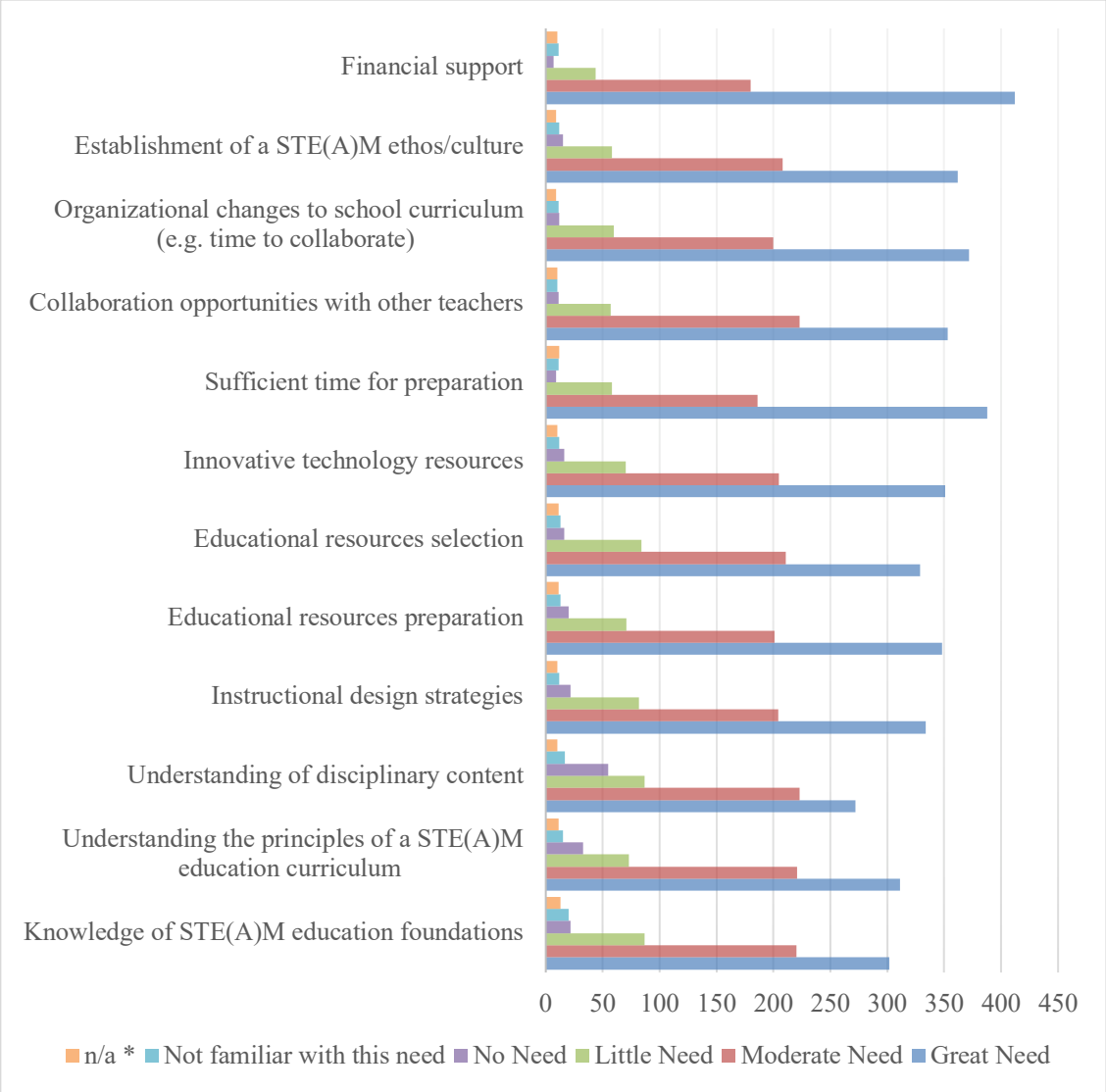
Findings And Discussion

The survey results reveal substantial needs and structural gaps in the preparation and development of STEAM education programmes for in-service teachers. Figure 1 presents an overview of the results for the survey questions. The most prominent finding concerns financial support, which emerged as the highest-ranked need. More than 62% of respondents reported a strong need for funding, while an additional 27% indicated a moderate need. This clearly shows that many schools lack the financial capacity to support teachers and STEAM implementation, including the purchase of materials, technological equipment, laboratory resources, and digital tools.

Closely linked to funding constraints is the issue of time for preparation, which nearly 58% of respondents identified as a major need. STEAM education requires careful planning, coordination across subjects, and the design of interdisciplinary learning activities. The findings indicate that current school schedules do not adequately support these demands, leaving teachers to prepare STEAM activities outside formal working hours. The data also indicate the need for organizational changes within school curricula, with 56% of respondents emphasizing the importance of structural flexibility, underscoring the need for curricular arrangements that enable collaboration, co-teaching, and interdisciplinary planning.

Another important finding relates to the establishment of a STEAM ethos and culture within schools. More than half of respondents indicated that institutional support, shared vision, and leadership commitment are essential for successful STEAM implementation. In addition, teachers reported significant needs related to the preparation of educational resources and access to innovative technologies. More than half of the respondents identified the preparation of STEAM-specific teaching materials and the integration of digital and technological resources as critical. Finally, the development of instructional design strategies tailored to STEAM was identified as a key gap. Teachers expressed the need for guidance on designing interdisciplinary learning activities that align learning objectives, teaching methods, and assessment practices.

Figure 1. Questions result from STEAM educators' needs.



The open-ended responses provided additional insights into the challenges and needs of educators in STEAM education. The thematic analysis revealed four key themes, as outlined in the table below (Table 1):

Table 1. Themes and key findings from open-ended questions.

Theme	Key Findings
Infrastructure and Resources	Lack of modern facilities, need for dedicated STEAM labs, and increased financial support
Curriculum and Assessment	Demand for innovative assessment methods, continuous curriculum feedback
Cultural and Systemic Changes	Resistance to change, calls for reduced bureaucracy, public awareness initiatives
Inclusivity and Accessibility	Need for inclusive learning environments ensuring equal access to STEAM education

Infrastructure and resources emerged as a central concern. Educators frequently referred to the lack of modern facilities, the absence of dedicated STEAM laboratories, and limited access to equipment and digital tools. These constraints were closely linked to insufficient financial support and were seen as a major barrier to implementing hands-on and inquiry-based STEAM activities. Curriculum and assessment challenges were also strongly represented in the responses. Participants highlighted the need for more flexible curricula that support interdisciplinary learning, as well as assessment approaches better aligned with STEAM pedagogy. In particular, educators called for project-based assessment, peer review, and formative feedback mechanisms that reflect collaboration and problem-solving rather than traditional testing practices. A third theme concerned cultural and systemic changes within education systems. Educators reported resistance to change at institutional and administrative levels, alongside excessive bureaucracy that limits innovation. Several respondents stressed the need for stronger leadership support, reduced administrative burden, and broader public awareness initiatives to legitimise and promote STEAM education within schools and communities. Finally, inclusivity and accessibility were identified as critical considerations. Respondents emphasised the importance of inclusive learning environments that ensure equal access to STEAM education for all learners, regardless of gender, socio-economic background, or learning needs. This includes accessible infrastructure, inclusive pedagogical approaches, and targeted support measures to avoid reinforcing existing inequalities.

Discussion And Conclusion

The findings of this study highlight a clear and consistent message: the effective implementation of STEAM education depends on systemic support for educators, extending beyond individual professional development to include financial investment, curriculum flexibility, and strong institutional backing.

Financial support emerged as the most critical need, confirming previous research that identifies funding as a prerequisite for meaningful STEAM implementation (Harris & de Bruin, 2017). STEAM education relies heavily on access to materials, digital tools, laboratories, and flexible learning spaces. Without sustained financial investment, STEAM practices risk remaining

fragmented, project-based, or dependent on short-term initiatives rather than being embedded within school systems.

In parallel, the strong demand for time and professional development reflects broader challenges in teacher preparation and working conditions (Ariza & Olatunde-Aiyedun, 2024). STEAM education requires educators to collaborate across disciplines, design interdisciplinary learning activities, and adopt innovative pedagogical and assessment approaches (Amanova et al., 2025). However, existing school structures often limit opportunities for joint planning and peer learning (Spyropoulou et al., 2025). Consistent with earlier studies, the findings show that targeted professional development, combined with protected time for collaboration, is essential for building educators' interdisciplinary competences and confidence (Conradty & Bogner, 2020).

Rigid subject-based timetables and assessment structures were perceived as major barriers, strengthening the view that STEAM education cannot be effectively implemented without systemic adjustments at the school and policy level (Spyropoulou, Ioannou & Kameas, 2025).

The results also point to curriculum and organisational barriers as major constraints. Rigid subject-based curricula, standardised assessment practices, and limited flexibility in scheduling were perceived as incompatible with interdisciplinary teaching. These findings align with the literature emphasising the need for curriculum innovation and adaptive assessment models to support inquiry-based and project-based learning in STEAM contexts (Shernoff et al., 2017). Addressing these barriers requires policy-level action to allow schools greater autonomy in curriculum design and assessment practices.

Insights from the open-ended responses further illustrate the multifaceted nature of educators' challenges. Infrastructure and resource limitations were repeatedly mentioned, reinforcing the quantitative findings and highlighting the importance of modern learning environments and dedicated STEAM spaces. Educators also called for assessment approaches that better reflect collaboration, creativity, and problem-solving, such as project-based and peer-reviewed methods (Firmansyah, & Aslan, 2025). These findings suggest a mismatch between STEAM pedagogical goals and existing evaluation systems. Cultural and systemic resistance to change emerged as another significant challenge. Educators reported bureaucratic constraints and limited institutional openness to interdisciplinary innovation. Overcoming these barriers requires a cultural shift within education systems, supported by leadership commitment, reduced administrative burden, and increased awareness of the value of STEAM education among policy makers, school leaders, and the wider community. Finally, inclusivity and accessibility were identified as essential dimensions of sustainable STEAM education. Respondents stressed that STEAM initiatives must ensure equal access for all learners, avoiding the reinforcement of existing social, gender, or digital divides. Inclusive pedagogical approaches, accessible infrastructure, and targeted support measures are therefore central to ensuring that STEAM education contributes to both equity and innovation (Weisberg et al., 2025).

In conclusion, the study demonstrates that advancing STEAM education requires coordinated action across multiple levels of the education system. Targeted policy reforms, increased and sustained funding, innovations in curriculum and assessment, and structured professional development are all necessary to support educators effectively. By addressing both structural and cultural barriers, education systems can move towards more inclusive, coherent, and sustainable STEAM learning environments. Such environments are essential for preparing learners to navigate complex societal and technological challenges and to participate actively in an increasingly interdisciplinary and digital world.

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Section: Reflective Practice And Teacher Research In Science Education

EUROPEAN SCIENCE EDUCATION RESEARCH ASSOCIATION ESERA 2025 Copenhagen

Building Knowledge Together: How Collaborative Professional Development Fostered New Learning Opportunities For Secondary Physics Teachers

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This paper, guided by transformative learning theory, presents how new learning opportunities emerged during three topic-specific collaborative senior physics workshops. We identified structured activities and participant interactions that created opportunities for transformative learning and examined the barriers limiting these opportunities. Using a multiple case study approach, audio recordings during and reflective interviews after the workshops were collected from six participants teaching Year 12 (Grade 11) physics in New Zealand. Qualitative analysis revealed that the CoRe framework's structure and prompts together with the collaborative dialogue created disorienting dilemmas and opportunities for critical reflection, the initial phases of transformative learning. The findings suggest that professional development designed to make teacher thinking visible combined with collaborative conditions that encourage questioning and uncertainty-sharing can systematically create opportunities for transformative learning if teachers have sufficient content knowledge and are willing and ready to engage in alternative perspectives. The study provides facilitators with practical insights for designing collaborative professional learning that may contribute to meaningful shifts in how teachers plan their practice.

Keywords: Physics, Professional Development, Transformative Learning Theory

Introduction

Collaborative Content Representation (CoRe) workshops have been shown to contribute to the development of teachers' pedagogical content knowledge for pre-service and in-service science teachers at both secondary and primary levels (Carpendale, 2018; Eames & Birdsall, 2019; Hume & Berry, 2013; Williams et al., 2012). In these studies, there has been less focus on the specific mechanisms that create learning opportunities within these workshops. Previous studies have instead focussed on learning outcomes, with less exploration of how structured activities and participant interaction created opportunities for learning. This paper examines these approaches through the lens of transformative learning theory (Mezirow, 2003) by answering these questions: How were learning opportunities created in the collaborative-CoRe physics PLD, and in what ways do these learning opportunities align with the initial phases of Mezirow's TLT?

In this study we use "learning opportunities" to refer to moments within the workshops where conditions emerged that could facilitate transformative learning. We focus on opportunities characterised by disorienting dilemmas and critical reflection, the initial phases of Mezirow's transformative learning process. We recognise that while these opportunities create the potential for transformation, whether individual teachers experienced actual transformation in their frames of reference require longer-term investigation that was beyond the scope of this study.

This study focuses on two aspects of TLT: disorienting dilemmas and critical reflection through dialogic interaction. When participants experience disorienting dilemmas, they question their assumptions and consider alternative perspectives. In literature, disorienting dilemmas have been explored in a professional development setting with beginning teachers (Laros & Košinár, 2019) and through the self-reflection of an experienced teacher-educator (Berry, 2010). These studies

show how disorienting dilemmas can disrupt their thinking and act as catalysts for adults to become critically conscious (Mezirow, 1991) and transform their learning.

Critical reflection supports teachers to understand "what they do and why they do it" (Cranton & King, 2003, p. 35). According to Liu (2015), critical reflection incorporates processes (e.g. analysis, questioning), content (e.g. assumptions about teaching), and goals (e.g. improved student outcomes). Despite there not being consensus about whether critical reflection is necessary for new learning, (Fleming, 2018; Mezirow, 2003) it is still one aspect that could lead to transformative practices. Philp-Clark & Grieshaber's (2024) meta-aggregative qualitative evidence synthesis identified that teachers use critical incidents, such as disorienting dilemmas, to reflect and identified that collaborative critical reflection embedded in professional learning and connected to clear objectives appeared to be a successful strategy for supporting a change in teachers' thinking.

Another key aspect of Mezirow's (2003) TLT is the critical role dialogue and dialectic discourse play in learning, which is especially relevant to collaborative professional learning. Mezirow emphasises that transformative learning occurs through dialectic dialogue, where adults critically examine their assumptions and engage with alternative perspectives. Richman et al. (2019) claimed that collaborative professional learning can facilitate changes to science teachers' practice with the New Generation Science Standards. Similarly, while not at secondary level, Nolan and Molla (2018) demonstrated that early childhood teachers learn best when they engage in thorough and thoughtful analysis through social collaboration, suggesting that this collaborative approach may be beneficial for teachers regardless of age groups taught.

Method

This qualitative study employed a multiple case study approach to examine how new learning opportunities occurred during collaborative professional learning. The design was useful because it enabled us to explore deeply how teachers created opportunities for new learning through dialogue in their experiences of disorienting dilemmas. Full ethical approval was obtained from the Human Ethics Committee at Victoria University of Wellington (VUW) (0000030762), and the research process was conducted in accordance with the NZARE (2010) guidelines.

Six fully informed and consenting participants teaching senior physics in New Zealand participated in this study. All participants had more than five years of teaching experience and worked in English-medium schools following New Zealand's national curriculum. Their schools represented diverse socio-economic backgrounds. Participants were recruited through convenience sampling, replying to an email seeking expressions of interest.

Three audio recordings and six interviews were analysed using Johnson and Christensen's (2020) analytical approach. First, it was transcribed before being segmented during preliminary reading. Deductive coding identified instances of learning opportunities, and inductive coding identified patterns in the new learning opportunities and themes were created. A hierarchical coding system and network diagram helped us to explore the relationships between the codes and themes. Intercoder reliability checks were completed once themes had been established and themes were linked to specific approaches of TLT.

The study centred around three four-hour workshops based on Loughran et al.'s (2008) Content Representations (CoRe) which were operationalised in collaborative settings for pre-service secondary chemistry teachers (Hume & Berry, 2011, 2013) and in-service secondary science (Carpendale & Hume, 2020; Eames & Birdsall, 2019) and primary science teachers (Hume, 2016). The workshop utilised a bottom-up approach (Timperley, 2011) to develop individuals' teaching and learning knowledge and skills related, in this study, to a physics topic. The

workshops aligned with the participants' upcoming physics topic, the New Zealand Curriculum (Ministry of Education, 2007), and the relevant Physics Achievement Standards from the New Zealand Qualifications Authority (NZQA, 2014a, 2014b, 2014c). Participants met in groups of between two and four to collaboratively create a CoRe-design. They identified the key concepts and big ideas in the topic and, using the prompts discussed for each big idea, the importance of the concepts, the teaching strategies, the difficulties, misconceptions, and associated models and representations that could be used to teach the big ideas, and strategies to assess the big ideas.

Teachers attended between one and two workshops which were spaced two months apart. This spacing reflected the need to schedule topics before teachers began teaching them. They were facilitated by the first author, an experienced physics teacher, who intentionally avoided providing content explanations. Direct facilitator interventions offering content support or pedagogical solutions were excluded from the data analysis, however, procedural facilitation was included as this formed part of the workshop structure and did not pre-determine participant responses. The semi-structured one-on-one interviews exploring teachers' perceptions of learning, reflections of changes in their thinking about physics content and pedagogy were completed within two weeks of the workshops and lasted between 45 and 60 minutes, these were conducted in person or online by the first author.

Results And Discussion

Structure and Prompts

Opportunities for new learning occurred when teachers articulated their uncertainty into a shared space which allowed others to offer alternate perspectives. The structure and prompts of CoRe seemed to support teachers to discuss topic-level PCK in a more nuanced way than when they first considered it. This progression can be identified in the following example. Initially teachers' thoughts around assessment were relatively undifferentiated.

P1: "Assessments for different concepts, we can just put the same approach can't we?"

P2: "I mean just walking around and asking students about the work"

P3: "Really? Like what, more quizzes?"

After further exploration of the big ideas through the CoRe prompts, one teacher articulated a more sophisticated understanding of assessment:

> I'll still go round and talk to students and ask them questions, but actually, you could build circuits and get students to check their understanding with me… That way they start to understand some of the practical [skills], concepts, and how they go together.

This shift towards a more nuanced understanding suggests that the prompts and structure of the CoRe contributed to deepening this teachers' understanding of assessment strategies in this topic.

The collaborative aspect supported by CoRe prompts appeared to encourage teachers to experience disorienting dilemmas. Sorting key concepts into groups provided opportunities for teachers to question and disagree with each other, which served as a productive tool for deepening their understanding. In the following example, three teachers explored what "nuclear stability" meant to them and whether it is an appropriate term to use.

P1: "we have atomic structure, so could another big idea be nuclear stability?"

P2: "what do you mean by stability and why would you use it?"

P1: "because those are released when we undergo nuclear decay."

P2: "Does that make it more stable? … for me this is not stability, because it just goes ting, ting, ting, ting, ting (indicates transformation of atomic nuclear by decay)…

P3: "are you looking at the fundamental forces when you mean stability?""

P1: "some atoms are more stable than others… in using the term 'stability' I'm describing a measure of how stable a particular atom is… The forces are a bit beyond what is needed I think.

P3: Those are covered at year 13, perhaps we could use reaction.

P1: Stability is good for half-life though

P2: I think you're talking about two different things. We should look at each idea first before grouping them.

Through these interactions, P1's initial vague notion of nuclear stability was challenged and refined. P2's questioning revealed a conceptual ambiguity which resulted in the group collectively recognising that they needed to clarify the individual concepts thoroughly before organising them. When multiple interpretations were shared and disagreement created, participants were able to experience disorienting dilemmas.

The structure of the collaborative CoRe also encouraged opportunities for critical reflection. When discussing why it was important to teach and understand the history of the atom, the teachers initially began with surface level justifications, including "teaching vocabulary" and "it's required content." When the facilitator contextualised one of the prompts, "why is it important to know about this general atomic model changes over time?", one teacher began to examine their underlying assumption that they "teach it because I'm required to" and recognised this framing as problematic to students' deep understanding of science as an ever changing body of knowledge and appeared to shift her perspective.

> The biggest thing for me is that they need to realise that when I start with an atom, I'm like 'ohh this is an atom, the nucleus is in middle and electrons outside,' but now this is not how it looks like anymore. Then they go, 'why didn't we learn that in year 9?'. That [progression] is helpful as it shows them that ideas change, and this change is because of technology and changes over time.

Building on this insight, a second teacher extended this critical reflection by suggesting another historical example from different scientific domains to demonstrate how scientific understanding evolves and highlighting the importance of students gaining this epistemological understanding of science: "if you can get access to the medical texts from the 16th century. [you'd see] 'He has a headache, so we're going to drill a hole into his head through his skull to relieve the pressure.'" This example illustrated the teachers understanding that the history of atomic models helps students see science not as a collection of facts, but as a field where mistakes have been made and corrected, making it important to learn from past errors and essential for developing students' critical awareness.

This example illustrates Mezirow's (1981, 2003) concept of critical reflection in action and demonstrates how the CoRe prompts facilitated critical reflection which then contributed to transform teachers' understanding from viewing content as something that needs to be covered to recognising its role in developing students' epistemological understanding of science.

Barriers To Learning

Two barriers were identified that did not appear to encourage these opportunities to be created. The first, was teachers' self-reported understanding of the content and concepts being taught in

the topics. These included one teacher who was new to teaching physics and suggested he "didn't have enough content knowledge." This teacher reported being "a passive observer," did not participate a lot in discussions, and reported during workshops that "this is just going over my head." This teacher was sometimes dismissive of other teachers' desire to explore concepts in more detail stating, "kids' don't need that" and "do we want to make physics boring for them?" Another teacher also made minimal contributions in some sections, they reported during the workshop and in the follow up interview that "to be honest I don't know a lot about it." Discussions about concepts and pedagogy were unable to progress when teachers were unable to participate or explain more fully.

The second barrier identified was teachers' willingness or unwillingness to consider alternative approaches and ideas. Beyond the teachers already identified, a third teacher demonstrated an unwillingness to engage with alternative perspectives. They expressed boredom "I'm so bored… I feel like we're trudging through the same thing again," showed resistance to probing concepts further "I hadn't intended to [discuss fundamental forces], do you [the facilitator] want us to?" and were content with their teaching methods "for level 2 I just have a booklet that I made and the students go through the booklet. it's the same each year… and I know it works because I wrote it." These types of interactions not only reduced their own opportunities to engage with new ideas but also other teachers' opportunities to explore new concepts and approaches.

These instances showcase how teachers' content knowledge limitations and unwillingness to engage not only reduced their participation in the conversations but also appeared to reduce the chances of them experiencing disorienting dilemmas and critical reflection. Whether these conversations created an opportunity for these processes to occur internally was not captured in the data and cannot be discounted. The evidence, however, suggests that for transformative learning to occur, teachers need both sufficient content knowledge to recognise challenges to their existing frameworks and an openness to engage with alternative perspectives. It should be noted though, that these less open-minded behaviours not only did not progress conversations for others, but may have deterred others sharing when the comments seemed dismissive. These barriers emerged despite the facilitators' repeated attempts to prompt reflection and create opportunities for deeper engagement, suggesting that structural factors alone, such as collaborative time and prompting questions, may be insufficient when teachers lack content knowledge or appear unwilling to engage in learning.

Discussion

This study demonstrates that structured collaborative professional development can systematically create the conditions for transformative learning as described by Mezirow's theory (2003). The CoRe framework's prompts and collaborative structure facilitated the initial phases of transformative learning: disorienting dilemmas and critical reflection, by creating spaces where teachers were able to articulate their uncertainties and experience alternative perspectives through discussion. When teachers engaged in productive disagreement, they were prompted to reconsider their understanding when other teachers challenged their ideas and assumptions. Similarly prompts pushed teachers beyond surface-level responses and allowed them to examine their underlying pedagogical assumptions and shift their thinking. These findings align with previous research showing how disorienting dilemmas can catalyse transformative learning in professional development settings (Berry, 2010; Laros & Košinár, 201) and support Philip-Clark and Grieshaber's (2024) conclusion that collaborative critical reflection that is embedded in professional development can contribute to changing teachers' thinking.

Fewer opportunities for new learning were identified for teachers with limited content knowledge. Mezirow (2003) defined transformative learning as "learning that transforms

problematic frames of reference" to make them "more inclusive, discriminating, open, reflective, and emotionally able to change" (p. 58). For transformation to occur, adults must first have an existing frame of reference that can be challenged. Teachers who lacked experience teaching the content and confidence in their content knowledge may not have yet established conceptual and teaching frameworks for the topics behind discussed that could be disrupted or transformed. This finding suggests that transformative learning opportunities may be inappropriate for teachers in the early stages of developing their content knowledge or pedagogical content knowledge. Instead, of this collaborative approach, they may require professional learning that focusses on acquiring new knowledge and skills rather than transforming existing perspectives. Furthermore, the "not knowing" about content prevented teachers from engaging in what Mezirow describes as "critical dielectric discourse involving the assessment of assumptions and expectations supported by beliefs, values, and feelings" (p. 60). In these cases, it appeared the teachers had not yet formed assumptions about what these concepts were and how to teach them.

Teachers' dispositions did not sometimes appear to suit to this type of professional learning. Mezirow (2003) emphasises that participating in critical dialectical discourse requires "having an open mind, learning to listen empathetically, 'bracketing' premature judgement, and seeking common ground" (p. 60) as well as emotional intelligence including "empathy and social deftness" (p. 60). Participants who were unwilling seemed resistant to exploring deeper, appeared satisfied with their existing understanding of concepts and practices, which suggests they held a frame of reference that was not "open, reflective, and emotionally able to change" (p. 58). Despite having access to potential disorienting dilemmas, such as the debate about nuclear stability, this teacher appeared to actively avoid engaging with these challenges, suggesting they were not actively engaging in learning.

Whether these conversations that are supported by the CoRe framework created opportunities for internal disorienting dilemmas and critical reflection that were not verbalised could not be discounted. Mezirow (2003) states that adult educator's role is "to help learners acquire the skills, sensitivities, and understandings essential to become critically reflective of assumptions and to participate more fully and freely in critical-dialectical discourse" (p. 62). This assumes that providing such help will be effective, and that learners are willing and able to develop these capacities. These findings challenge this assumption and reveal that transformative learning requires both sufficient content knowledge as well as a dispositional openness to engage with alternative perspectives. When these prerequisites are not present, even appropriate facilitation and structures may not be sufficient to create conditions for transformative learning. Furthermore, in collaborative professional learning settings, individual resistance may compromise the conditions required for discourse for themselves and other group members.

Conclusion

To create learning opportunities that support transformative learning, these findings suggest PLD providers consider including structured activities where teachers are required to make their thinking visible, create collaborative conditions where teachers feel comfortable sharing uncertainties and questioning their teaching practice to enable authentic dialogue, and find strategies to identify whether teachers are ready to learn, both with their content knowledge and dispositions. While the study provides insight into collaborative professional development, several limitations exist. The small sample size, while useful for gathering rich and in-depth data, limits generalisability. Additional limitations include potential researcher bias due to the facilitator also being the primary researcher. While this provided deep insight into workshop dynamics, it may have influenced both the facilitation approach and data interpretation. We attempted to mitigate this through reflexive journalling, intercoder reliability, and member

checking. Additionally, whether this approach can be used in other subject areas or cultural contexts requires further research, given the focus on senior physics and a New Zealand setting. Further research might explore how this approach transfers to other subject areas and whether the effectiveness persists in longitudinal studies that track sustained changes in teaching practices.

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Development Of Teacher Training Model That Transforms The Science Teacher Competencies

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This study aims to develop a professional learning model based on lesson study as a form of on-the-job training (OJT). It responds to the current situation in Japan, where teachers have difficulty participating in professional development outside of working hours. Teacher competencies were conceptualized as Competency in Mind (CM), which appears in teachers' conscious awareness, and Competency in Action (CA), which appears in their behaviors during lesson study. The study examined the process through which these competencies transform, based on the relationship between CM and CA. As a theoretical framework, Naumescu's (2008) GPC (Good Practices related on Competencies) and Kiper & Mischke's (2009) Structural Theory of Instruction were adopted. The GPC items were reclassified into three categories—TTC (Teacher–Teacher), TSC (Teacher–Student), and TCC (Teacher–Context)—and used for analysis.

A qualitative study was conducted with one science teacher (Mitsuzane), using a combination of the GPC questionnaire (for CM) and utterance analysis during lesson study (for CA). Prior to the lesson study, the teacher received feedback on his CM profile to enhance awareness of his competency tendencies. The researchers then examined changes in CA during the lesson study. Afterward, interviews were conducted to explore the gaps between CM and CA. Results showed that the teacher made conscious efforts to improve GPC items that had been rated low in his CM. Actual improvement in CA—particularly within the TCC domain—was also confirmed. Notably, GPC items related to classroom management and the analysis of students' responses were prominently manifested in CA. These items had been rated low in CM. The teacher also stated that the prior presentation of CM influenced his actions during lesson study. This suggests that CM awareness may foster intrinsic motivation for learning and may lead to behavioral transformation.

Analyses with three additional teachers indicated that researchers' recommendations contributed to changes in CA. This further supports the influence of targeted guidance. The significance of this study lies in showing that incorporating a CM-awareness process into lesson study can establish an effective learning model. This model enables teachers to enhance their competencies autonomously.

Keywords: Teacher Competencies, Lesson Study, Professional Learning

Introduction

According to TALIS 2018, Japanese elementary and lower secondary teachers spent the least amount of time on professional development among all participating countries. This limited participation was attributed to factors such as scheduling conflicts and responsibilities at home.

In Tokyo, professional development is described as comprising three modalities: on-the-job training (OJT), off-the-job training (Off-JT), and self-directed learning. OJT refers to professional learning that takes place within the school, grounded in concrete situations and teacher actions. Off-JT includes group or online training organized by boards of education and dispatch programs to professional graduate schools of teaching. Self-directed learning refers to voluntary professional learning such as reading books and attending seminars. In other words, the TALIS

2018 results suggest that Japanese teachers face difficulties allocating time for Off-JT or self-directed learning. The same survey also found that many Japanese teachers viewed professional learning in instructional methods and content knowledge more positively when others observed their lessons and provided feedback.

Given this context, professional development that is feasible for Japanese teachers is that which can be conducted during working hours as OJT. To enhance competencies related to instructional methods and content knowledge, it is necessary to create a professional learning environment in which teachers' classroom instruction is observed by others and feedback is provided.

In Japan, lesson study has long been practiced as one form of professional development. According to Isozaki (2015), lesson study consists of the following:

> Lesson study aims to improve teachers' instructional expertise and build collegiality through collaborative engagement among teachers. It is divided into three stages: the planning stage, the implementation stage, and the reflection stage.
>
> In the planning stage, teachers collaboratively identify issues of concern and decide on the research theme, learning goals, and lesson plan. They also determine the lesson content, instructional focus, materials, and assessments. These planned activities serve as concrete indicators that clarify the value of lesson study for both the teacher conducting the lesson and the observers.
>
> During the implementation stage, observers evaluate the lesson using the lesson plan as a guide. They collect data related to learning goals and focal activities, record observations, and attend carefully to the utterances of teachers and students to interpret their understanding of the content. In science classes involving hands-on activities such as experiments, observers may also examine motor-skill aspects or move around the classroom to capture the learning status of specific students. Japanese lessons often follow an inquiry-based learning process consisting of problem setting, information gathering, analysis, and synthesis. Lessons may also be recorded for later analysis.
>
> During the reflection stage, immediately after the lesson, teachers, observers, and invited experts review the lesson based on the collected data. The results of these discussions—both strengths and challenges—are accumulated and often compiled into a research report at the end of the study period. A research presentation meeting may also be held, showcasing the lesson and its outcomes and featuring a lecture by an invited expert.

However, in recent years, lesson study in Japan has been deteriorating due to the severe worsening of teachers' working conditions. TALIS 2024 also reported that Japan had the lowest ratings worldwide on items such as "All in all, I am satisfied with my job," "If I could decide again, I would still choose to work as a teacher," "I enjoy working at this school," and "I would recommend this school as a good place to work." Therefore, this paper seeks to reconstruct lesson study as a method of professional development. This study develops a professional learning model through lesson study to enhance science teachers' competencies and to cultivate teachers who are deeply aware of the noble mission of their profession, who continuously engage in inquiry and self-cultivation, and who strive to faithfully fulfil their professional responsibilities.

Theoretical Framework

This section summarizes prior studies that form the theoretical background of the present paper. Before explaining the theoretical background, Table 1 summarizes the key concepts and abbreviations used in this paper.

Table 1. Key Concepts and Abbreviations

Abbreviation	Full Term	Definition / Explanation
CM	Competency in Mind	Competencies consciously recognized by teachers, measured through the GPC questionnaire.
CA	Competency in Action	Competencies manifested in teachers' behaviors during lesson study.
GPC	Good practices related on competencies	Framework by Naumescu (2008) consisting of 28 competency items used for analysis.
TTC	Teacher–Teacher Competencies	GPC items related to teachers' knowledge, epistemological understanding, and interactions with colleagues.
TSC	Teacher–Student Competencies	GPC items related to teaching–learning processes and interactions with students.
TCC	Teacher–Context Competencies	GPC items related to managing instructional contexts, classroom situations, and contextual factors.
LPM	Lesson Planning Map	Framework adapted from Kiper & Mischke (2009) to analyse teacher competencies across planning, implementation, and evaluation stages.

GPC: Good Practices Related On Competencies

In Japan, no competency framework specifically defines the professional competencies required of science teachers. Therefore, we attempted to apply Naumescu's (2008) "Good Practices related on Competencies (GPC)" to Japanese science teachers (Table 2). Conventional competency frameworks generally focus on qualities derived from knowledge of scientific concepts. In contrast, GPC assumes actual classroom situations and therefore includes competencies related to managing instructional contexts—an essential aspect of science teaching. This study investigates how competencies transform through lesson study. Therefore, we focused on Naumescu's 28 GPC items and examined their applicability to Japanese science teachers.

Table 2. Good practices related on competencies (Naumescu, 2008).

Competence in epistemology
- Epistemological competence on models building, on processes of the students' modelisation, and on the functions and limits of each model.
- Competence in the use of technical and scientific apparatus and engineering.
- Competence to define criteria of categorisation (an important process in different scientific domains, as taxonomy, DNA sequences, …)

- Competence on the history and limits of validity of each scientific concept, and on the social dimension of the science.
- Ability to differentiate a scientific proposition to a non-scientific one.
- Ability to differentiate a scientific discourse to a dogmatic one.

Competence in bibliography

- Competence to use internet, CD-Rom, books library, etc.
- Competence for a critical analysis of documents of science popularisation (journals, magazines, books, radio, TV, etc.)

Competence in Science Education (Didactics of Sciences)

- Analysis of learners' conceptions on a scientific topic, before teaching this topic, and after this teaching to evaluate the eventual conceptual changes.
- Use the learners' errors not to judge them but as conceptions to be analysed and then changed.
- Identification of epistemological (and didactical) obstacles, to define new strategies of teaching focused on these obstacles
- Building of didactical situations adapted to learning. For instance, problem based situations, or projects (to realise individually or by little groups).
- In particular, sequences to learn scientific concepts, and / or scientific processes (laboratories).
- Competence to define the didactical contract and the situation to the learners, and to present them to learners as a space of active autonomy for them.

Competence in Didactics of Sciences and in Pedagogy

- Competence to induce the devolution of this situation by the learners: they must be motivated to be active in this situation. They have to be implied in the choice of their topics and activities.
- Competence to manage the situation, to improve debates and socio-cognitive conflicts.
- Competence to hear the pupils and students, and to take into account their questions.
- Competence to manage problems of violence, disorder and other difficulties in the classroom.
- Competence to analyse his or her own reactions (psychology) and the students' ones.
- Competence of the teachers to analyse their own reactions in these situations; to manage students' practical, theoretical or speculative works.

- Competence to analyse the scientific background of each student activity and to help them to find these theoretical pre-required.

Competence in didactical transposition and use of language
- Adaptation of the scientific language in a language adapted to children; idem for the images (didactic transposition for each scholar level). - For each scientific notion, proposition of a progression of teaching – learning sequences, in respect with different students' ways and speed of learning. - Use of good metaphor, examples and other pedagogical strategies. - Competence to motivate and help students to write reports on their activities.
Competence in Evaluation
- Competence to imagine processes of analysis and validation of the students works, of their hypotheses and conjectures. - Competence to do evaluation of the students activities at different steps of their work, to help them in their learning and to prepare them for the final evaluation. - Competence for a final evaluation on known criteria, if possible avoiding the "by heart learning", and corresponding to acquisitions of the taught competencies.

In this study, teachers' utterances during lesson study were analysed to identify competencies. Specifically, each utterance was examined to determine which GPC item it corresponded to. The "interaction target" was categorized as Teacher, Student, or Context (Naumescu, 2008). Based on these interaction types and the nature of the competency, the 28 GPC items were reclassified into three categories, namely TTC (Teacher–Teacher Competencies), TSC (Teacher–Student Competencies), and TCC (Teacher–Context Competencies).

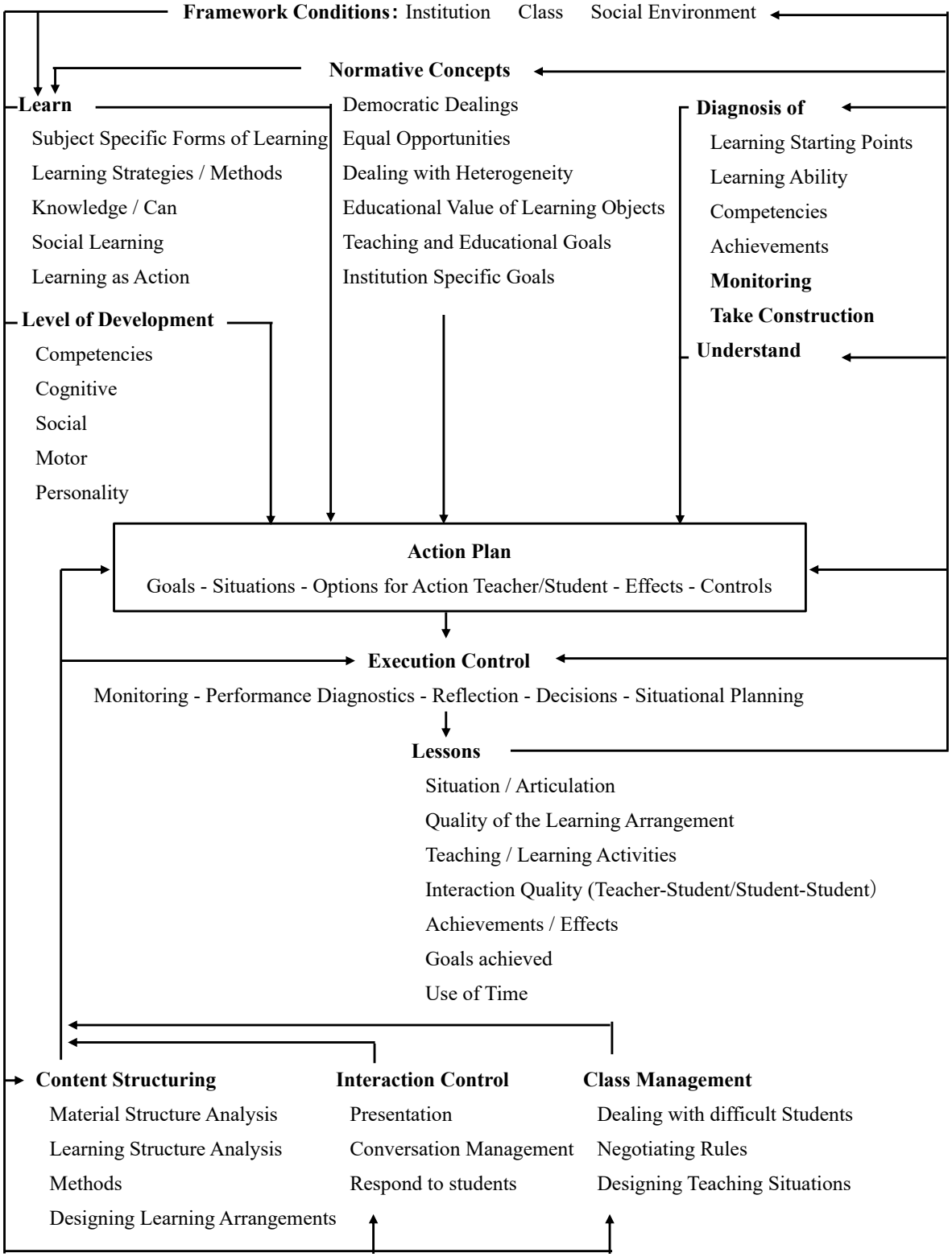
A questionnaire survey using the GPC framework was administered to 135 elementary and lower secondary science teachers in Tokyo. Using a seven-point Likert scale, teachers rated the degree to which they believed each item should be considered an essential science teacher competency. Results showed positive evaluations across all 28 items, indicating that GPC was accepted by Tokyo's science teachers as a valid competency framework.

Further analysis examined correlations among the three GPC categories. Pearson's correlation coefficients revealed strong positive relationships between TSC and TTC ($r = .75$) and between TSC and TCC ($r = .86$). This suggests that Tokyo teachers primarily conceptualize competencies with a focus on interactions with students—namely, TSC.

LPM: Lesson Planning Map

Japan lacks a theoretical model for analysing lesson study. Therefore, we drew on Kiper & Mischke's (2009) Structural Theory of Instruction (Figure 1). In this theory, instructional practice is conceptualized as a cyclical route map consisting of a planning stage, an implementation stage, and an evaluation stage—an idea consistent with Japanese lesson study. We adapted this theory into a lesson-study framework and named it the Lesson Planning Map (LPM).

Figure 1. Structural Theory of Instruction (Kiper & Mischke, 2009).



In this model, teacher utterances from the planning, implementation, and evaluation stages are recorded. In the planning and evaluation stages, interactions occur mainly with colleagues and facilitators; in the implementation stage, interactions occur with students. Recorded utterances are transcribed, and multiple researchers determined whether each sentence corresponds to a GPC item. Then, each utterance is mapped onto the appropriate LPM element according to the stage of lesson study in which it occurred. GPC items, categorized into TTC, TSC, and TCC, are tallied, and these counts are summarized in a table along with GPC questionnaire results.

CM: Competency In Mind And CA: Competency In Action

When comparing a teacher's TTC, TSC, and TCC scores, one may notice distinctive patterns in mean values and frequencies of utterances. These patterns represent the teacher's competency tendencies. Moreover, comparing GPC results from questionnaire data and lesson-study utterances reveals discrepancies (gaps) between mean scores and actual utterance frequencies. These gaps indicate differences between competencies recognized consciously and competencies manifested in practice.

Hokari & Wada (2025a) defined CM (Competency in Mind) as the competencies reflected in a teacher's conscious awareness, as revealed through questionnaire responses, and CA (Competency in Action) as the competencies expressed through actions during lesson study. A gap between CM and CA may indicate competencies that teachers believe they possess but do not exhibit during lesson study, or conversely, competencies that teachers do not consciously recognize but nevertheless demonstrate in practice.

Research Questions

The theoretical framework discussed above has been clarified in Hokari & Wada (2024) and Hokari & Wada (2025b). To further advance this line of inquiry, the present study addresses the following research questions:

RQ1: When teachers are explicitly informed of their CM prior to lesson study, do they attempt to autonomously transform their competencies through the lesson study process?

RQ2: Does teachers' intention to transform their competencies influence their CA?

Methods

This study adopts a qualitative research approach based on questionnaire data and interviews. Using the GPC questionnaire results, the researcher first presented the teacher's CM tendencies to promote self-awareness. In this study, "utterances" refer to all verbal statements produced by teachers during the planning, implementation, and reflection stages of lesson study. Each utterance was treated as a unit of analysis and coded according to the corresponding GPC item. If a teacher expressed multiple ideas in a single turn, these were segmented into separate utterances. The teacher's utterances during lesson study were then analysed to capture changes in CA. After comparing CM and CA, the researcher provided feedback and conducted an interview to explore the observed gaps.

The participant in this study was one teacher, referred to as Mitsuzane (a pseudonym). He holds a bachelor's degree in science education and has worked as a public elementary school teacher for more than 20 years. He has participated in over 26 science lesson studies. At the time of the study, he was teaching a fifth-grade class. The participant had a prior professional relationship with the researchers, which was disclosed to the institution and managed appropriately.

The lesson study analysed in this research was conducted within a district-level research group of science teachers from 29 public elementary schools under the same municipality. The group conducts two to three lesson studies annually, and one of these was selected for analysis. In Japan, the fifth-grade science curriculum includes learning about the flow of rivers—specifically, that flowing water erodes land, transports and deposits stones and soil, that the size and shape of riverbed stones differ between upstream and downstream regions, and that rainfall affects the speed and volume of flow and can cause significant changes to landforms. The present study focused on a lesson within this unit on flowing water. This unit was selected because novice

teachers often report difficulty in conducting science lessons on this topic, making it a meaningful context for examining how teacher competencies transform during lesson study.

Before the lesson study, the researchers identified Mitsuzane's CM tendencies and provided suggestions for improving his GPC in relation to the target unit. After the lesson study, the teacher's utterances were analysed by two researchers to determine which GPC items appeared and at which elements of the LPM these utterances were produced. Based on these analytical results, an interview was conducted to explore the gap between CM and CA. All utterances during the lesson study were recorded using a tablet device. Written consent was obtained from all participating teachers and students after explaining the research purpose and procedure.

Results

The results of the GPC questionnaire for the participating teacher showed mean scores of 5.5 for TTC, 5.3 for TSC, and 4.8 for TCC (Table 3). This indicates that the teacher's CM reflected relatively lower awareness of GPC items related to interactions with the context.

Table 3. Mitsuzane's GPC Profile.

	TTC	TSC	TCC
GPC for Questionnaire Survey	5.5	5.3	4.8
GPC for Lesson Study	32	30	31
Framework Conditions	0	0	1
Normative Concepts	1	0	0
Learn	1	0	1
Level of Development	1	0	1
Content Structuring	7	2	1
Interaction Control	0	0	0
Class Management	0	0	0
Action Plan	0	0	0
Execution Control	3	13	4
Lessons	8	9	12
Diagnosis	8	5	10
Understand	3	1	1

Prior to the lesson study, the researcher provided concrete suggestions to the teacher about how GPC related to interactions with the context could be transformed in the unit on flowing water.

> **Researcher:** Among the TCC competencies, one that did not appear strongly in your CM was "Competence to manage problems of violence, disorder and other difficulties in the

classroom." Perhaps you have had few experiences teaching in challenging class environments?

Mitsuzane: No, I think I do have experience. I have often been in charge of classes that were considered difficult to manage.

Researcher: I see. In that case, although you have experience, it appears that you do not regard this as an essential competency for science teachers. In other words, you may be perceiving that classroom management is not necessary for effective science instruction.

Mitsuzane: That's not the case. But I agree there may be a discrepancy between the numerical results and my self-perception of my teaching practices. So I'm curious to see what my CA will look like.

Researcher: Another GPC within TCC that appeared weak in your CM was "Competence to analyse his or her own reactions (psychology) and the students' ones." This suggests that you may not be frequently anticipating students' reactions before lessons, nor analysing them afterward.

Mitsuzane: That's certainly true. I don't do that very often.

Researcher: For example, during the post-lesson discussion, if you are able to say things like, "I intended to do this in the lesson, but since the students responded in this way, I adjusted my approach," such exchanges could help transform this GPC through CA.

Next, the analytical results of the lesson study (CA) were fed back to the teacher, and interviews were conducted to determine whether changes in GPC were related to the teacher's awareness of CM prior to the lesson study.

Researcher: Analysis of the GPC that appeared during lesson study revealed 32 instances of TTC, 30 of TSC, and 31 of TCC. Unlike your CM, your CA did not indicate a weak awareness of TCC. To be more specific, the TCC item "Competence to manage problems of violence, disorder, and other difficulties in the classroom" emerged 12 times during the implementation stage in CA. This occurred despite the item being rated low in CM. For example, before each experiment, you paused all student activity and provided clear instructions. You also verified students' self-designed experimental procedures before allowing them to continue. When a student reprimanded another for talking, you intervened and clarified that classroom discipline is the teacher's responsibility. These behaviors demonstrate clear articulation of class norms and effective classroom management. This was evident in your CA. Similarly, "Competence to analyse his or her own reactions (psychology) and the students' ones" was rated low in CM but was observed 10 times during the evaluation stage in CA. You frequently commented on how you adapted your instruction based on students' responses. Through this analysis of your CA, we were able to gain a clearer understanding of your TCC.

Mitsuzane: Wow, that's surprising. But hearing this analysis, I see your point. I've conducted many lesson studies, and I recognize that I still have weak GPC areas. I now realize that gaps in my own GPC may be connected to areas where I am not fully fostering students' competencies.

Researcher: There were 93 total GPC-related utterances. This is high relative to previous studies that used similar analyses. In other words, the large number of GPC manifestations suggests that the science teacher's competencies you already possess are relatively advanced.

Mitsuzane: Thank you.

Researcher: Do you think receiving information about your CM before the lesson study—and being asked to anticipate how weak areas might emerge in this unit—had any influence on your CA?

Mitsuzane: When I was told that certain GPC scores were low based on the questionnaire, I felt that there must be something lacking in me. So I made a conscious effort to focus on those areas during the lesson study. Although I do not believe that I neglect those competencies in my everyday teaching, having them pointed out numerically made me think that I may be weaker than I had realized. So I reflected on those GPC during my daily lessons as well.

Researcher: Which GPC stayed in your mind most strongly?

Mitsuzane: The TCC item, "Competence to analyse his or her own reactions (psychology) and the students' ones." When it was pointed out, I thought it might indeed be one of my challenges. So yes, discussing my CM before the lesson study definitely shaped my CA.

As Mitsuzane stated, "I made a conscious effort to focus on those areas during the lesson study." This directly answers Research Question 1: When teachers are informed of their CM prior to lesson study, do they attempt to autonomously transform their competencies? Furthermore, Mitsuzane's comment that "discussing my CM before the lesson study definitely shaped my CA" answers Research Question 2: Does a teacher's intention to transform competencies influence CA?

Discussion And Conclusions

The names Furuichi, Wada, and Miyauchi are pseudonyms used to protect the participants' identities. This study demonstrates that providing teachers with their CM prior to lesson study can enhance their awareness of professional competencies and promote autonomous behavioral transformation during lesson study. Moreover, the findings indicate that teachers' intention to improve their competencies plays a significant role in shaping their CA. This intention was evident in the teacher's explicit statements during the interview, in which he reported consciously focusing on areas identified as weak in his CM. These conclusions are supported by the interview results showing that teachers consciously attempted to work on competency areas identified as weak in their CM. The same pattern was confirmed with three additional teachers, suggesting that CM awareness and targeted recommendations may consistently contribute to changes in CA (Table 4).

Furuichi previously worked as a lower secondary science teacher and holds specialized expertise in science. Initially, Furuichi demonstrated limited consideration for TTC. The researcher therefore proposed specific methods for transforming the TTC items "Ability to differentiate a scientific proposition from a non-scientific one" and "Ability to differentiate a scientific discourse from a dogmatic one." As a result, the TTC scores in CA improved, and Furuichi evaluated that the researcher's suggestions contributed to changes in GPC.

Wada's specialty is physical education. In Japanese elementary schools, teachers who are not specialists in science often teach science as well. Through lesson study, Wada's TSC improved in CA, and this was attributed to the researcher's suggestions regarding the GPC item "In particular, sequences to learn scientific concepts, and/or scientific processes (laboratories)."

Table 4. GPC Profiles of the Three Additional Teachers.

	Furuichi			Wada			Miyauchi		
	TTC	TSC	TCC	TTC	TSC	TCC	TTC	TSC	TCC
GPC for Questionnaire Survey	5.7	6.8	6.9	5.5	5.2	5.6	6.4	6.1	6.4
GPC for Lesson Study	13	12	14	16	18	8	14	22	27
Framework Conditions	0	0	0	0	0	0	0	0	0
Normative Concepts	1	0	1	1	1	0	0	0	2
Learn	0	3	2	1	4	2	0	4	1
Level of Development	0	0	0	0	0	0	0	1	0
Content Structuring	2	2	0	2	3	2	6	0	0
Interaction Control	0	0	1	0	0	0	0	0	0
Class Management	0	0	1	0	0	1	0	0	2
Action Plan	0	0	0	0	0	0	0	0	0
Execution Control	0	2	2	0	0	0	1	5	7
Lessons	5	3	3	8	8	2	1	4	8
Diagnosis	5	2	4	3	2	1	4	7	6
Understand	0	0	0	1	0	0	2	1	1

Miyauchi's specialty is Japanese language. In the district research group's lesson study, the high frequency of TSC observed in his CA was attributed to specific recommendations from the researcher concerning the GPC item "Competence to define the didactical contract and the situation to the learners, and to present them to learners as a space of active autonomy for them."

This study has several limitations. First, the primary analysis was conducted with a single science teacher, and the subsequent verification involved only three additional teachers. As a result, the findings should be interpreted with caution, as the sample size and diversity constrain the generalizability of the results. Moreover, all participating teachers had substantial teaching experience, which may have influenced how they interpreted and acted upon their CM. Therefore, future research should examine teachers with different backgrounds, including novice teachers, to further validate and extend the present findings.

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Exploring Physics Teachers' Use Of Lab Through Actor-Network Theory

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The study explored the application of Actor-Network Theory (ANT) in understanding physics experiment lessons, focusing on the development and implementation of the simplified Michelson Interferometer (MI). Traditional approaches to physics experiments often view tools as passive and prioritize human-centered teaching methods. ANT, however, highlights the active role of non-human actors in shaping networks of interactions. The research investigated two aspects of ANT application to teachers' use of laboratory activity: (a) the process of developing the interferometer and its associated actor networks and (b) teachers' use of new experimental tool and the networks formed during this process. Participants included physics teachers from two groups of teacher learning communities (total 32) and two experienced physics teacher for focus of observations and interviews. Data were collected through observations, surveys, and interviews and analytic framework was based on ANT. Findings revealed that developing the interferometer involved diverse human and non-human actors, creating a dynamic network. In the classroom, the experimental tool demonstrated agency by connecting teachers, students, and other resources, fostering meaningful interactions and emotional engagement. Teachers adapted and reinterpreted the experimental tool based on their goals and contexts, while students engaged with it to achieve experimental objectives, often generating unexpected results and insights. Ultimately, the study highlights the generative role of physics experiment tools in co-creating knowledge alongside students and teachers. Viewing such tools as active participants rather than passive objects offers an alternative perspective on teaching and learning physics, emphasizing the dynamic and collaborative nature of the process.

Keywords: Actor-Network Theory, experimentation, physics

Introduction

Laboratory has been the signature pedagogy in physics education and science education in general. The laboratory serves as more than a supplementary space; it is the signature environment for inquiry and the most distinctive method of both teaching and learning. At its core, physics is an experimental science. While mathematics provides the language, the laboratory experiment remains the most distinctive method of inquiry in science and science education. It is the space where abstract ideas meet reality. As a key pedagogical tool, the laboratory has evolved from the notion of scientific method as static steps to be taken into a dynamic process of observation, measurement, and revision practiced in groups (Hofstein and Lunetta, 2004; National Research Council [NRC], 2012).

The basic premise of using a laboratory as a pedagogical tool in school science education is that meaningful learning occurs when students have opportunities to manipulate equipment and materials to construct their own knowledge. Laboratory experience is essential for helping students move beyond rote memorization toward a deep, conceptual understanding of the physical world. Without the "minds-on, hands-on" interaction with physical phenomena, a student's understanding of concepts such as torque, electromagnetism, or entropy might remain purely symbolic and detached from the material world.

Beyond its pedagogical value, the laboratory serves as a benchmark for science pedagogy because science is fundamentally rooted in the interaction between theory and empirical evidence.

Science—and physics in particular—is defined by empirical **arguments**. Because the goal of scientific knowledge is to understand how things work, human-created explanations must be based on and supported by empirical evidence. Thus, science education aims to help students understand the ways scientists build explanations based on empirical evidence through direct investigative experiences (Berland & Hammer, 2012; Driver et al., 2000; NRC, 2012; Windschitl et al., 2008). The presence and quality of laboratory work act as a standard of authentic instruction; if the lab is missing or reduced to simple cookbook verification, the pedagogy is no longer truly scientific in the professional sense of the word (Lee & Butler, 2003).

The COVID-19 pandemic exposed a significant vulnerability in science education. During this period, students faced a profound lack of opportunity for hands-on physics laboratory experiences, which are traditionally the cornerstone of the discipline. This disruption turned physics into a purely theoretical pursuit for many, stripping away the essential minds-on, hands-on interaction required for meaningful learning. This crisis served as a catalyst for science teachers to be creative in filling the gap (Kang & Seo, 2021). Some teachers in South Korea developed simple and productive physics experimental devices designed for the home environment. The goal was to provide students with opportunities to easily manipulate on their own at home. By shifting the site of inquiry from the school lab to the student's home, experimental physics has been redefined as a flexible, decentralized practice, proving that high-quality inquiry does not always require industrial-grade equipment.

Whereas home-based experiments for classical mechanics are relatively accessible, a significant pedagogical gap persists regarding practical experiments for modern physics concepts. Current physics education lacks accessible, hands-on experimental devices that allow students to manipulate the abstract concepts of modern physics outside of a specialized laboratory. While students can easily drop a ball to study gravity at home, concepts like quantum spin, wave-particle duality, or atomic transitions are often relegated to abstract math or computer animations.

This research is motivated by the need to expand the home-lab revolution into the modern physics realm. By focusing on the development of simple and productive physics experimental devices specifically designed to teach modern physics concepts, we aim to provide students with the same empirical grounding in 20th-century physics that they currently enjoy in classical mechanics. This approach ensures that even the most abstract concepts in the curriculum are supported by a tangible, experimental foundation.

The purpose of this study is to understand how a newly developed simple laboratory setup is adopted by teachers. In particular, this study seeks to move beyond traditional human-centric analyses of education by exploring physics laboratory instruction through the lens of Actor-Network Theory (ANT). By adopting this symmetrical approach, the study aims to reveal the often-invisible influence of non-human actors—such as lab equipment, digital interfaces, and curriculum—on instructional designs of teachers. Ultimately, the study investigates the laboratory instruction as a complex network of interrelated entities, identifying which specific actors serve to catalyze or constrain productive instructional flows.

Theoretical Framework

This research is grounded in the emphasis on the role of experiments within the context of so-called the practice turn in the philosophy of science that refers to a broad shift away from analysing science primarily as a system of theories, propositions, and logical relations, and toward understanding science as a set of situated practices: what scientists *actually do* in laboratories, field sites, and research communities (Gooding, 2012; Schatzki et al., 2001).

Hacking famously argued in *his book (1983)*, "Experimentation has a life of its own" (p. 150), meaning that experiments can lead to discoveries even without a guiding theory. This claim has been supported by several historical reconstructions of detailed experimentation. In an analysis of three episodes in the history of modern science, Galison (1987) demonstrates that experimental traditions have their own continuity and logic that is distinct from the rise and fall of theoretical paradigms. Drawing on his background as an experimental physicist, Franklin (1989) reconstructs detailed experimental sequences from twentieth-century physics—including both successful discoveries and notable non-discoveries—to show how experimental knowledge is generated, stabilized, and sometimes revised. His inclusion of failed or inconclusive experiments is especially significant, as it highlights the contingent, iterative nature of experimental work.

Given the perspective that experiments are not merely servants of theory but are independent, practice-based sources of scientific knowledge experimental practice is seen as an epistemic activity. Experiments are structured sequences involving instrumentation, calibration, and error control that can produce reliable knowledge. This process is shaped by material, instrumental, and procedural constraints. Thus, experiments are open-ended, performative process (Pickering, 1993). Conducting experiments is not only about justification, but also about coping, adjustment, and emergence. Using Galison's historical account of particle physics experimentations in the 1950s and 1960s, Pickering demonstrates that scientific activity unfolds through a continuous struggle between human intentions and material resistance, which Pickering calls the mangling process (1993).

Scientists' struggles during experimentation are best understood through the interplay between human and material agency—the core premise of Actor-Network Theory (ANT) (Pickering, 1993). By rejecting a human-centred perspective, ANT highlights how human and non-human elements interweave to produce collaborative outcomes (Fenwick & Edwards, 2010; Latour, 2007; Law, 2009). As a post humanist framework, ANT is particularly effective for analysing scientific work, where the constant interaction between researchers, instruments, and experimental materials is foundational to constructing knowledge (Latour & Woolgar, 1986).

In his account of how human and material agencies interact, Pickering (1993) utilize the history of the bubble chamber—an instrument that uses superheated transparent liquid to detect electrically charged particles. Invented by Donald Glaser, who received the 1960 Nobel Prize for this achievement, the bubble chamber serves as a prime example of what Pickering called the mangle of practice - a dialectic between material and human agencies. Pickering demonstrates that repeated failures to meet experimental goals, such as increasing detection rates, forced an iterative process of modifying both the equipment and the goals themselves. These failures represent material agency or resistance. Because this resistance is unpredictable, material agency is emergent, requiring the human actor to respond and adapt in real time. Consequently, both human and material agencies are seen as temporally emergent—evolving together through the experimental process.

From the ANT perspective, learning is an effect generated by an assemblage of diverse elements. For example, a physics lesson can be viewed as an "assemblage" where the teacher (human), the student (human), and the lab apparatus (non-human) interact. The knowledge produced is an emergent property of this specific network. We draw on the idea that non-human elements, such as lab apparatus and digital tools are not passive tools but are actants that shape what can be learned. In this framework, the laboratory is viewed as a site of productive intervention. When a student manipulates a device, they are not just verifying an idea; they are engaging in a material practice that has its own internal logic. By analysing how the experimental device (non-human)

and the teacher and students (human) come together, we can understand how abstract concepts become tangible and real.

Methods

The authors devised a low-cost, student-operable Michelson interferometer intended for qualitative use in high school physics classrooms. To address the limitations of commercial interferometers—namely, high cost, complex alignment, and the need for precise optical components—the authors redesigned the apparatus using every day, easily obtainable materials, including convex mirrors commonly used as automobile auxiliary mirrors, slide glass as a beam splitter, and a low-power laser pointer. A key design choice was the replacement of plane mirrors and lenses with convex mirrors, which naturally expand the laser beam into a spherical wave. This eliminates the need for additional optical components such as lenses while making optical-axis alignment significantly easier for students. The expanded beam allows interference fringes to be projected directly onto a wall or sheet of paper, further simplifying the setup and reducing cost and fragility. Details of the lab setup is reported elsewhere (Kim & Kang, 2023). We introduced the interferometer to teachers in a local physics teacher workshop and examined how it was adopted—or not adopted—in their physics classrooms.

As an analytic framework we utilized the concept of translation in ANT to map the sociotechnical evolution of the physics experiment. Callon (1984) adopt the concept of translation to explain how scientific knowledge and social order are co-produced through networks of human and nonhuman actors. Translation is defined as the process through which actors construct, negotiate, and stabilize networks by defining roles, aligning interests, and enrolling both human and nonhuman entities so that collective action becomes possible. In a case study of marine science research, Callon identified four elements of translation: problematization, Interessement, enrolment, and mobilization. Problematization refers to the moment when the focal actor defines a problem and frames other actors' identities and roles in resolving the problem. Interessement refers to the efforts to lock actors into the roles defined in the problematization by using strategies, devices, or arguments that align their interests.

Enrolment refers to the successful acceptance and coordination of the proposed roles by actors, resulting in stabilized relationships within the network. Mobilization refers to the process by which a few actors come to represent and speak for many, ensuring that enrolled actors continue to act as expected. Mobilization is the final stage of the translation process. In this study, mobilization happens when the lab setup reaches a steady state when the students stop asking "What do I do next?" and start acting according to the roles the teacher assigned them. At the same time, the equipment stops being a collection of parts and starts being a measurement or observation system that is mobilized to represent physical reality, such as interference patterns.

Data were collected from multiple sources to examine how the interferometer was taken up in teachers' instructional practice. First, surveys were administered to workshop participants to document teachers' initial responses, perceptions, and intentions regarding the use of the interferometer. Second, in-depth interviews were conducted with two focal teachers to explore their decision-making processes, instructional adaptations, and experiences with adopting—or choosing not to adopt—the interferometer in their classrooms. Third, classroom observations of physics lessons were carried out to capture how the interferometer was enacted in practice, including patterns of teacher guidance, student engagement, and classroom interactions. Finally, instructional materials such as textbooks, handouts, and laboratory materials were collected and analysed to examine how the interferometer was integrated into existing curricular resources and instructional sequences.

Analysis begins by identifying how teachers translate the simplified interferometer into their lessons by mobilizing specific human and non-human actors. We track the four elements of translation to see how a stable network is formed. The analysis culminates in exploring the state of black-boxing, identifying the point at which the complex interrelations of the lab setup become a singular, unquestioned unit of experiment.

Results

Cases Of Non-Adoption

In this section, two cases of non-adoption of the experiment are described. As shown in the case descriptions, the teachers' goals for the experiments in both cases were inconsistent with the goals of the original design, which produced resistance in the experimental setup. This resistance was not accommodated by the teachers and therefore prevented the experiment from being adopted for classroom instruction.

Teacher H, a veteran physics teacher with 22 years of teaching experience, places a high value on meaningful laboratory experiences in physics learning. Despite this strong commitment to experimental instruction, Teacher H ultimately did not adopt the interferometer activity in the classroom.

During the workshop, Teacher H initially failed to produce expected interference patterns and spent relatively more time than other teachers to obtain predicted patterns. Although he succeeded in the end, Teacher H decided not to use the lab in his class. As the primary barrier, he indicated a concern about the reliability and interpretability of the experimental results, particularly the appearance of interference patterns that were perceived as ambiguous or unstable.

Teacher H also expressed reservations about the level of manual dexterity required to manipulate the apparatus, noting that fine adjustments might be challenging for students. This concern reflected an expectation for quantitative analysis of interference patterns—an outcome that the original lab design did not intend, but that Teacher H aimed for. In addition, the use of convex mirrors introduced visual noise in the interference patterns, which Teacher H felt could distract students or undermine confidence in the validity of the results.

Together, Teacher H concluded that the effort required of him and his students was not worth the results they could obtain from the experiment. Consequently, these concerns led Teacher H to judge that the activity did not sufficiently meet classroom expectations for clarity and robustness, resulting in a case of non-adoption.

Teacher Y, who has seven years of experience teaching general science, values experiments that are engaging, accessible, and easy for students to carry out when learning physics. Despite this emphasis on enjoyable hands-on activities, Teacher Y ultimately chose not to adopt the interferometer in classroom instruction. During the workshop, Teacher Y easily produced expected interference patterns and spent much time in explaining the patterns.

A primary barrier for his adoption was uncertainty regarding the experimental results, particularly concerns that the interference patterns might not be sufficiently stable or interpretable for instructional purposes. Similar to Teacher H, Teacher Y also noted limitations in supporting quantitative validation, which reduced confidence in using the activity to substantiate physics concepts rigorously. In addition, the visual noise introduced by the use of convex mirrors was perceived as potentially confusing for students. Collectively, these concerns led Teacher Y to conclude that the activity did not adequately align with instructional goals, resulting in a case of non-adoption.

A Case Of Adoption

In this section, one case of adoption of the experiment is described. Because the teacher applied the experiment in his teaching, the analysis focuses on how the experiment was utilized in the classroom, i.e., the translation process, resulting in the formation of an actor–network.

Teacher J, a physics teacher with six years of teaching experience and an alternative certification background in physics, brought prior experience with a failed Michelson interferometer experiment to the workshop. This experience shaped a strong instructional focus on laboratory activities that are both meaningful and reliably successful for students. As a result, Teacher J approached the interferometer with heightened sensitivity to issues of experimental robustness and classroom feasibility, prioritizing activities that could consistently produce interpretable results within typical instructional constraints.

Problematization

Teacher J framed the instructional problem in terms of both curricular alignment and classroom feasibility. As he explained, “Mere observation of interference patterns is not enough for the time and effort involved… I am trying to connect this to the wave interference conditions in the curriculum, such as path difference and interference conditions. Another concern is helping all students reliably produce stable interference patterns” (workshop interview). Through this framing, Teacher Y positioned successful and reproducible interference patterns as essential to the experiment’s instructional value, defining both conceptual coherence and experimental reliability as necessary conditions for adoption.

Mobilization

Teacher J designed and enacted the lesson by mobilizing a network of key human and nonhuman actors around the goal of understanding and quantifying interference. The instructional sequence began with lectures on the principles of superposition and wave interference, with particular emphasis on interference arising from path differences in the double-slit experiment. These conceptual resources were then extended through a dedicated lecture on the Michelson interferometer, which positioned the apparatus as a legitimate and meaningful tool for exploring interference phenomena.

Building on this conceptual foundation, Teacher J organized student-led experimental exploration using the simplified convex-mirror interferometer, incorporating performance evaluation to encourage active engagement and accountability. Through this sequence, students, curricular concepts, experimental apparatus, and assessment practices were aligned to sustain the instructional network, allowing the interferometer to function as a central actor in classroom practice.

In the process of Teacher J’s translation and actor–network formation, non-human actors—such as simulations, a thermal expansion apparatus, and a micrometre—exercised agency by affording, allowing, encouraging, suggesting, influencing, and rendering particular actions and understandings possible. In addition to the original lab setup, Teacher J created a digital video demonstrating how to set up the experiment so that students could watch it repeatedly as needed, and he added a thermal expansion bar for fine-tuning and a micrometre for measuring interference patterns.

As part of the translation process, the teacher problematized producing quantifiable results and additional laboratory materials were incorporated into the actor–network. In particular, a copper rod was introduced to enable fine-tuning of the interferometer through controlled thermal expansion. This material actor played a key role in stabilizing interference patterns and supporting

quantitative exploration, thereby strengthening the functional alignment of the network and reinforcing the instructional goal of understanding and quantifying interference.

At this point, the translation process is completed, and the actor–network becomes capable of producing instructional outcomes. Diverse actors—including the teacher, students, curricular concepts, experimental apparatus, and assessment practices—are successfully linked and coordinated to form a stable and functional actor–network. Through this alignment, each actor is effectively enrolled to contribute to a shared instructional goal, enabling the experiment to operate as intended within classroom practice.

Student reflections indicated that the experiment supported conceptual understanding of interference by making abstract wave concepts more tangible. As one student noted, “This experiment allows us to understand how the path difference changes as the laser displacement in the Michelson experiment is finely adjusted, resulting in different interference patterns. It provides a valuable introduction to the various properties of waves, which might otherwise remain abstract.” This response suggests that the experimental activity helped students connect physical manipulation of the apparatus with underlying theoretical concepts, reinforcing the coherence of the actor–network in supporting learning outcomes as Teach J intended.

Discussion

This study examined how physics teachers adopt—or choose not to adopt—a newly designed laboratory device through the lens of Actor–Network Theory (ANT). The findings highlight the importance of conceptualizing physics laboratory instruction as a socio-material network rather than as a series of isolated instructional events. When the laboratory device became black-boxed, functioning as a stable and reliable agent within the network, it could be mobilized to support extended learning objectives beyond initial demonstration. Across cases, the teacher’s emotional openness to uncertainty and adaptability in responding to resistance played a crucial role in the translation process, shaping whether the actor–network stabilized or unravelled.

This perspective encourages a shift away from teacher-centred explanations that attribute ineffective experiments to individual shortcomings and instead directs attention to the broader network of human and non-human actors that shape classroom dynamics. From this viewpoint, teacher professional development should be reconceptualized to address the multilayered actor–networks surrounding experimental tools, while the design of laboratory devices should intentionally support connections to existing curricular, material, and pedagogical networks. Such an approach foregrounds relational alignment over individual blame and highlights the distributed nature of instructional success.

Future research should investigate methods to foster diverse and creative translation processes when teachers engage with new pedagogical materials or instructional tools. In particular, studies are needed to examine how teachers adapt, reconfigure, or extend innovations as they interact with local classroom conditions and existing actor–networks. Furthermore, additional research should investigate how teachers’ professional competence, encompassing their knowledge, attitudes, and values, interacts with non-human actors, such as instructional tools, representations, and materials, in the design of innovative lessons. Such work would deepen understanding of how pedagogical innovation emerges through socio-material interactions rather than through the transmission of fixed instructional models.

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Addressing Misconceptions Through Questioning: The Application Of Teacher Knowledge In A Primary Science Lesson

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This study explores the role of the knowledge deployed by an expert primary teacher during a lesson on the organs of the human body. The research attempts to uncover which elements of subject knowledge and pedagogical content knowledge underpin her classroom practice and how they interrelate. Employing an intrinsic case study design with a qualitative focus, the study analyses teaching episodes from video-recordings of four lessons with pupils aged 7 to 8 years. From the analysis of the knowledge revealed in her practice, three elements stand out: her knowledge of students' common misconceptions about the topic, her knowledge of questioning as a teaching strategy and her knowledge of facts. The teacher uses purposefully generated questions to elicit the pupils' knowledge about the position of the lungs, and the relationship between the size of the lungs and the heart. Through this approach, the teacher uncovers misconceptions about the topic, such as the idea that there are not two lungs and uncertainty about the heart's location. The findings highlight how the teacher's knowledge of common misconceptions shapes her questioning, enabling her not only to identify these misconceptions but also to promote pupils' knowledge construction by guiding them in re-evaluating their ideas. Furthermore, her science subject matter expertise allows her to identify and address the misconceptions effectively. The study underscores the interplay between subject matter knowledge and pedagogical content knowledge, demonstrating how these knowledge bases underlie the primary teacher's instructional practices.

Keywords: Primary science instruction; Teaching intervention; Case studies

Introduction

It is widely assumed that teachers' knowledge indicates instructional quality (e.g. Barendsen & Henze, 2017) and that teaching requires subject matter knowledge (SMK) and pedagogical content knowledge (PCK) (Shulman, 1986). Science teachers' PCK has been studied extensively, with various conceptualisations (e.g., Gess-Newsome, 2015; Park & Oliver, 2008), often considering SMK as a prerequisite. Moreover, studies on PCK have focused more on secondary than primary school teachers (Chan & Hume, 2019). This study examines the SMK and PCK of a primary teacher, focusing on interconnections between PCK elements and between PCK and SMK. These connections are of particular interest, as both the depth of the teacher's knowledge and its connection demonstrate the strength of her understanding and its transfer to the classroom (following Barendsen and Henze (2017), and Park & Chen (2012), referring to PCK). Previous studies highlight differences in how science teachers' knowledge impacts student performance, though combining SMK and PCK is crucial for addressing misconceptions (Sadler et al., 2013). Further research is needed on how high SMK and PCK teachers engage students (Chen et al., 2020) and how SMK influences PCK (Sen et al., 2018).

The topic of this study, human body, is complex. Research reveals that students aged 7 to 8 can locate two or more internal organs but often struggle to link them (Dempster & Stears, 2014). For students to develop their understanding of the organs, teachers must help students transition from

abstract ideas to detailed understanding, emphasising the characteristics and differences of each organ (Andersson et al., 2019). This requires teachers to be knowledgeable about how students learn, and to have a range of teaching strategies at their disposal.

The study was intended to address the following research question, what are the main elements of SMK and PCK that underpin a primary school teacher's practice in teaching the organs of the human body and how do they interrelate with each other? Our contribution to the research literature on science teacher knowledge is threefold: a) Studying an expert teacher, which is expected to provide access to high SMK and PCK; b) Integrating the study of SMK, less explored in science, with PCK, as well as their interconnections; c) Focusing on a primary school teacher, who has received less attention in studies on science teacher knowledge than secondary school teachers.

Methodology

This research was designed as a case study design (Yin, 2018). We selected an experienced teacher (26 years as primary teacher, with a degree in Primary Education and a doctoral thesis in science education) working in a state school in southern Portugal. Four consecutive lessons, each lasting approximately 1 hour, on the organs of the human body were videorecorded, over the course of a week with second-year pupils aged between 7 and 8.

The data collected was analysed with the PCK categorisation of Park & Oliver (2008), considering Knowledge of Instructional Strategies and Representations for teaching science (KISR), Knowledge of Students' Understanding in science (KSU) and Knowledge of the Science Curriculum (KSC). For categories pertaining to SMK, due to the absence of specific categorisations with respect to science teachers, we drew on the doctoral thesis of Luís (2021), focusing on (biological) subject matter knowledge, encompassing knowledge of: observation procedures and techniques; concepts and associated examples; laws, principles and theories; models associated with the content; and of biological facts and phenomena.

Results

In order to answer the research question, we present two situations in which we can see how the teacher uses different types of knowledge to support her students' learning about organs.

What stands out most is her knowledge of students' possible misconceptions about the organs of the human body (KSU). When approaching, the teacher mainly shows knowledge of questioning as a teaching strategy (KISR). Through questioning, the teacher encouraged her pupils to articulate their existing ideas and to reflect on these. An example occurs during an activity based on a worksheet depicting two bodies, male and female. The pupils call out various ideas about the organs of the body, including the four (heart, lungs, stomach and kidneys) targeted by the teacher. At this point she says:

> Teacher: *Can you all draw these organs here in the outline of the women – or the girl – and the man.* [Focusing the activity on eliciting prior knowledge about the location of the organs].

In doing so, she reveals her knowledge of possible student misconceptions regarding the position of the organs. She tries to elicit her pupils' intuitions through questions such as the following, in which she asks the pupils to say organs they feel most confident of locating:

> Teacher: *And you, Maria, which organ are you confident about? Where is it?* [...] *Are the lungs in the middle* [pointing]*?*

Two misconceptions arise during this episode. First, inaccurate information about the number of lungs:

> Teacher: *How many lungs are there?*
>
> [The teacher repeats various students' answers: two, one]
>
> Teacher: *Is it just one big lung at the front? But I'm talking about lungs* [stressing the plural 's']. *Is that because it's one big one? Is its name in the plural?*

The teacher is aware of the misconception that some students may have regarding the number of lungs, and for this reason draws out these ideas with her questions, and supplies the right answer, thus demonstrating her knowledge of the facts of the subject (there are two lungs) (SMK).

Second, there arises a misconception about the position of the organs, this time the heart. The teacher continues in the same way, using the questioning strategy, but this time she also uses questions to find out how the students perceive their hearts:

> Teacher: *You're saying you feel it here, like Mel?* [Touching her neck] [...] *I'm puzzled. So, the heart is on the left, Mel feels her heart in her neck. Can you feel your heart in your foot?* [...] *Where do you think we can feel our heart, in our knee? Or here?* [She touches her neck] O*r in our foot? Does it make a noise?*

Finally, we infer that the teacher has SMK regarding the slight displacement of the heart to the left, which allows her to be aware of misconceptions about the position of the heart. Likewise, she also knows the fact of the connection between the heart and the size of the left-hand lung. While questioning the pupils about this curious difference in size between the two lungs the following exchange occurs:

> Student: *Because one must have good oxygen, and the other mustn't have oxygen.*
>
> Teacher: *No, that's not why. Ah, look what's in the middle here, come on, what's in the middle?* [...] *That's the heart in the middle. So, to make room for the heart, the other organs have to fit in. And the heart is a little more to the left here, it's not quite in the middle, it's a little more to the left.*

While addressing these misconceptions, in the second situation she goes on to demonstrate awareness of similar misconceptions about whether these organs differ between men and women:

> Teacher: *The worksheet about the body that I gave you, there is a man and a woman on it. Are these organs the same in men and women?*

In response to various doubtful answers, the teacher draws one her knowledge that the lungs and heart are essentially the same in men and women, albeit noting the knowledge of the fact of the relativity of the size for everyone.

> Teacher: *Men and women have the same lungs and the same heart, but a very big person has a bigger heart.*

In summary, the teacher not only uses her KISR, with the use of questioning as the main strategy, to elicit misconceptions from the pupils (supported by KSU), but also uses the questions and answers that emerge during the exchanges to construct basic knowledge of the subject. Throughout the dialogical teaching process, the teacher gives evidence of SMK, namely about the facts underpinning the above-mentioned PCK and especially her knowledge of misconceptions.

Discussion

This study has shown how a primary education teacher's SMK and PCK interact at the point when she adopts a questioning strategy to address misconceptions about the organs and guide the pupils to construct their knowledge. We concur with Akman and Öztekin (2023) regarding the connection between in-depth SMK and knowledge of pupils' misconceptions. We have identified the questions used by the teacher to elicit the pupils' existing notions about the number and position of the lungs, and the position of the heart, along with the fact that these organs are identical in men and women. Her questions are staged so as to guide the pupils away from misconceptions towards the correct subject matter knowledge (Chin, 2007). The use of questioning not only enables misconceptions to be identified, but also facilitates the construction of knowledge, by making the pupils rethink their original ideas and reformulate them where necessary (Benedict-Chambers et al., 2021). The SMK that seems to underpin mainly her knowledge of misconceptions refers to factual knowledge. This may be conditioned by the content of the lessons observed and requires further study. We believe that this study can contribute to how an expert teacher's knowledge supports her approach to teaching particularly complex topics in relation to students' misconceptions.

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Section: Evaluating The Impact Of In-service Teacher Training

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Exploring The Impact Of A Multidisciplinary Sustainability Course For Teachers: Analysis Through GreenComp

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This paper presents the results of the second cycle of a training course on sustainability for in-service teachers, designed according to a Design-Based Research approach. The course was designed to be multidisciplinary, based on the European GreenComp framework. Analysis of the lesson plans developed by teachers and feedback questionnaires shows how the training supported the design of activities that integrate different dimensions of sustainability and are strongly anchored in everyday life contexts. The results also highlight the central role of collaborative work and co-design in supporting sustainability-oriented teaching practices.

Keywords: Sustainability, Teachers, Multidisciplinary

Introduction

Educating for sustainability means dealing with complex issues that not only concern the environment but also involve social, economic and cultural aspects (UNESCO, 2017). For this reason, teacher training cannot be limited to individual disciplines but must offer interdisciplinary and participatory workspaces where it is possible to reflect on teaching practices and design activities that help students develop critical thinking, awareness and the ability to act (Blonder et al., 2014; Fensham-Smith, 2019; Monroe et al., 2019).

The work presented in this contribution is part of a broader research project developed according to a Design-Based Research (DBR) approach (Guisasola et al., 2017). The project began with the design of a Teaching–Learning Sequence on the greenhouse effect, designed to address students' mental models and support teachers in introducing the physical principles underlying the phenomenon (Toffaletti et. al., 2022). However, it became clear that a perspective focused exclusively on physics was not sufficient to adequately address the issue of sustainability. Based on this awareness, a multidisciplinary training course on sustainability was designed for teachers in service, with the involvement of university professors from different departments.

This paper presents the results of the second cycle of the course, which was redesigned on the basis of previous experiences and gave greater space to collaborative work, interdisciplinary integration and shared planning.

Theoretical Framework

The theoretical framework that guided this research is GreenComp (Bianchi et al., 2022), the European framework for sustainability skills. It interprets sustainability as an integrated set of knowledge, skills and attitudes that guide the way people think, make decisions and act. The framework provides a structure that can be adapted to different educational contexts and used as a guide for instructional design.

The framework is organised into four interconnected areas of competence. The first concerns sustainability values and includes reflection on personal and collective values, attention to equity and intergenerational justice, and recognition of the value of nature. The second area focuses on understanding complexity through skills such as systemic thinking, critical thinking and the ability to define sustainability issues in relation to context. The third area is dedicated to the future perspective, promoting the imagination of sustainable scenarios and the ability to deal with

uncertainty and change. Finally, the fourth area concerns action for sustainability, including individual initiative, collective action and participation in decision-making processes.

Together, these four areas offer a coherent framework for supporting educational design that can integrate the value-based, cognitive and operational dimensions of sustainability, providing a useful method for analysing teaching practices and designing them.

Methods

The second cycle of the teacher training program was conceived and implemented within a DBR framework. The course was designed as an iterative intervention aimed at supporting teachers' professional development and informing the refinement of subsequent design cycles. The course took place over two intensive days. This decision was made based on the results obtained in the first cycle (Fiorello et al., 2024) with the aim of improving accessibility while preserving the multidisciplinary structure of the intervention.

On the first day of the course, the conceptual and methodological aspects of sustainability and sustainability education were presented, which then served as resources for the teachers' project work the following day. The day was divided into four thematic sessions. The course began with an introduction to the European framework of sustainability competences (GreenComp). This was followed by three sessions dedicated to environmental, social and economic sustainability. These sessions combined disciplinary perspectives with explicit attention to sustainability as a multidimensional construct, supporting participants in connecting scientific content with broader social, economic, and cultural dimensions. In these sessions, the aim was not only to provide disciplinary perspectives on the topic, but also to highlight how scientific content is linked to other aspects of sustainability. The structure and main topics of the first day are summarized in Table 1.

Table 1. Structure and main topics of the first day of the course.

Session	**Main contents**
Introduction to GreenComp	Presentation of the European framework for sustainability competences (GreenComp): its four competence areas. Discussion on how GreenComp can guide educational practices and lifelong learning for sustainability.
Environmental sustainability	Scientific context relating to climate change and decarbonisation. Analysis of climate data on a global and Alpine scale (temperature, precipitation, snow cover) and the physical basis of greenhouse gas effects. Discussion on energy production and consumption, renewable sources and decarbonisation.
Social sustainability	Reflections on the social and cultural dimensions of sustainability. Legal and anthropological perspectives on community-based governance and the concept of 'territories of life' in mountain areas. Exploration of human-environment relationships, rights and responsibilities, and the role of collective domains in ensuring dignity, justice and long-term coexistence.
Economic sustainability	Introduction to economic indicators for sustainability and the multidimensional nature of sustainable development. Analysis of the ecological footprint and Earth Overshoot Day. Discussion on consumption patterns, global inequality and strategies to reduce humanity's environmental impact.

The second day, on the other hand, was designed as a collaborative and project-based workshop. Participants worked in mixed groups (3 groups), composed in such a way as to ensure diversity in terms of disciplinary background and educational level. Teachers were asked to design educational activities inspired by the GreenComp framework using the Trialogical Learning Approach (CIT.).

Data collection was based on two main sources. At the end of the course, a satisfaction questionnaire was administered. The questionnaire was identical to the one used in the previous cycle, allowing for comparability between iterations, and was designed to gather teachers' perceptions of the organization, content and perceived relevance of the training program. The second resource for analysis concerns the lesson plans developed by the working groups. These constituted a central source of qualitative data, providing information on how teachers interpreted and implemented sustainability skills within their teaching projects.

The teaching plans were analysed qualitatively based on identifying how the different dimensions of sustainability – environmental, social and economic – were developed and integrated into the proposed activities. Attention was paid to the use of elements related to the GreenComp framework and the conceptual structures used by teachers to frame sustainability issues. The aim of this analysis was to evaluate the current intervention and refine the course design for future iterations. At the same time, the qualitative analysis of the feedback questionnaires aimed to capture the suggestions and critical reflections expressed by the teachers. Attention was paid to teachers' perceptions of collaborative work and co-design opportunities, as these were critical issues that emerged from the first training cycle and which we wanted to see improved in this cycle.

Results And Discussion

To give an overview of the teachers' proposals, Table 2 outlines the three lesson plans developed, highlighting the topics addressed, the activity structure, and the resulting artefacts.

Table 2. Summary of the lesson plans developed by participating teachers.

Lesson Plan	**Main contents and artefact**
Group 1: Food waste (lower/upper secondary)	Brainstorming on food waste; identification of local contexts to investigate (markets, restaurants, canteens, households); design of questionnaires and interviews; field data collection; selection and analysis of results; creation of a short documentary to communicate findings to the community. Artefact: documentary on food waste.
Group 2: Everyday energy saving (primary/lower secondary)	Analysis of students' everyday behaviours related to energy use; class discussion of possible improvements; collaborative construction of a "good practices" list to promote energy saving at school and at home; dissemination of the final document within the school community. Artefact: digital energy-saving decalogue.
Group 3: Fast fashion and textile supply chain (lower secondary)	Data collection on students' wardrobes (number of items, frequency of use); graphical representation of the data; reflection on environmental and social impacts of the textile industry; activities aimed at raising awareness of personal consumption habits; creation of a traffic-light tool to guide more responsible clothing purchases. Artefact: traffic-light decision tool.

Analysis of the teaching programmes developed by the teachers shows that each group interpreted the theoretical framework presented during the course (the multidimensional nature of sustainability and GreenComp skills) in a different way. In fact, the proposals vary in terms of pedagogical approaches and teaching choices.

The first project, focusing on food waste in the local area, is characterized by a strongly collective and community-oriented approach. The social dimension of sustainability is a key aspect of the planned activities. The project involves guiding students in exploring the phenomenon through research-based activities, including interviews and data collection. This approach helps students feel actively involved in the issue and develop a sense of shared responsibility towards something they perceive as real and close to their everyday lives. From GreenComp's perspective, the project activates skills mainly in Areas 1, 2 and 4. In Area 1, students develop an awareness of the value of food and its social role (1.1 Valuing sustainability) and reflect on issues of equity and justice in the distribution of resources (1.2 Supporting fairness) in Area 2, investigative activities promote systemic thinking (2.1), which is essential for understanding the relationships between food production, distribution, consumption and waste, and critical thinking (2.2), through the evaluation and reinterpretation of the information gathered in the documentary. Through brainstorming and peer discussion of research questions, it is possible to frame the problem (2.4). Finally, the production of the documentary constitutes a form of collective action (4.2) and an expression of political agency (4.1), as students communicate their findings to the wider community and position themselves as agents of change. Overall, the project coherently integrates the environmental, social, economic and cultural dimensions of sustainability through inquiry-based activities rooted in real-world contexts.

The second project focuses on energy saving in everyday behaviour and represents an intermediate approach between the first lesson plan, where activities are more focused on collective attitudes, and the third lesson plan, which is purely individual. In fact, teachers have designed activities that encourage students to reflect on their energy consumption habits and gradually develop a series of good practices to share with the school. From the point of view of the multidimensionality of sustainability, the project mainly addresses the environmental dimension, linked to the reduction of energy waste, but also involves the social dimension, as the final document seeks to influence shared practices and promote new behavioural norms. The greencomp competences activated are mainly related to Areas 1 and 4. In Area 1, the project supports the value of sustainability (1.1) by encouraging an understanding of energy as a shared and limited resource. Area 4 emerges in two aspects: students reflect on their personal responsibilities through individual initiatives (4.3) and the development of a collective "ten-point charter" promotes collective action (4.2) aimed at influencing the behaviour of the entire school community.

The third project, which addresses the issue of fast fashion and the textile supply chain, takes a more individual approach and is closely linked to the students' everyday experiences. The activity starts with an analysis of the students' personal wardrobes, how often they wear their clothes and why they buy them. This makes the topic concrete and relevant to their experience, helping them to reflect on their own consumption habits. From a sustainability perspective, the project addresses both environmental aspects, linked to the impact of the production chain, and social aspects, such as working conditions and workers' rights, inviting students to reflect explicitly on the ethics of consumption. The GreenComp skills activated in this project cover all four areas. In Area 1, reflection on personal consumption is linked to the importance of promoting sustainability (1.1) and focusing on fairness and rights within the production chain (1.2). Area 2 is activated through systemic thinking (2.1), necessary to grasp the complexity of the textile supply chain, critical thinking (2.3), necessary to analyse personal habits and assess their impact, and problem

definition (2.4), supported by meetings with experts and analyses conducted during the visit. Area 3 is involved through the invitation to plan future purchasing decisions (3.1), linking present actions to possible future scenarios. Finally, Area 4 is supported by the use of the decision-making "traffic light" system for individual use (4.3) and by opportunities to share results with the wider community (4.2).

The analysis of the questionnaires administered at the end of the course provides a very positive overall picture. Participants expressed a high level of satisfaction with both the organisation and the overall quality of the course. Almost all teachers perceived the programme as well-structured and carefully planned, with clear objectives and well-prepared materials. These results suggest that the more compact and practice-oriented format adopted in the second cycle was perceived as coherent and effective. The course content was also highly appreciated. All participants described the training as interesting and motivating, and around 70% said they had learned "many" new concepts. The trainers received very positive evaluations: most teachers found them clear and engaging, with no negative comments. Almost all participants acknowledged that the course content was directly applicable to their teaching practice, and all indicated that what they had learned could be used in their professional context. Furthermore, the fact that most teachers have already applied some ideas in their practice, or intend to do so shortly, clearly indicates the perceived relevance of the course. Another significant result concerns collaboration between teachers. While this emerged as a critical issue in the first cycle, the second cycle saw a marked improvement: around 85% of participants reported an increased ability to work in teams and collaborate with colleagues. The open responses highlighted above all the value of the second day, which was mainly devoted to workshops and shared design activities, where some participants suggested dedicating more time to design.

Conclusions

Analysis of the teaching plans and questionnaires from the second cycle indicates a development in the way teachers interpret and translate sustainability into teaching planning. The questionnaire data show a very positive overall assessment. Teachers particularly appreciated the opportunity to plan collaboratively, confirming co-design as a central and effective element of the programme.

The teaching plans reveal a tendency to frame sustainability through concrete issues closely related to students' everyday experiences, such as food waste, energy use and consumption practices. This suggests that sustainability is increasingly being addressed not only as a set of concepts to be taught, but as a dimension that is part of everyday life.

GreenComp has emerged as a reference point for educational design, providing a framework that has guided the integration of sustainability-related skills into the proposed activities. Overall, the results show a strengthening of sustainability-oriented educational planning, combining scientific content, participatory approaches and a focus on everyday practices.

Acknowledgement

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Enhancing Teachers' Beliefs, Self-Efficacy And Professional Knowledge Through In-Service Teacher Professional Development Programs On The Use Of (Interactive) Experimental Videos

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In the context of digital progress, the implementation of Information and Communication Technologies (ICT) in schools is becoming increasingly frequent. Innovative learning media, such as (interactive) experimental videos, are emerging as a significant component in physics education. These technologies are characterized by high interactivity, which facilitates a constructivist approach to domain-specific learning. Despite the increasing availability of such ICT for physics education, its utilization remains limited. This phenomenon can be attributed to a combination of factors, including teachers' beliefs, self-efficacy, technology commitment, and professional knowledge. Specifically, weak beliefs and a lack of professional knowledge regarding the integration of (interactive) experimental videos, coupled with the subjective perception of being unable to meet the digital requirements, can lead to reduced utilization in physics lessons. The implementation of professional development (PD) programs can be a key element in minimizing these effects. For example, the presented study shows that the integration of (interactive) experimental videos within a PD program has a positive effect on professional knowledge and ICT reaction beliefs.

Keywords: beliefs, in-service teacher programs, (interactive) experimental videos

Introduction

Information and communication technology (ICT) is becoming an increasingly relevant part of teaching practice (KMK, 2016). In classrooms, ICT offers innovative approaches to foster students' learning. However, it also creates new demands on teachers' professional development (Caena & Redecker, 2019). Teachers need digitalization-related skills to effectively integrate ICT in their teaching practice (Fernández-Batanero et al., 2020). This is particularly important for domain-specific ICT, since its meaningful implementation depends on the connection between general digitalization-related skills and domain-specific didactic knowledge, as highlighted in current frameworks (DigCompEdu; Redecker, 2017).

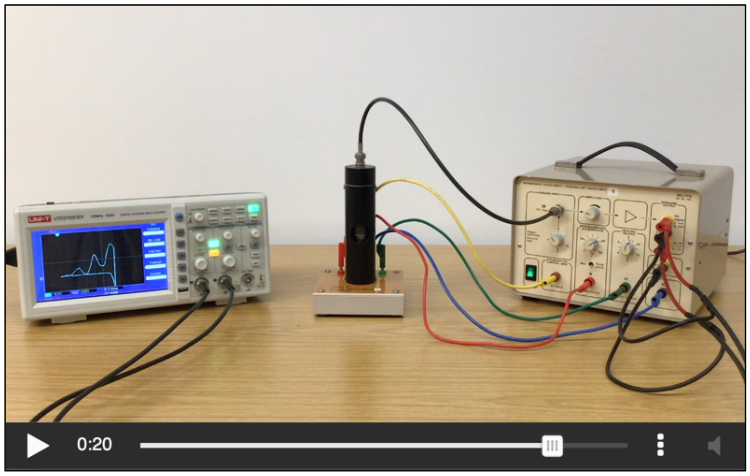
Although the frequency of ICT utilization has increased in recent years (Drossel et al., 2024), this mainly relates to established and cross-disciplinary ICT. More innovative and domain-specific ICT, such as (interactive) experimental videos, is still rarely used in classrooms (Drossel et al., 2024; Vogelsang et al., 2019). This can be attributed to teachers' ICT beliefs, their self-efficacy as well as their professional knowledge. Rudimentary digitalization-related skills (Huber et al., 2020) and weak beliefs coupled with the perceived inability to meet digital demands can lead to low utilization of ICT in classrooms.

Despite the availability of in-service teacher professional development (PD) programs, teachers only participate to a limited extent, partly due to a lack of adequate and contextually appropriate offerings (Eickelmann, 2019). Therefore, further tailored domain-specific PD programs are necessary to promote teachers' beliefs, their self-efficacy and their professional knowledge regarding the implementation of domain-specific ICT in lessons (Eickelmann, 2019).

Theoretical Background

(Interactive) Experimental Videos

Figure 1. Experimental Video of the 'Franck-Hertz experiment'. The students' task is to observe the typical curve displayed on the oscilloscope.



One such example is the presented PD on (interactive) experimental videos. Experimental videos are defined as the combination of the classic demonstration experiment and the digital tool of videography (Stinken-Rösner & Meier, 2023). So, initially, these are videotaped demonstration experiments, showing the individual steps of the experiment in linear sequence (see Figure 1). While watching the video, the students observe the outcome of the experiment and may record measurements. In this case, students act as 'passive' viewers in an observing role (ICAP-model; Chi & Wylie, 2014), as is also the case when a demonstration experiment is carried out in reality. To increase cognitive activation, interactive H5P elements can be integrated into experimental videos. These videos, then referred to as interactive experimental videos, are characterised by the fact that students can actively interact with the medium, thereby achieving a deeper understanding of the domain-specific content (Meier et al., 2022a).

In the literature on domain-specific education, (interactive) experimental videos are particularly present in practice-oriented articles (e.g. Meier et al., 2022a; Pfafferodt et al., 2023), highlighting their potential for inclusive teaching and learning (Stinken-Rösner et al., 2023). However, empirical studies dealing with the implementation of experimental videos in physics lessons, as well as teachers' attitudes towards the use of experimental videos, are still rare. A first survey revealed that science teachers generally have a positive attitude towards (interactive) experimental videos (Meier et al., 2022b). At the same time, it became clear that a group of sceptics attributed greater importance to real-world experiments. They worry that interactive experimental videos could replace real-world experiences in physics lessons (Meier et al., 2022b). This concern can be explained by the fact that these teachers do not regard the (interactive) experimental videos as a supplement to real-world experiments, but as a substitute with no added functional value for the experimental process (SAMR-model according to Puentedura, 2006).

Professional Knowledge

Successful integration of ICT into teaching practice largely depends on teachers possessing ICT-related professional knowledge. The TPACK framework proposed by Mishra and Koehler (2006) combines three main components of teachers' knowledge: pedagogical, content and technological knowledge. Pedagogical knowledge (PK) encompasses knowledge of teaching methods and learning strategies. Content knowledge (CK) refers to domain-specific knowledge about the

content to be taught in lessons. Finally, technological knowledge (TK) describes the use of digital tools and software like tablets and presentation programs.

These dimensions are not considered separately but form four important intersections (Mishra & Koehler, 2006). Pedagogical content knowledge (PCK) is equivalent to domain-specific didactic knowledge and focuses on how a particular domain-specific content can be taught effectively. Technological pedagogical knowledge (TPK) deals with how ICT can be used in a didactically meaningful way in the classroom. Technological Content Knowledge (TCK) describes how ICT can be used in the subject. Finally, the central component is Technological Pedagogical Content Knowledge (TPACK). It describes the knowledge required to convey domain-specific content in a meaningful way using ICT in the classroom.

Current research on professional knowledge suggests that targeted interventions can effectively promote STEM teachers' TPACK. Specialized courses within teacher education have resulted in significant improvements in pre-service STEM teachers' TPACK (e.g. Stinken-Rösner et al., 2023; Chai et al., 2010). Furthermore, it has been found that specific in-service teacher PD programs can also contribute to an increase in their TPACK (Lehiste, 2015).

Teachers' ICT Beliefs

In order to implement ICT in a pedagogically meaningful way, teachers need to purposefully apply their professional knowledge in the classroom. (Stinken-Rösner et al., 2023). However, the actual utilization of ICT in teaching practice is not only a matter of teachers' professionalization but also closely related to their subjective beliefs. Schmidt and Reintjes (2020) investigated the ICT beliefs of pre-service teachers and identified three central forms. First, so called reaction beliefs that conceptualize ICT primarily as an instrumental tool to support existing teaching practices. Second, design beliefs that emphasize the pedagogically meaningful integration of ICT in classrooms. Third, identity beliefs that relate to teachers' self-concept in the context of digitalized teaching.

Self-Efficacy

Self-efficacy in general 'refers to beliefs in one's capabilities to organize and execute the courses of action required to produce given attainments' (Bandura, 1997, p. 3). A domain-specific form of this construct is described by the computer-related self-efficacy, which refers to one's confidence in one's ability to successfully perform computer-related tasks (Spannagel & Bescherer, 2009). In the context of utilization of ICT in lessons, computer-related self-efficacy is of central importance as it substantially determines whether certain behaviours (such as integration of ICT in the classroom) are initiated at all (Bandura, 1977). Teachers with a high level of self-efficacy exhibit strong confidence in their ability to use ICT in teaching and are more persistent when encountering problems. Consequently, self-efficacy is a key predictor of successful ICT implementation in teaching practice.

A recent meta-analysis examining the effects of PD programmes on teachers' self-efficacy revealed statistically significant medium effect sizes (Zhou et al., 2023). These findings were confirmed by further studies (e.g. Yang, 2020).

Technology Commitment

Technology commitment consists of three components: Technology acceptance, technology competence beliefs and technology control beliefs. According to Neyer et al. (2012) technology acceptance refers to the subjective assessment of technical advances. Technology competence beliefs describe the subjective evaluation of one's own competencies in utilizing established ICT

and adapting innovative ICT for teaching practice. Technology control beliefs are defined as the degree to which a person perceives having influence or control over technological processes.

Studies on technology acceptance indicate that ICT-related beliefs influence one's intention to use ICT, which in turn is considered a central predictor for actual ICT utilization (Venkatesh et al., 2003). Therefore, PD programs are required to systematically foster teachers' digitalization-related skills and, consequently, strengthen their technology commitment. Current studies on pre-service teachers indicate a higher level of success in the use of ICT when technology acceptance is strongly developed (Köstler & Wolff, 2025). These findings suggest that, for in-service teachers, higher technology acceptance may result in increased implementation of ICT in physics lessons.

PD Program Concept

As explained above, teachers' beliefs and their high level of professional knowledge are considered essential prerequisites for the successful use of ICT in the classroom. However, these characteristics do not develop automatically but require targeted support. In-service teacher PD programs could play a key role here, as they offer structured learning opportunities. Against this background, the concept of the designed pd program (see also Ziegler and Stinken-Rösner, 2024) is presented below (Table 1).

Table 1. Description of the designed PD program.

Module 1 (7 hours)	
Actions	Aims
At the beginning, the participating teachers are introduced to the use of videos in physics lessons, along with a definition of experimental videos. This is followed by an input on design principles for demonstration experiments and multimedia applications, as well as on different scenarios for using experimental videos in teaching practice. Subsequently, the participating teachers independently produce experimental videos based on the introduced design principles. For this purpose, they use prepared experiments or alternatively experiments of their own choice. The produced experimental videos are then exchanged with the task of adding a voice-over that describes the experimental procedures (video dubbing). Finally, the participating teachers receive peer feedback from other participants for their experimental videos.	The participating teachers should be able to… … distinguish between different types of videos. … identify design principles in experimental videos. … independently produce an experimental video of a demonstration experiment, considering design principles for demonstration experiments. … add a voice-over to an experimental video.
Module 2 (4 hours)	
The pedagogical usefulness of interactive elements in digital media is discussed, with reference to the ICAP model as a theoretical framework. This is followed by an introduction to the 'Lumi' software and, more specifically, the various interactive H5P tools it provides. Subsequently, the participating teachers integrate the interactive H5P tools into their experimental videos produced in the first module. Finally, teachers receive peer feedback on their interactive experimental videos from other participants.	The participating teachers should be able to… … describe the pedagogical usefulness of interactive elements in digital media in physics lessons. … produce interactive experimental videos.
Module 3 (4 hours)	
Participating teachers visit the student lab with a class from their school. There, the students work with experimental videos either as an independent learning medium or in combination with a real-world experiment. The experimental videos used for this purpose are produced in advance by academic staff. During the implementation in the student lab, the teachers observe the students' learning processes and interactions.	The participating teachers should be able to… …assess the pedagogical usefulness of (interactive) experimental videos across different scenarios.

Research Question

Previous research shows that the utilization of (interactive) experimental videos by teachers has not yet been sufficiently researched. An initial study shows that the majority of teachers have a positive attitude towards experimental videos, but there are also concerns about their use (Meier et al., 2022b). However, the extent to which in-service teacher PD programs affect teachers' professional knowledge, their beliefs towards, as well as the resulting implementation of (interactive) experimental videos in practice was not considered. Therefore, the present study investigates the following research question:

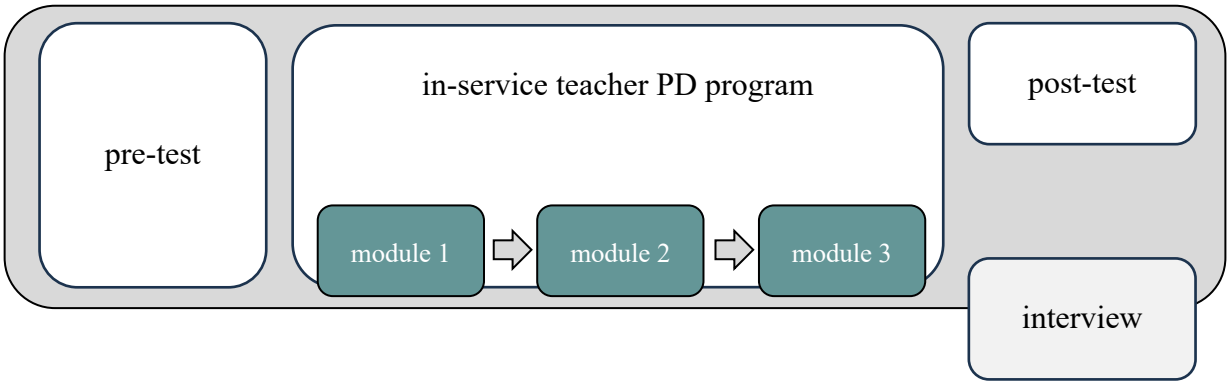
To what extent does participating in a PD program on the use of (interactive) experimental videos influence in-service physics teachers' technology commitment, their ICT beliefs, their self-efficacy and their professional knowledge regarding the use of ICT?

Methods

Study design

The data is collected using a mixed-methods approach (see Figure 2). In a pre-post design, the quantitative data were collected using a standardized questionnaire, which includes, among others, well-established scales on technology commitment (TC; Neyer et al., 2012), ICT reaction beliefs (ICT RB; Schmidt & Reintjes, 2020), self-efficacy (SE; Beierlein et al., 2012) and professional knowledge (Stinken-Rösner, 2021). All items are recorded on a six-point Likert scale (1 = strongly disagree, 6 = strongly agree). Regarding professional knowledge, a specific methodological consideration applies. As (interactive) experimental videos are not yet widely used in teaching practice, it can be assumed that the participating teachers had no prior experience with this medium. Consequently, the TK and TCK scales were operationalised with reference to digital media in general at the pre-test measurement and with reference to (interactive) experimental videos at the post-test measurement. As a result, changes over time cannot be directly assessed for these scales. However, there are comparisons between pre- and post-measurements possible. In addition, qualitative semi-structured group interviews were conducted with the participating teachers following the completion of the PD program to explore the conditions for success and the barriers to the implementation of ICT integration.

Figure 2. Visualization of the study design.



Sample

The PD program was offered three times. Three teachers took part in the first round, while five teachers each took part in the second and third rounds. In total, 12 physics teachers took part in the accompanying study (50 % male, 50 % female) and completed both pre- and post-test.

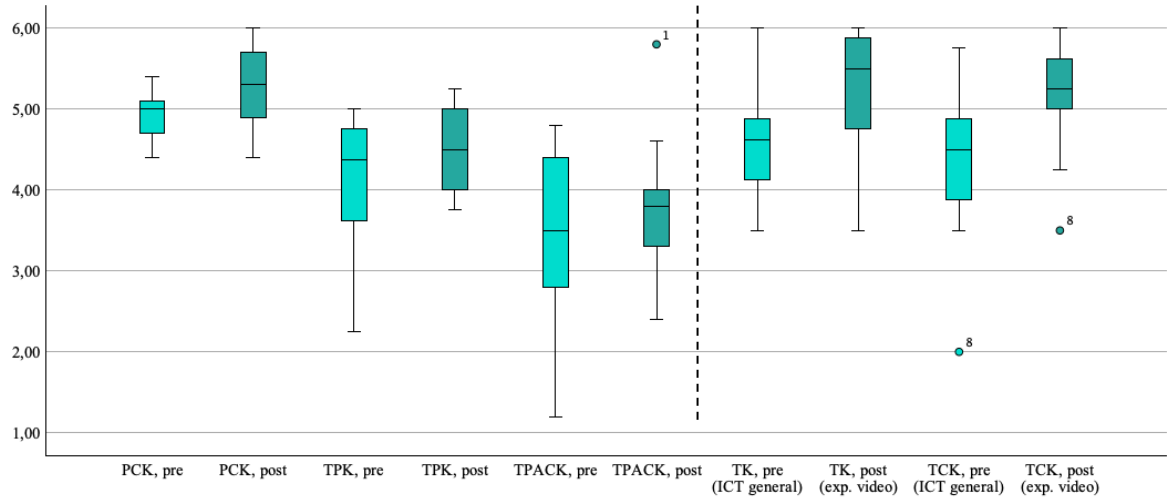
Participation was voluntary and anonymous. The average age of the participants was 39.6 years (SD = 5.9 years), with an average of 13.4 years of professional experience (SD = 16.6 years).

Results

Professional Knowledge

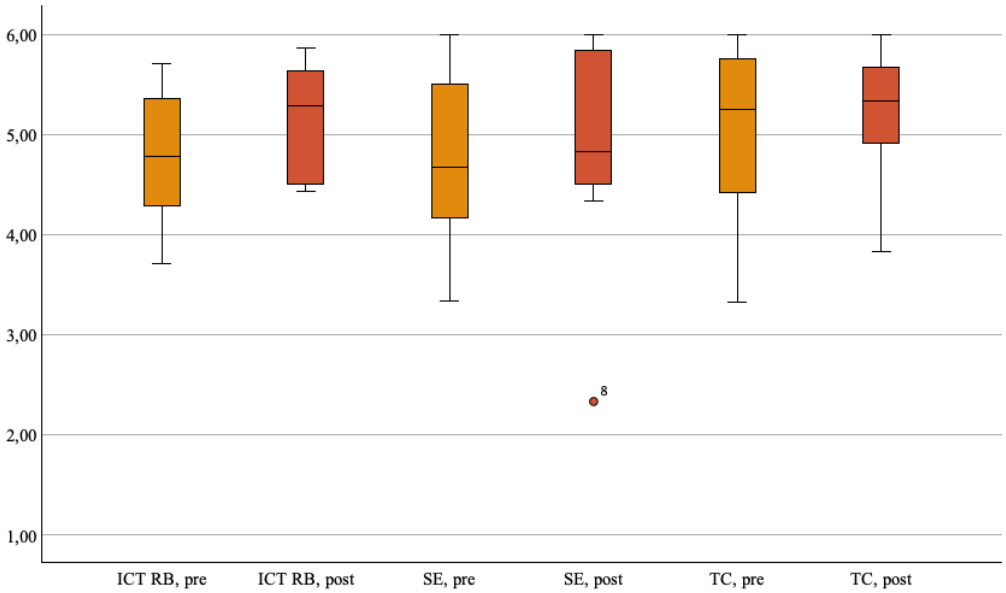
The following Figure 3 presents the results of the study for all TPACK dimensions.

Figure 3. Boxplots for TPACK dimensions, pre-test data (left) and post-test data (right).



A comparison of the pre-test and post-test values suggests a slight upward trend in most TPACK dimensions. PCK, TPK and TPACK show a slight improvement. The post-test values (relating to experimental videos) for TK and TCK are higher than the corresponding pre-test values (relating to ICT in general). Overall, the variance of the post-test scores is slightly lower compared to the pre-test scores.

Figure 4. Boxplots for ICT reaction beliefs (ICT RB), self-efficacy (SE) and technology commitment (TC), pre-test data (left) and post-test data (right).



The results shown in Figure 4 indicate that participation in the PD program led to a slight increase in participants' ICT reaction beliefs and self-efficacy, while the technology commitment remained largely at the same level. It can also be observed that the variance of the post-test data tends to be lower than that of the pre-test data.

The results of the comparison of the mean values between pre- and post-test confirm most findings (see Table 2). The small increase in the mean self-efficacy score could be attributed to the presence of an outliner in the data (see Figure 4).

Table 2. Overview of the pre- and post-test mean values of all constructs.

Construct	Mean Value, Pre	Mean Value, Post
Pck	4.90 (Sd = 0.31)	5.28 (Sd = 0.51)
Tpk	4.08 (Sd = 0.92)	4.50 (Sd = 0.54)
Tpack	3.47 (Sd = 1.09)	3.80 (Sd = 0.86)
Tk	4.60 (SD = 0.76), ICT General	5.23 (SD = 0.79), Exp. Video
Tck	4.31 (SD = 0.95), ICT General	5.15 (SD = 0.71), Exp. Video
Ict Rb	4.79 (Sd = 0.67)	5.14 (Sd = 0.57)
Se	4.78 (Sd = 0.87)	4.94 (Sd = 1.05)
Tc	5.07 (Sd = 0.87)	5.21 (Sd = 0.69)

The analysis of the qualitative data has not yet been completed.

Discussion

The present study aimed to investigate the impact of an in-service teacher PD program addressing learning with (interactive) experimental videos on teachers' professional knowledge as well as on their ICT-related beliefs. Comparing pre- and post-test data, slightly positive tendencies were observed in selected TPACK dimensions, for ICT reaction beliefs and for self-efficacy. In contrast, no increase was identified for technology commitment. For this construct, the post-test score remained approximately at the same level as before participating in the PD program.

The designed PD program aimed to enhance teachers' competencies in using domain-specific ICT, specifically (interactive) experimental videos. During the PD program, participating teachers engaged intensively with this domain-specific ICT and acquired fundamental skills for the independent production of such media. As a result, teachers rated their TK and TCK regarding the specific medium '(interactive) experimental video' higher after participating in the PD program than they had prior to participation regarding digital media in general. Moreover, positive tendencies were observed for PCK, TPK and TPACK. These findings are consistent with further studies reporting positive effects of targeted interventions on professional knowledge (within the TPACK framework), both for pre-service teachers (Stinken-Rösner et al., 2023) and in-service teachers (Lehiste, 2015). In particular, the results demonstrate that practice-oriented PD programs can make a substantial contribution to teacher professionalization.

One key element of the PD program is the implementation of (interactive) experimental videos in the student lab, where participating teachers gain experience in using these videos with their own class. During this implementation phase, teachers were able to observe students' interactions with the (interactive) experimental videos and thereby identify their potential for effectively conveying domain-specific content as well as domain-specific language (through adding a voice-over to an experimental video). We hypothesized that an embedded implementation phase would be an opportunity to positively affect teachers' beliefs about the use of digital media. Positive tendencies for ICT reaction beliefs and self-efficacy were found, with the increase in self-efficacy being marginal. Furthermore, no change in technology commitment could be observed (see

Figure 4). This finding is not entirely consistent with previous research reporting a medium effect of general PD programs on STEM teachers' self-efficacy (e.g., Zhou et al., 2023). This discrepancy may be related to the PD program itself. It was both domain- and media-specific, whereas teachers' self-efficacy was assessed in the questionnaire with respect to the utilization of digital media in general. Consequently, the small increase in general self-efficacy suggests that the domain-specific focus of the program was not reflected in overall self-efficacy beliefs. However, this does not preclude the possibility that teachers' domain- and media-specific self-efficacy increased more strongly because of the program.

Furthermore, observing students working effectively with (interactive) experimental videos may explain the increase in ICT reaction beliefs. Thus, teachers perceived (interactive) experimental videos as effective and meaningful digital tools for physics lessons. However, this would also suggest an increase in technology commitment, which is not indicated by the data. One possible explanation may lie in the independent production of (interactive) experimental videos, which several participants perceived as time-intensive during the program. This may represent a potential implementation barrier. Also, these outcomes suggest that technology commitment can be regarded as a relatively stable construct. So, the targeted promotion may require long-term interventions, as stated by Lipowsky and Rzejak (2021). In this context, no generally valid appropriate time frame can be specified, as the assessment of appropriateness depends on a wide range of factors, such as individual prerequisites of the participating teachers or specific focus of the PD program (Lipowsky & Rzejak, 2021). In addition, one can identify that the scales used to assess the teachers' beliefs were utilized to a high degree (see Figure 4), meaning that the presence of potential ceiling effects cannot be ruled out.

Limitations

When interpreting the results, several limitations need to be considered. Firstly, the present study concerns a small sample size with only 12 physics teachers. Therefore, the generalizability of the results is limited. Consequently, future research with larger samples is needed to examine the reported effects. Secondly, the study relies on self-assessed measures of professional knowledge, which may not accurately reflect teachers' actual levels of competence. As self-assessed competencies do not fully correspond to objectively measured professional knowledge (Stinken-Rösner et al., 2023), future research should incorporate performance-based measures to more comprehensively assess teachers' professional knowledge. Finally, the transferability of the results to school practice needs to be critically assessed. In this context, instructional actions were conducted under conditions that differ from regular school practice, in the learning environment, the availability of technical resources, and the instructional role. This role was assumed by a scientific staff member rather than the classroom teacher. Consequently, actual belief-related constructs may be lower than indicated in the post-test, as participating teachers may experience uncertainties when implementing (interactive) experimental videos in their own teaching practice. Therefore, future studies should include follow-up assessments to examine the development of teachers' self-efficacy in authentic school settings.

Conclusion

This study investigated the impact of an in-service teacher PD program focusing on learning with (interactive) experimental videos on physics teachers' professional knowledge (TPACK) and ICT-related beliefs. The findings indicate that the designed PD program slightly positively influences selected dimensions of teachers' professional knowledge, their ICT reaction beliefs, as well as their self-efficacy. However, no changes were observed in teachers' underlying technology commitment. Two main conclusions emerge from the findings. First, digitalization-

related, domain-specific PD programs have the potential to foster teacher professionalization. Second, an implementation phase in which the domain-specific medium is tested may represent a condition to successfully initiate changes in teachers' beliefs. In this context, it is assumed that the time-intensive production of (interactive) experimental videos may constitute a potential barrier. To further investigate these assumptions, the data obtained from the interviews regarding conditions for success and barriers to the implementation of ICT, particularly (interactive) experimental videos, will be analysed in future work.

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Navigating Digital STEM Professional Development: Insights From Out-Of-School Labs

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The demand for high-quality teacher professional development (PD) is significant, especially in the context of a digitalised world. Effective PD fosters collaborative work, self-efficacy and student-centred approaches. In this context, PD programmes that take place in out-of-school labs or are closely linked to them in various ways offer great potential that has not yet been realised. The ministry-funded research project "LFB-Labs-digital" investigates this potential in Germany by taking eight STEM out-of-school labs as venues for PD in teachers' information and communication technology (ICT) skills. An accompanying interdisciplinary quality management captures, among other things, the expectations and perceptions of the participating teachers regarding the PD programmes. The study explores these aspects as well as teachers' perceived relevance, cognitive activation, and the sustainability of the implementation of PD content. Data was collected from 83 teachers in pre-surveys and 48 teachers in post-surveys across eight out-of-school labs. Pre-survey results indicate that teachers primarily demand subject-specific digital media use, the application of specialized software, and guidance on designing digital learning environments. Teachers consider the PD programmes relevant when it offers feasible implementation, manageable workload, and curriculum relevance. Post-survey results show positive perceptions of PD programmes' perceived relevance, cognitive activation, and sustainability regarding digital teaching. The data shows promising potential for the approach of out-of-school lab-based teacher PD across multiple STEM subjects.

Keywords: digital learning, teacher education, professional development

Introduction

Due to ongoing digitalisation worldwide, the development of digital competencies is more important than ever in society and is therefore a core topic of the European Union's Digital Education Action Plan (European Commission, 2023). As the development of students' digital competencies largely depends on teachers' instructional practices, there is a particular need for professional development (PD) targeting teachers' information and communication technology (ICT) skills (OECD, 2019). Teachers must not only possess digital competencies themselves but also give their students possibilities to improve these skills. Added to this is subject-specific knowledge required in the classroom, so that teachers are faced with multifaceted requirements: the integration of technological, pedagogical and content knowledge (TPACK) (Mishra & Koehler, 2006). The continuous development of relevant competencies must be a cornerstone of teacher education and PD (Eickelmann et al., 2019).

While offering ICT-related PD for teachers is highly relevant due to deficits with regard to ICT training among teachers (Eickelmann et al., 2019; Fernandes et al., 2020; Fernández-Batanero et al., 2022), implementation and evaluation is challenging in many countries (Popova et al., 2022). Despite high demand, comparatively low participation rates in PD are observed (Popova et al., 2022). Another problem is that many PD programmes are conducted as so-called one-shot events (Fernandes et al., 2020), although research indicates longer-term programmes being more sustainable regarding positive effects on students (Lipowsky & Rzejak, 2015). These challenges are also evident in Germany (Mußmann et al., 2021), even though the national Conference of Ministers of Education and Cultural Affairs strongly emphasises the importance of digital media (Kultusministerkonferenz, 2017).

In recent years, out-of-school labs and other non-formal learning environments have established themselves as innovative extracurricular learning opportunities for students (Kirchhoff et al., 2022). They provide a unique setting where students can gain authentic practical experience and apply scientific concepts, potentially increasing interest and motivation in STEM subjects (Itzek-Greulich & Vollmer, 2017; Mohr-Schroeder et al., 2014; Roberts et al., 2018). These characteristics present promising potential to use these out-of-school learning environments as venues for PD related to digitalisation. This potential has been empirically examined by Reher et al. (2025), who found positive effects of digitalisation-related PD in out-of-school labs on teachers' self-assessed professional knowledge, while belief-related dimensions such as self-efficacy and technology commitment remained largely stable.

Within the same project, complementary analyses have focused on success factors and implementation barriers of these PD programmes (Lüsse et al., 2025). This research identifies factors such as technical support, curricular alignment, hands-on orientations, and structured reflection as potential success conditions, alongside persistent organisational and technical challenges. However, this research has primarily focused on the perspectives of PD facilitators or on external observations of programme implementation. The perspectives of teachers as the users of these PD programmes, particularly with regard to how they perceive and evaluate digitalisation-related PD in out-of-school lab settings, remain underexplored.

Addressing this research gap, the present study focuses explicitly on teachers' perspectives on digitalisation-related PD programmes conducted in out-of-school labs. The study examines teachers' needs and expectations prior to participation and investigates how participating teachers perceive the relevance, cognitive activation, and sustainability of the PD programmes with respect to digitalisation-related aspects. By adopting the users' perspective, the study aims to contribute to a more differentiated understanding of the potential and limitations of out-of-school labs as venues for effective and sustainable teacher PD.

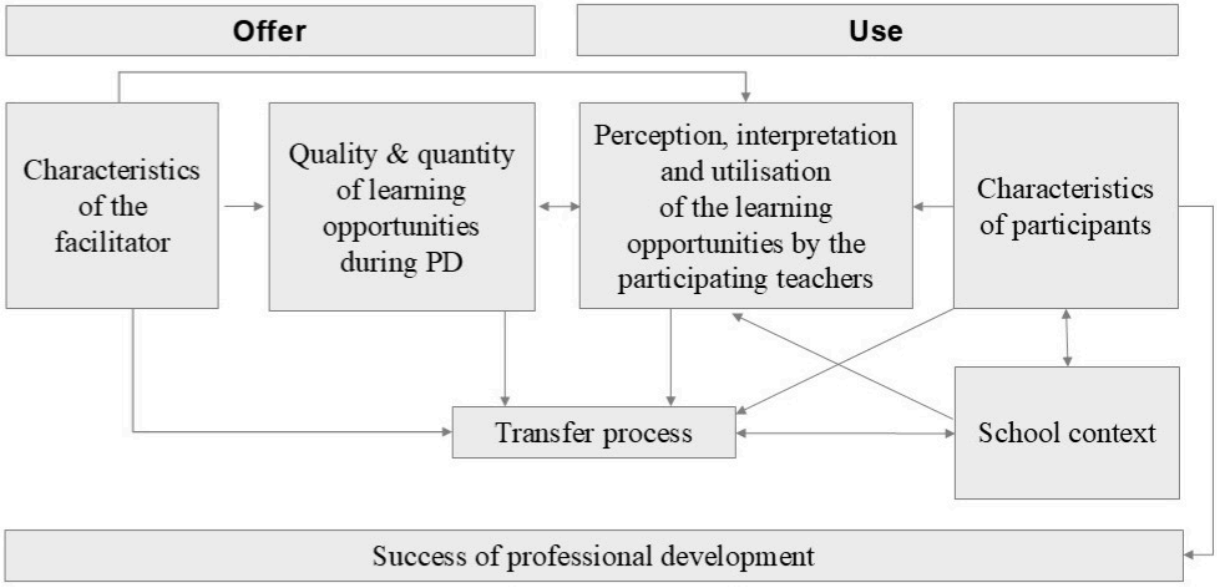
Theory And State Of Research

Key Features Of Effective Professional Development

To illustrate the multifactorial transfer processes and influencing factors in PD, an adapted offer-and-use model by Lipowsky and Rzejak (2015) can be applied (Figure 1). The model conceptualises PD as an interaction between the offer side, referring to the design and implementation of PD programmes, and the use side, representing participating teachers with their individual prerequisites and school contexts.

On the offer side, relevant aspects include the professional expertise of facilitators as well as the quality, structure, and coherence of the learning opportunities provided. Empirical research has consistently shown that effective PD for STEM teachers is characterised by a strong focus on subject-specific content, pedagogical approaches, and the integration of technology into teaching and learning processes (Joseph & Uzondu, 2024). Lipowsky and Rzejak (2015) also identify essential characteristics of effective PD, including the integration of input, trial, and application phases, as well as creating situations where teachers experience self-efficacy and focus on student learning within professional learning communities. These principles, including inquiry-based and collaborative learning, also apply to ICT-related PD programmes (Fernandes et al., 2020).

Figure 1: Offer-and-use model for research on teacher PD (adapted from Lipowsky & Rzejak, 2015, p. 30).



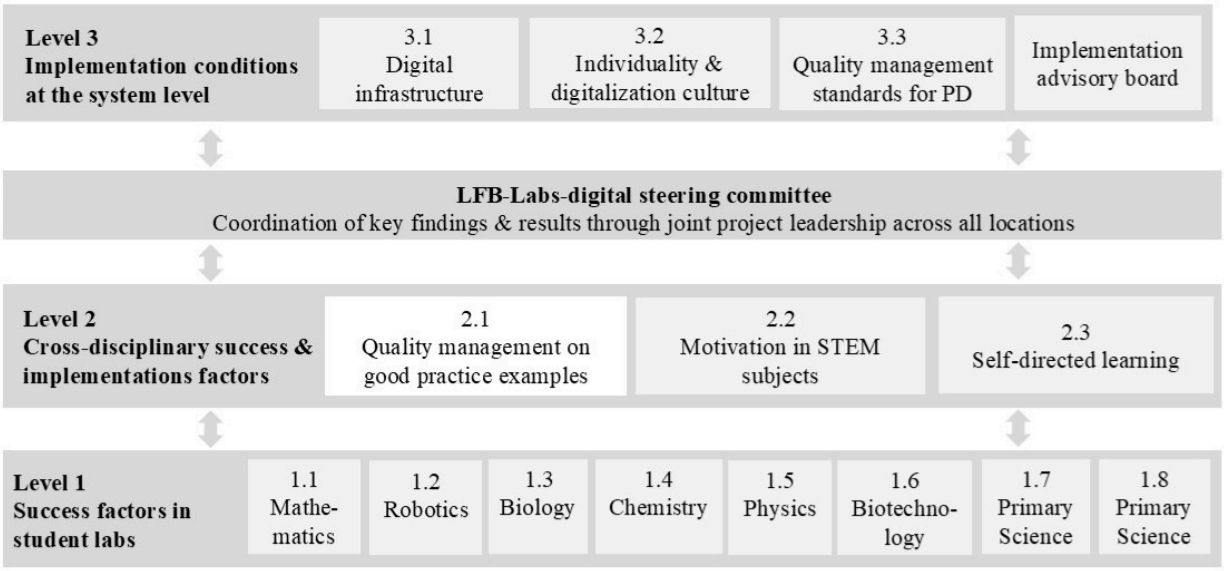
Beyond these general features, recent empirical studies have begun to specify conditions for effective PD in non-formal learning environments such as out-of-school labs. Focusing on digitalisation-related PD in such contexts, Lüsse et al. (2025) identified technical support, curricular alignment, flexible formats, hands-on orientations, peer exchange, and structured reflection opportunities as potential key success factors for PD in out-of-school labs. These features support teachers in critically reflecting on and adapting digital tools and strategies for their own teaching practice. At the same time, the study highlights persistent technical and organisational challenges as well as heterogeneous digital competencies among teachers as implementation barriers. Together, these findings underline the importance of designing PD programmes that combine coherence and adaptability in order to address diverse teacher needs.

Context Of The Study

Against this theoretical and empirical background, the collaborative, ministry-funded project *LFB-Labs-digital* was initiated (Figure 2; Kirchhoff et al., 2024). The primary objective of this project is to establish out-of-school labs as innovative learning environments for digitally supported PD programmes. To achieve this, eight STEM-focused out-of-school labs in the state of North Rhine-Westphalia, Germany, are being adapted and expanded to serve as PD venues. These labs cover a range of disciplines, including Mathematics, Biology (two labs), Chemistry, Physics, Biotechnology, and Primary Science Education (two labs).

As part of the project, an interdisciplinary quality management approach accompanies the ongoing PD programmes. This involves systematic observation, continuous exchange with PD facilitators, and the identification and discussion of good practice examples across sites. Previous analyses conducted within the project context have examined PD programmes from the perspectives of facilitators and external observers, focusing on implementation conditions and barriers (Lüsse et al., 2025). However, the perspectives of teachers as the users of these PD programmes have not yet been systematically investigated.

Figure 2: Project structure of LFB-Labs-digital (adapted from Kirchhoff et al., 2024, p. 136).



Addressing this research gap, the present study focuses explicitly on the teachers' perspectives. The central research question is how teachers perceive the PD programmes. Initially, the needs and expectations of teachers regarding digitalisation-related out-of-school labs PD programmes will be assessed. Furthermore, it will be examined how participating teachers evaluate the relevance, cognitive activation, and sustainability of the PD programmes concerning aspects related to digitalisation.

Method

The study combines qualitative feedback and quantitative surveys and was conducted via LimeSurvey. Participation in both the pre- and post-survey was voluntary. In the pre-survey, teachers were asked about their expectations and perception of relevance regarding the out-of-school lab PD programme using self-developed two open-ended items:

1. "In the PD programme, I would like to learn more about ... / I expect insights into ... from the programme."
2. "For me, a PD programme is relevant to my teaching if it…"

Table 1: Post-survey instrument.

	Relevance	Cognitive Activation	Sustainability
	3 Items α = .900	6 Items α = .910	6 Items α = .896
Example item	RelAd1: "In the PD programme, we talked about why the topic is important for digital teaching."	KogA2: "In the PD programme, we reflected on our professional practice regarding digital teaching."	Nach4: "In the programme, we discussed how the PD content on digital teaching can be implemented at our schools."
Measurement	Post-Survey: 6-point Likert scale from 1 = strongly disagree to 6 = strongly agree		

In the post-survey, validated six-point Likert scales developed by Rzejak et al. (2023) were shortened and adapted to the context of digital learning. These scales assessed teachers'

perceptions of relevance, cognitive activation, and sustainability after participating in the PD programme (Table 1). The post-survey was administered immediately after the PD programme.

The open-ended responses were analysed using content analysis (Kuckartz, 2018). An inductive category system was developed and subsequently discussed, revised, and refined in collaboration with two additional research associates. The resulting category system was then validated using the AI Assist tool in MAXQDA Analytics Pro (24.0.0), but no further modifications were deemed necessary.

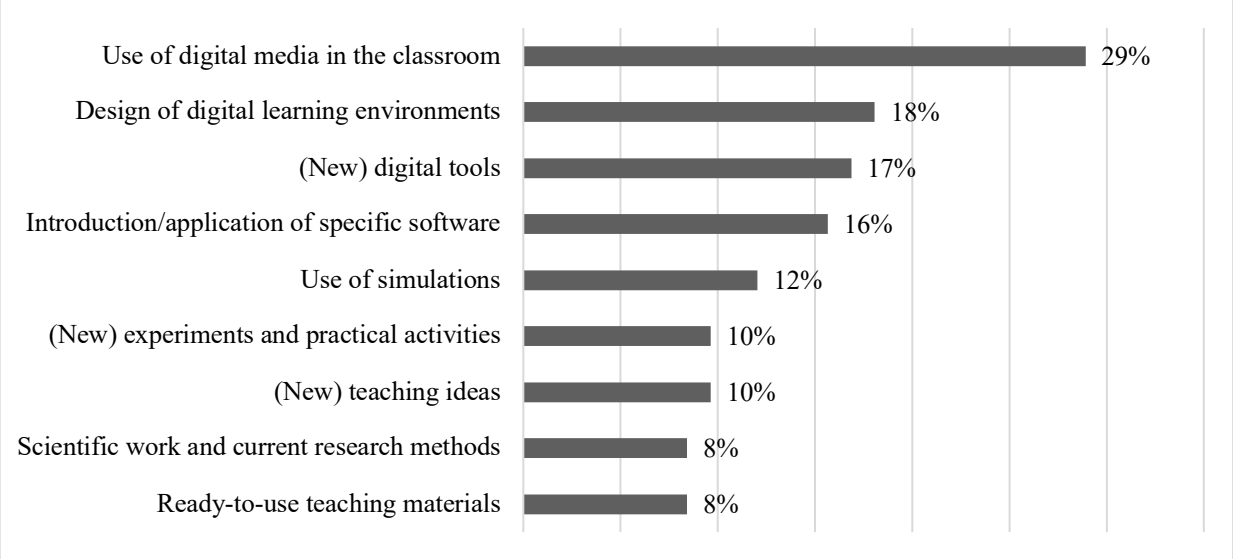
To analyse the quantitative data of the post-survey, descriptive statistics were applied. Additionally, potential changes in participants' evaluations across different PD programme iterations were examined in the context of the design-based research approach. Here, comparisons between the first and second iteration were conducted for PD programmes that were implemented more than once, as not all programmes were offered in multiple iterations. Given the ordinal scale level and small sample sizes, Mann-Whitney U tests were applied.

Results

Pre-Survey

Data was collected from 107 teachers (83 teachers in pre-surveys and 48 teachers in post-surveys) across all eight PD programmes. The results of the pre-survey indicate that teachers most frequently expected the aspects shown in Figure 3 from digitalisation-related PD programmes in out-of-school labs. In some cases, individual teachers' responses were assigned to multiple categories.

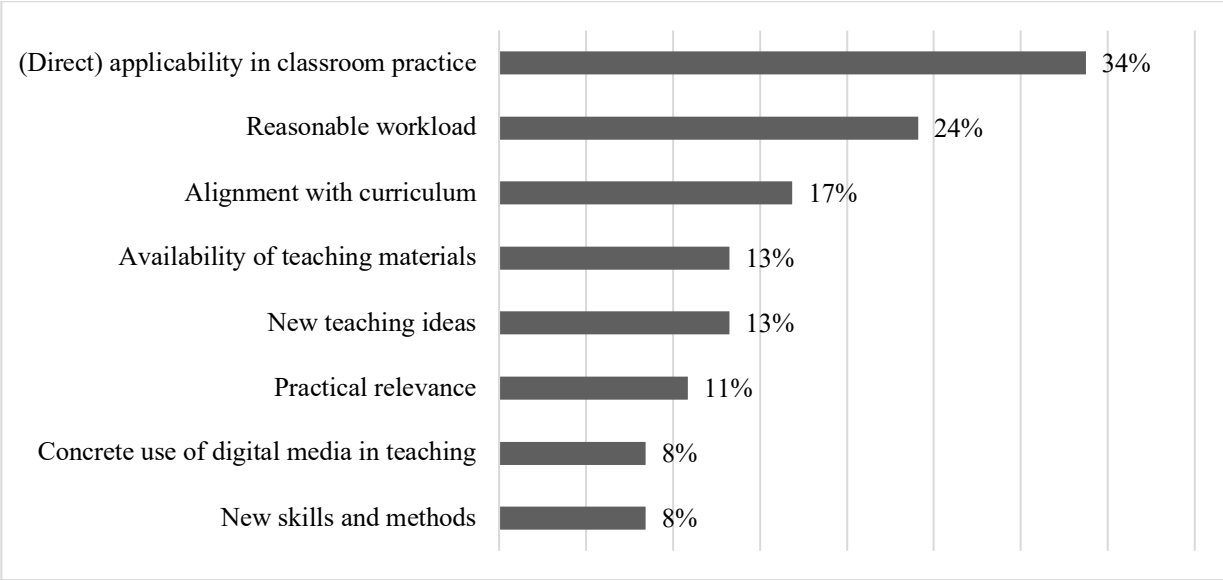
Figure 3: Most frequently expected aspects from digitalisation-related PD programmes in out-of-school labs mentioned by participating teachers (*n* = 83).



Among the most frequently mentioned expectations, many responses were related to digitalisation, e.g.: information on using digital media in the classroom (29%), designing digital learning environments (18%), and discovering new digital tools (17%). However, participants also expressed expectations that were not directly related to ICT, such as engaging in practical activities and (new) experiments (10%), exploring new teaching ideas (10%), engaging with scientific methods and current research practices (8%), and receiving ready-to-use teaching materials (8%).

In response to the question on relevance, the surveyed teachers stated that they consider a PD programme relevant to their teaching if it addresses the aspects shown in Figure 4.

Figure 4: Aspects that make a PD programme relevant to teachers (*n* = 83).



Across all topics, the most frequently mentioned criterion for relevance was that the PD content should be directly applicable to classroom practice (34%), and that it should involve a reasonable amount of time and effort (24%). Teachers also emphasized that content should be aligned with the curriculum (17%) and offer real-world or practical relevance for students (11%). Additional aspects mentioned included the desire for new teaching ideas (13%) and opportunities to learn new skills and methods (8%). As already seen in the expectations, teachers considered a PD programme to be relevant if it provided ready-to-use teaching materials (13%) and gave practical guidance on how to implement digital media in the classroom (8%). A few teachers also mentioned aspects such as strategies for differentiated instruction (4%) and opportunities for collegial collaboration (2%).

Post-Survey

In the Post survey, 48 teachers rated the relevance of programme regarding digital teaching with a mean value of $M = 4.78$ ($SD = 1.19$, $\alpha = .900$) on a scale range from 1 for negative perception to 6 for positive perception. Cognitive activation regarding digital teaching was scored with a mean value of $M = 4.02$ ($SD = 1.26$, $\alpha = .910$) and sustainability regarding digital teaching with a mean value of $M = 4.62$ ($SD = 1.13$, $\alpha = .896$) on the same scale range.

The PD programmes in the subjects of Mathematics, Chemistry, Physics, and Biotechnology were each conducted more than once. Table 2 presents the descriptive post-survey results for the three evaluated scales for the first and second iteration of these PD programmes.

Table 2: Post-survey results of the PD programmes with more than one iteration: Mathematics, Chemistry, Physics, and Biotechnology.

	First Iteration (n = 19)		Second Iteration (n = 33)	
	M	*SD*	*M*	*SD*
Relevance	4.67	1.26	4.96	1.02
Cognitive Activation	3.68	1.23	4.33	1.22
Sustainability	4.64	0.93	4.86	0.98

To examine whether these observed differences between the two PD iterations were statistically significant, Mann-Whitney U tests were conducted for each of the three scales. The comparison revealed no statistically significant difference in perceived relevance between the first and second

iteration (U = 282.00, Z = -0.606, p = .545). Similarly, ratings regarding sustainability did not differ significantly between the two iterations (U = 273.00, Z = -0.772, p = .440). For cognitive activation, the difference did not reach statistical significance but showed a trend toward higher ratings in the second iteration (U = 212.50, Z = -1.923, p = .054).

Discussion

Initial insights of the pre-survey demonstrate that effective PD for teachers must balance theoretical knowledge with practical applicability, which is consistent with findings of other studies (Darling-Hammond et al., 2017; Rzejak et al., 2023). Additionally, teachers demand subject-specific digital tools, digital learning environments, and use of specific software. From a theoretical perspective, the pre-survey results contribute to existing research on PD by highlighting the importance of subject-specific digital competence training (Mishra & Koehler, 2006). The findings further underscore the need for continuous professional learning in digital environments that are closely connected to authentic, practice-oriented learning settings. These findings support the growing body of literature on TPACK and its role in effective teaching in the digital age (Fernandes et al., 2020; Thoms et al., 2022). Additionally, the results provide insights into the user side of PD, capturing aspects such as the perception, interpretation, and utilisation of the offered learning opportunities (Lipowsky & Rzejak, 2015). In this regard, the findings underline the relevance of teachers' subjective relevance judgements for understanding PD effectiveness, as design features alone may not determine how learning opportunities are perceived and taken up.

The scales used in the post-test, adapted from Rzejak et al. (2023), have shown to be a suitable instrument for evaluating the perceived relevance, cognitive activation, and sustainability of out-of-school labs related PD regarding digital aspects. The positive trend in the results provides initial indications that the expectations of teachers on the offer side could be addressed. In particular, the descriptively higher ratings observed in the second iteration, especially with regard to cognitive activation, may point towards iterative improvements within the design-based research process, although these differences did not reach statistical significance.

However, the findings need to be interpreted with caution. First, the results are based on teachers' self-reports and rely on relatively small sample sizes, which limits the generalisability of the findings. Second, the use of open-ended items in the pre-survey constitutes a further limitation. Teachers were likely to articulate only one or two aspects they perceived as most important, while other potentially relevant dimensions remained unmentioned. As a result, aspects such as collegial collaboration appear only marginally in the resulting category system, although they are well established in the literature as important features of effective PD (Lipowsky & Rzejak, 2015; 2021). This should therefore not be interpreted as a lack of relevance, but rather as an effect of prioritisation processes in teachers' spontaneous responses.

Conclusion And Outlook

In conclusion, this study provides insights into teachers' perceptions of digitalisation-related PD programmes conducted in out-of-school labs. The findings show that participating teachers particularly value PD formats that combine subject-specific digital tools with practical applicability and curricular relevance. Overall, the participating teachers reported positive perceptions of the PD programmes with regard to relevance, sustainability, and cognitive activation. However, cognitive activation was rated comparatively lower, indicating a potential area for further development.

By explicitly focusing on the teachers' perspective, this study extends previous research on PD in out-of-school labs, which has predominantly addressed design features and facilitator

perspectives (Lüsse et al., 2025). The results underline the importance of teachers' subjective relevance judgements in understanding PD effectiveness, thereby supporting the offer-and-use model of PD. Moreover, the descriptively higher ratings observed in the second implementation cycle suggest that iterative refinements within a design-based research approach may contribute to perceived improvements in PD quality. Due to the limited number of participants, this assumption needs further research.

Taken together, the findings highlight the potential of out-of-school labs as innovative learning environments for digitally supported teacher PD, particularly when PD offers are closely aligned with teachers' professional needs and classroom realities.

Looking ahead, several areas warrant further investigation. Future research should examine the longer-term impact of such PD programmes, particularly regarding the transfer of acquired digital competencies into classroom practice. Furthermore, as highlighted by Lipowsky and Rzejak (2015), the role of PD facilitators deserves closer attention. Investigating facilitators' perspectives, professional backgrounds, and attitudes towards digitalisation may provide valuable insights into factors influencing PD effectiveness.

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EUROPEAN SCIENCE EDUCATION RESEARCH ASSOCIATION ESERA 2025 Copenhagen

Assessing The Impact Of Lesson Study-Based Professional Development On Spatial Skills Of Primary Students

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This study evaluates a structured professional development (PD) program aimed at enhancing primary students' spatial ability by equipping teachers with targeted instructional strategies. As the final cycle of a design-based research (DBR) framework, it assesses student outcomes to determine PD effectiveness. The PD program, implemented through lesson study, guided 24 teachers in integrating spatial reasoning into STEM instruction using hands-on activities, visualization tasks, and spatial problem-solving exercises. Pre- and post-tests administered to 345 students in grades 1–3 showed significant gains, particularly in spatial visualization, followed by mental transformation and spatial orientation. Findings highlight the effectiveness of PD in fostering spatial ability and underscore the need for structured spatial ability instruction in early STEM education.

Keywords: Spatial ability, professional development, primary education

Introduction

This study examines the impact of a structured professional development (PD) program on enhancing primary school students' spatial ability by supporting teachers in integrating spatial ability into instruction. As the final cycle of a design-based research framework, it evaluates student outcomes as a measure of PD effectiveness. Spatial ability—the capacity to visualize, manipulate, and reason about objects in space—is a critical cognitive skill linked to success in STEM education (Uttal et al., 2013). Despite its importance, it remains underrepresented in primary curricula (Cheng & Mix, 2014). Research shows that PD programs focusing on spatial reasoning equip teachers with effective instructional techniques, such as hands-on activities, visualization tasks, and spatial problem-solving exercises (NRC, 2006). This study provides empirical evidence on how teacher PD improves student performance in spatial tasks, including mental transformation, spatial orientation, and spatial visualization, demonstrating the broader impact of targeted teacher training on STEM-related cognitive skills (Wai et al., 2009).

Theoretical Framework

This study explores the impact of PD on student learning and the role of spatial ability in STEM education. Using lesson study (LS) (Lewis et al., 2009) within a design-based research (DBR) framework, teachers collaborated to refine spatial reasoning lessons. The study applies the IMTP framework (Sims et al., 2023) to assess PD effectiveness through insights, motivation, techniques, and embedding practices. Results show that teachers deepened their understanding, improved instructional strategies, and enhanced student gains in mental rotation and spatial orientation. By linking teacher learning to student outcomes, this research highlights the value of structured, collaborative PD in fostering STEM-related skills.

Aim Of The Study

This study evaluates the impact of a structured teacher PD program on student spatial performance in primary STEM education. As the fourth cycle of a DBR project, it examines how improved instructional practices from LS translate into student gains, identifying which spatial components show the most and least improvement. Findings offer insights into the effectiveness of PD in fostering spatial ability in young learners by addressing the following research questions:

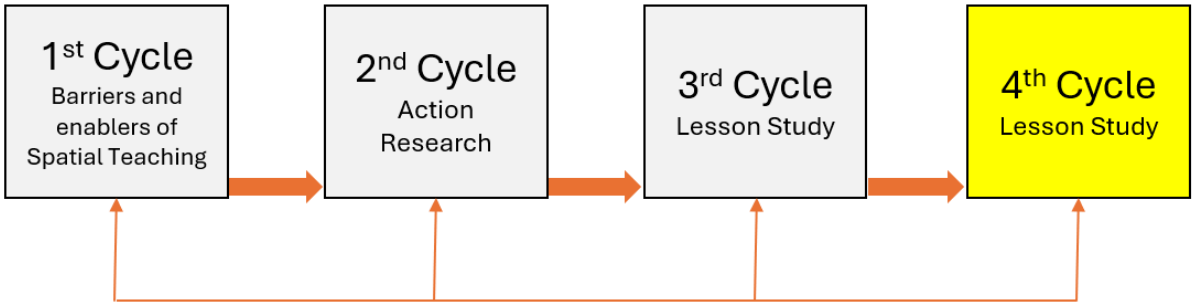
1.To what extent did students' spatial performance improve after teachers implemented the PD-based instructional strategies, as measured by pre- and post-test results?

2.Which spatial ability components (spatial visualization, mental transformation, spatial orientation) showed the most significant improvements, and which demonstrated the least change after the PD intervention?

Method

This study is part of a broader DBR project aimed at developing and refining a PD model to enhance spatial ability instruction in primary STEM education. Specifically, this paper reports on the fourth cycle of DBR, which focuses on evaluating the impact of the PD program on student spatial performance (see Figure 1). The study was conducted in two primary schools, involving 24 female teachers from grades 1–3 (with teaching experience ranging from 4 to 47 years) and their 345 students—104 first-grade students, 115 second-grade students, and 126 third-grade students. The PD program was designed to equip teachers with strategies for integrating spatial reasoning into STEM subjects, ensuring that the enhanced pedagogical practices translate into measurable student learning outcomes. The PD intervention followed a structured four-phase workshop model: (1) Reflection, where teachers analysed their current teaching practices; (2) Input and Modeling, where they explored core spatial ability components—spatial visualization, mental transformation, and spatial orientation—through expert-led activities; (3) Discussion, where collaborative engagement facilitated deeper pedagogical insights; and (4) Outcome Formulation, where teachers co-developed lesson plans incorporating spatial reasoning tasks. To embed these strategies into real classroom practice, the PD utilized a LS framework (Lewis et al., 2009), in which teachers worked in triads or groups of five to collaboratively design, implement, observe, and refine spatially enriched lessons for mathematics, science, and technology. This iterative process ensured systematic role rotation, promoting shared learning and continuous instructional improvement. To measure the impact of the PD program on student spatial performance, pre- and post-tests assessing key spatial ability tasks (e.g., mental transformation, spatial visualization, spatial orientation) were administered to the students of participating teachers. These tests provided quantitative evidence of changes in student performance, while teacher reflections and lesson study observations offered qualitative insights into how improved instructional practices influenced student learning. By systematically evaluating both student performance outcomes and teacher pedagogical growth, this study assesses the effectiveness of the designed PD model in enhancing spatial ability development in primary STEM education.

Figure 1. The Design-Based Research (DBR) process and the focus of the fourth cycle.



Findings

Findings For Research Question 1

A dependent t-test (paired t-test) was conducted for each grade level to compare students' pre- and post-test spatial performance scores. The results indicate a statistically significant improvement in spatial ability across all three grade levels. Below is a summary of the findings:

Table 1. Summary of Pre- and Post-Test Spatial Performance Scores Across Grade Levels,

Grade Level	Mean (Pre)	SD (Pre)	Mean (Post)	SD (Post)	t (df)	p-value	Significance
1st Grade	18.67	2.76	20.88	2.4	5.88	< .00001	Significant
2nd Grade	17.76	3.30	20.32	2.47	6.99	< .00001	Significant
3rd Grade	11.63	3.79	14.94	4.80	7.56	< .00001	Significant

*p < 0.05. SD: Standard deviation

All p-values are below the significance threshold ($p < .05$), indicating that the observed improvements in spatial ability are unlikely to be due to chance.

- First Grade: Students showed a significant improvement in spatial test performance after their teachers implemented PD-based instructional strategies ($M_{pre} = 18.67$, $SD = 2.76$; $M_{post} = 20.88$, $SD = 2.40$). The paired t-test yielded $t(104) = 5.88$, $p < .00001$, confirming a statistically significant increase.
- Second Grade: A notable improvement was also observed among second-grade students ($M_{pre} = 17.76$, $SD = 3.30$; $M_{post} = 20.32$, $SD = 2.47$). The dependent t-test result of $t(115) = 6.99$, $p < .00001$ supports the effectiveness of the instructional intervention.
- Third Grade: Students in third grade exhibited the most substantial improvement relative to their baseline scores ($M_{pre} = 11.63$, $SD = 3.79$; $M_{post} = 14.94$, $SD = 4.80$). The paired t-test analysis ($t(126) = 7.56$, $p < .00001$) confirms a significant positive shift in their spatial ability.

Findings For Research Question 2

This study also aimed to determine which spatial ability components (spatial visualization, mental transformation, spatial orientation) showed the most significant improvements after teachers implemented instructional strategies from the PD program. Since Grades 1 and 2 used the same test, the analysis was conducted for these two groups, while Grade 3 was excluded due to a different test format. To evaluate improvements, a dependent t-test (paired t-test) was conducted for each spatial ability component within Grades 1 and 2. The results indicate that all three spatial ability components demonstrated statistically significant improvements ($p < .05$) following the intervention. However, the degree of improvement varied across components as illustrated in table 2.

Table 2. Summary of Pre- and Post-Test Results for Spatial Ability Components in Grades 1 and 2.

Grade	Spatial Ability Component	Mean (Pre)	SD (Pre)	Mead (Post)	SD (Post)	t (df)	p-value	Significance
1st Grade	Spatial Visualization	6.21	1.21	7.13	1.05	5.73	<.00001	Significant
	Mental Transformation	6.43	1.25	7.11	0.96	4.74	<.00001	Significant
	Spatial Orientation	6.00	1.34	6.70	1.15	4.25	<.00001	Significant
2nd Grade	Spatial Visualization	5.95	1.28	6.73	1.12	6.10	<.00001	Significant
	Mental Transformation	6.14	1.43	6.90	1.08	5.79	<.00001	Significant
	Spatial Orientation	5.67	1.59	6.71	1.17	7.31	<.00001	Significant

Spatial visualization showed the greatest improvement across both grades, with first graders increasing from $M = 6.21$ to $M = 7.13$ ($t = 5.73$, $p < .00001$) and second graders from $M = 5.95$ to $M = 6.73$ ($t = 6.10$, $p < .00001$), indicating the strongest effect of PD-based strategies on spatial visualization. Mental transformation also showed substantial gains, with first graders improving from $M = 6.43$ to $M = 7.11$ ($t = 4.74$, $p < .00001$) and second graders from $M = 6.14$ to $M = 6.90$ ($t = 5.79$, $p < .00001$), though effect sizes were slightly lower than for spatial visualization. Spatial orientation showed the least improvement but remained significant, with first graders increasing from $M = 6.00$ to $M = 6.70$ ($t = 4.25$, $p = .00005$) and second graders from $M = 5.67$ to $M = 6.71$ ($t = 7.31$, $p < .00001$), suggesting a relatively stronger initial ability in this area, leading to smaller gains compared to the other two components.

Discussion

The significant gains in pre- to post-test scores highlight the effectiveness of structured PD interventions in enhancing students' spatial reasoning, a key skill for STEM learning and problem-solving (Newcombe, 2010). RQ1 findings indicate that students in Grades 1–3 showed

significant improvements in overall spatial ability after PD-based instructional strategies were implemented, supporting research on the benefits of early and sustained spatial training (Wai, Lubinski, & Benbow, 2009). The success of these strategies is likely due to their emphasis on hands-on, visualization-based, and problem-solving approaches, which strengthen spatial cognition (Lowrie, Logan, & Ramful, 2017). RQ2 analysis of spatial ability components in Grades 1 and 2 revealed that spatial visualization showed the greatest improvement, followed by mental transformation, while spatial orientation exhibited the least change. The strong gains in spatial visualization align with studies on the cognitive benefits of explicit training in mental imagery (Taylor & Hutton, 2013), while improvements in mental transformation support evidence on the malleability of spatial skills in classroom instruction (Levine et al., 2012). The smaller gains in spatial orientation suggest either a higher initial proficiency or a focus on static rather than dynamic spatial tasks (Verdine et al., 2014).

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EUROPEAN SCIENCE EDUCATION RESEARCH ASSOCIATION ESERA 2025 Copenhagen

Shifting Teachers' Knowledge And Confidence For Engaging Students In Science Practices From A Program Designed By Scientists And Pedagogical Experts

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The Next Generation Science Standards (NGSS) in the United States call for engaging students in authentic science through the practices of scientists (NRC, 2013). One challenge to translating the NGSS into the classroom is the lack of resources and programs that model and feature the scientific practices. This study describes a 10-day teacher professional development (PD) designed by both science researchers and education experts. As part of the PD, teachers developed and implemented a classroom research project (CLRP) curriculum plan centered on authentic scientific practices in molecular biology and the unique contexts of their schools. Following implementation, teachers delivered a presentation of their curriculums and the impact of implementing the curriculum on their instructional practices. In this mixed-methods study, we sought to answer two research questions: 1) To what extent do teachers who implement CLRPs increase their knowledge about how to align their teaching practices to the NGSS? and 2) To what extent do teachers who implement CLRPs increase their skills to engage students in scientific practices in their classroom? The findings indicate that teachers can increase their knowledge and confidence for aligning their teaching practices to NGSS. In addition, teachers also increased their skills and confidence for engaging students in science practices, particularly developing and using models. This study highlights the potential of teacher PD programs to enhance teachers' understanding and incorporation of science practices into their instruction, thereby promoting more authentic science learning experiences for students.

Keywords: Science practices, professional development, teacher education

Introduction

The Next Generation Science Standards (NGSS) in the United States call for engaging students in authentic science through the practices of scientists (NRC, 2013). Authentic science in the classroom involves engaging students in investigations that seek to answer scientific questions in ways that closely approximate those of scientists (Crawford, 2012, p.113). Traditional teacher education programs do not require preservice teachers to engage in scientific research (Burgin, 2020). This puts secondary science teachers at a disadvantage as most teachers lack expertise in the day-to-day practices of scientists such that they effectively integrate these practices into their science curriculum (Davidson et al., 2022). In particular, teachers' lack of understanding about scientific models and modelling limits their ability to engage students in developing and using models in the classroom (Gilber & Justi, 2016).

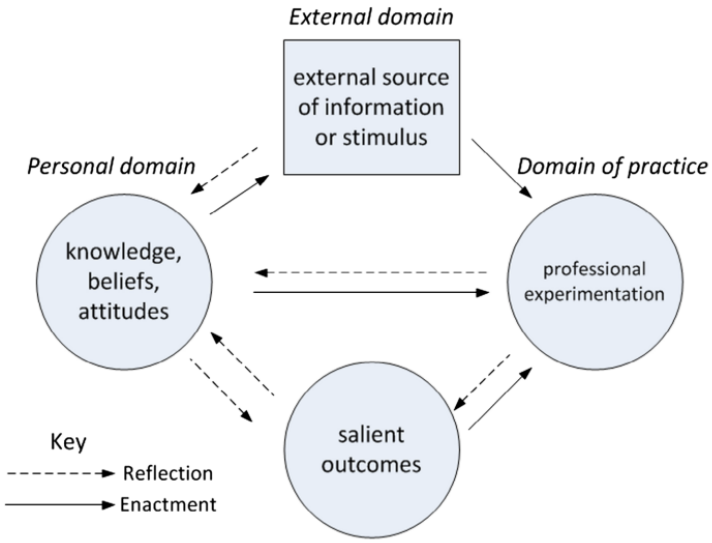
Successful implementation of high-quality instructional materials requires ongoing and sustained professional learning for teachers (Bybee & Chopyak, 2017). Biology curricular and instructional materials are loaded with visual representations and can be presented in a variety of ways (Dries et al., 2017). Yet, students are not explicitly taught how to interpret these representations and move between them as they are commonly used for exposure (Dries et al., 2017).

One strategy to increase teachers' knowledge of science practices and support the development and implementation of practices-based curriculum is to engage teachers in professional development (PD) involving both science education faculty and science research faculty.

Theoretical Framework

Clarke and Hollingsworth's (2002) teacher professional growth model served as the conceptual framework for designing the PD program and conducting this study (Figure 1), as it describes key elements for examining individuals or groups of teachers in the context of a particular PD program.

Figure 1. Clarke and Hollingsworth's (2002, p. 951) interconnected model of teacher professional growth.



Specific Aim And Research Questions

The program included a multi-disciplinary team with expertise from education, biochemistry, and medicine. The PD program was designed to engage high school biology and biochemistry teachers in molecular modelling science techniques and pedagogical strategies for classroom instruction.

The specific aim of the project was to create biomolecular science curriculum centred on authentic science practices. As part of a 10-day PD, teachers developed and implemented a classroom research project (CLRP) curriculum plan centred on authentic scientific practices in molecular biology and the unique contexts of their schools. Following classroom implementation, teachers delivered a presentation of their curriculum plans and the impact of implementing the curriculum on their instructional practices.

With this aim, we sought to answer two research questions:

1) To what extent do teachers who implement CLRPs increase their knowledge about how to align their teaching practices to NGSS?
2) To what extent do teachers who implement CLRPs increase their skills and confidence to engage students in scientific practices in their classrooms, with an emphasis on developing and using molecular models?

Methods

This mixed-methods study was designed to characterize teachers' understanding of science practices and how implementing their CLRPs increased their skills and confidence for engaging students in more authentic science practices.

Professional Development Program

The two-week summer PD program was designed to increase teachers' knowledge of the scientific practices, specifically *developing and using models*, *analysing and interpreting data*, and *communicating information*, involved in molecular biology research. The summer workshop was divided into three parts 1) content knowledge development, 2) research and design, and 3) curriculum development. During the content knowledge development portion of the workshop, teachers learned the fundamentals of protein folding, the technique of x-ray crystallography, and explored an example molecular story of insulin and diabetes. Teachers engaged in *modelling of* by using classroom molecular modelling kits. These kits were used to help build teachers' content knowledge, to map between a real molecule (insulin) and the representation being used, and to prepare teachers to engage in modelling for later in the workshop. Teachers engaged in *modelling for* through learning how the structures of proteins are determined using x-ray crystallography and how scientists make decisions based on data to generate a 3D model of a protein. Models generated from x-ray crystallography are published in a freely accessible public database, the Protein Data Bank (PDB). Using various PDB insulin files, teachers used JUDE, a molecular visualization program, to examine the active form of insulin, the monomer. Then, teachers looked at the dimer, and finally how insulin was stored as a hexamer. The workshop culminated with an open JUDE investigation looking at different designer insulins. Teachers worked in small groups to answer structure-function questions about how insulin was altered to control blood sugar in diabetes. Then, teachers transitioned to working with Penn State researchers to explore and develop a molecular story based on the work of Penn State research lab. The teachers developed a project poster and presented their findings at the workshop. Finally, in the curriculum development portion of the workshop, teachers collaborated with molecular biology researchers, science education faculty, and other participants in the cohort to develop a CLRP for their high school students around a protein of their choice.

Teacher Participants

Twenty-four teachers were recruited to participate in the program over three different cohorts. Teaching experience varied, with 42% of teachers reporting they had been teaching for 11 to 20 years. Teachers also indicated that they taught a range of subjects, the most common being biology (67%). Of the 24, 13 provided data pertaining to the implementation of their CLRPs.

Data Collection And Analysis

Multiple sources of data were collected for this mixed-methods study, including:

- Teacher surveys (CLRP survey)
- Teacher artifacts (CLRP documents and presentations slides)

Quantitative analyses of data collected from closed-ended survey items were conducted, including descriptive statistics and paired samples t-tests to determine whether the mean differences between participants' ratings from before to after implementation of the CLRP were statistically significant.

Qualitative analysis of teacher artifacts included a priori coding and comparative analysis. A priori coding involved applying predefined codes of the science practices to identify the presence of specific practices in their CLRPs (Creswell & Creswell, 2018) and implementation presentations. Open coding was conducted to identify shifts related to skills and confidence for engaging students in authentic science. Themes were identified using a thematic analysis approach (Clarke et al., 2015). The project team triangulated the findings from the various data sources.

Limitations

Several limitations exist in the study. Participating teachers self-selected to take part in the program, so the sample is skewed to teachers that are apt to participate in PD they chose, which limits generalizability to larger groups of teachers that do not select to participate in PD. In addition, we were only able to collect teacher-reported data, not the observations of implementation in the classroom.

Findings

Research Question 1

The teachers demonstrated knowledge of designing instructional plans for engaging students in science practices. In the CLRP documents, all teachers described how students would engage in molecular modelling practices to investigate a particular molecule (e.g., proteins, nucleic acid) of interest. Most teachers (67%) selected molecules for their CLRP that differed from those investigated during the workshop to attend to their students' interests and teaching context. This choice to explore other molecules indicates teachers' increased confidence in supporting students to use modelling practices to investigate molecules novel to teachers and students. Teachers also integrated the CLRP activities into their existing curriculum to provide scaffolding, align with state-level education standards, and incorporate molecular biology practices used by researchers.

Teachers reported increased knowledge in the three target NGSS science practices after implementing their CLRPs relative to before implementation (Figure 2). Their self-rated knowledge about all three practices increased from before to after the CLRP implementation, particularly regarding developing and using models. The mean differences between their pre- and post- ratings were all statistically significant based upon the results of the paired sample t-tests.

Figure 2. Teachers' self-rated knowledge in target NGSS science practices before and after implementing the CLRPs in Years 2, 3, and 4 (n=13).

Teachers also reported increased confidence in various techniques and teaching practices after implementing their CLRPs (Figure 3). Their self-rated confidence in all areas increased from before to after their CLRP implementation, particularly in their confidence in creating a new molecular story and the technical aspects of JUDE programming. The mean differences between their pre- and post-ratings were all statistically significant based on the results of paired samples t-tests.

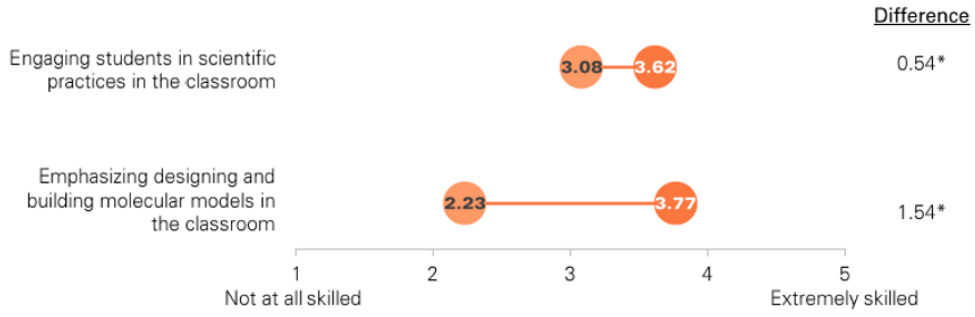
Figure 3. Teachers' self-rated confidence before and after implementing the CLRPs in Years 2, 3, and 4 (n=13).

*Statistically significant paired samples *t*-test at $p < .05$.

Research Question 2

Teachers reported increased skills to engage students in scientific practices and molecular modeling after participating in the CLRPs relative to before (Figure 4). After implementing their CLRPs, teachers rated their skills in engaging students in scientific practices and molecular modeling before and after implementation. Their self-rated skills increased from before to after the CLRP implementation, particularly their skills in emphasizing designing and building molecular models in the classroom. The mean differences between their pre- and post-ratings were all statistically significant based on the result of paired sample t-tests.

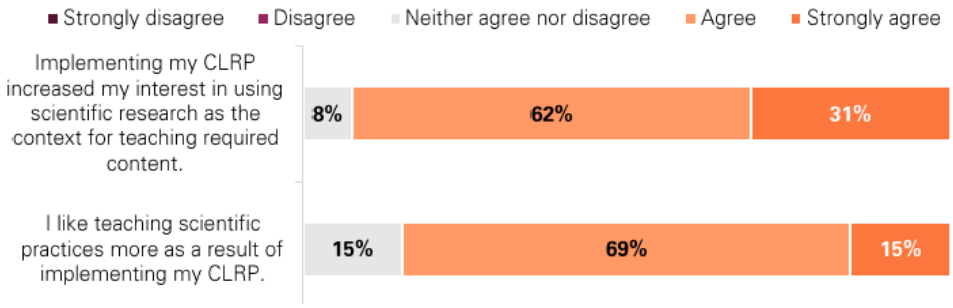
Figure 4. Teachers' self-rated skills in engaging students in scientific practices and molecular modeling before and after implementing the CLRPs in Years 2, 3, and 4 (n=13).



*Statistically significant paired samples *t*-test at $p < .05$.

After implementing their CLRPs, teachers rated the extent to which implementing their CLRPs increased their interest in and enjoyment of using scientific research and practices in their teaching (Figure 5). Most teachers agreed (62%-69%) or strongly agreed (15%-31%) with these statements, indicating that implementing the CLRPS not only increased teachers' skill in engaging students in scientific practices and molecular modelling, but also impacted teachers' interest in and enjoyment of using these practices in their teaching.

Figure 5. Teachers' ratings of the impact of implementing their CLRPs on their interest in and enjoyment of using scientific research and practices in Years 2, 3, and 4 (n=13).



In the post-implementation presentation slides, teachers identified specific NGSS science practices that students engaged in during the CLRP. All of the teachers described engaging students in developing and using models along with other science practices (e.g., asking questions, obtaining, evaluating, and communicating information). However, the practice of analysing and interpreting data was not mentioned. Multiple teachers described the challenges of scaffolding the learning of reading and understanding research papers and programming in JUDE to create 3-D visualizations of molecules.

Discussion And Implications

One of the key insights from this study is that sustained professional development can increase teachers' knowledge of and confidence for aligning their teaching practices with NGSS standards. With PD designed to engage teachers in current science practices and support their development of practices-based curriculum appropriate for their teaching context, teachers successfully incorporated science practices into their existing curriculum plans and identified molecules of interest relevant to their specific teaching situations. This alignment between NGSS standards and classroom implementation is particularly evident in teachers' adoption of the scientific practices—a central component of the three-dimensional learning framework outlined in NGSS. Consistent with Capps and Crawford (2013), sustained PD can help teachers to better understand these scientific practices and translate standards into meaningful classroom experiences.

The study revealed that teachers increased their skills and confidence for engaging students in science practices, particularly in developing and using models. This finding is unsurprising given that modeling was the central practice explored throughout the workshop. The depth of teachers' self-reported implementation and the transfer to their unique teaching contexts demonstrates meaningful learning. Our study supports the findings of Justi and Gilbert (2002) in that teachers identified the substantial scaffolding required for students to engage authentically in the developing and using models practice in molecular biology. We also found that teachers reported a high degree of interest and enjoyment in using scientific research and practices in their teaching. This positive affective response aligns with findings from Kreifels et al. (2021), who found that teachers participating in a 12-month inquiry-based learning professional development program developed increased confidence, possessed positive attitudes toward implementation, and felt that barriers could be controlled. Such affective outcomes are particularly important, as teacher confidence and interest often predict sustained implementation of new instructional approaches (Desimone, 2009).

The study also revealed teachers increased their skills and confidence for engaging students in science practices (Davidson et al., 2022), particularly *developing and using models* (Gilber & Justi, 2016). While teachers identified the challenges of scaffolding required for students to engage in these practices, the teachers reported a high degree of interest and enjoyment for using scientific research and practices in their teaching.

Several directions for future research emerge from this work. First, longitudinal studies are needed to examine whether teachers' increased confidence and skills in implementing science practices persist over time and become embedded in their regular instructional routines. Second, future research should investigate student learning outcomes associated with teachers' implementation of practices-based instruction following this type of PD. While teacher knowledge and confidence are important intermediate outcomes, the ultimate goal is enhanced student understanding of both disciplinary core ideas and the nature of scientific inquiry. Third, research is needed to identify the specific components of the PD model that were most effective in promoting teacher learning and implementation. Understanding which elements, whether the authentic research context, sustained duration, collaborative curriculum development, or other factors, most strongly influence outcomes would allow for more efficient and targeted PD design. Finally, exploring how this model might be adapted for teachers in different contexts (e.g., varying levels of resource availability, diverse student populations, different grade levels) would support broader dissemination and impact.

In conclusion, this study highlights the potential of carefully designed teacher PD programs to enhance teachers' understanding and incorporation of science practices into their instruction, thereby promoting more authentic science learning experiences for students. The findings suggest that when teachers engage directly in scientific practices within their own subject-matter contexts and receive sustained support for curriculum development, they can successfully align their instruction with NGSS standards and develop the confidence to implement challenging pedagogical approaches. Continued collaboration between science researchers and pedagogical experts is essential to bring such authentic science learning experiences to secondary classrooms at scale.

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Section: Lifelong Learning And Career Development For Science Teachers

EUROPEAN SCIENCE EDUCATION RESEARCH ASSOCIATION ESERA 2025 Copenhagen

Science Teacher Educators In Professional Learning Communities: Exploring The Possibilities Of Creating New Organizational Routines

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One of the ways to support the professional development of science teachers in schools is through the establishment of professional learning communities (PLCs). But what about the professional learning of science teacher educators? The aim of this paper is to analyse and discuss the following two research question: How is it possible to organise professional learning communities for science teacher educators? How do science teacher educators experience their participation in such professional learning communities? We explore these questions building on an ethnographic study of a national program in science teacher education (NAFA) involving all science teacher educators in Denmark. We use a practice theoretical and Routine Dynamics perspective to understand how the new PLC-routines are created in the program. We identify some of the strengths and weaknesses of working together in this type of routines and discuss possible implications for the further development of professional learning communities for science teacher educators.

Keywords: Science Teacher Educators, Professional Learning Communities, Organizational Routines

Introduction

The purpose of this paper is to analyse and discuss how science teacher educators participate in professional learning communities. In the recent 30 years professional learning communities (PLCs) have become a certain way of organising professional collaboration in educational institutions worldwide (Albrechtsen et al., 2022; Lee et al., 2022; Moosa et al., 2024; Nguyen et al., 2024; Olsson, 2019; Sai & Siraj, 2015; Stoll et al., 2006). Beginning in North America in the 1990's and building on theories of the learning organization and organizational learning, the research primarily focused on school-based teacher collaboration. Since, the practice of and research on PLCs has expanded to also include other participants, like the whole school, the whole school district, research-practice partnerships and collaboration across educational organizations (Admiraal et al., 2021; Mundry & Stiles, 2009; Stoll & Louis, 2007). The interorganizational collaboration is also conceptualised as 'professional learning networks' (PLN) (Carpenter et al., 2022; Poortman et al., 2022; Prenger et al., 2021). Some research focusses on the more subject-specific parts of PLCs such as how they play a role in the professional development of science teachers (Blonder & Vescio, 2022; Dogan et al., 2016; Eylon et al., 2020; Jones et al., 2013; Vossen et al., 2020), but it is still limited how much we know about their significance for the professional development of science teacher educators. Science teacher educators are expected to develop different forms of knowledge (Mork et al., 2021) and strengthen their 'pedagogical content knowledge' (Hume et al., 2019), but how they share it with colleagues and how they build a 'pedagogy of teacher education' together (Loughran, 2006) is not something we know much about. We want to contribute with knowledge on how this is made possible in local PLCs and across organizational boundaries such as PLNs. These questions concerning the professional development of science teacher educators lie behind this paper presentation, but it can also be seen in the light of a more general and current interest in research on the professional learning of

teacher educators as our empirical data stem from the Danish teacher education system (Kelchtermans et al., 2018; Klink et al., 2017; Ping et al., 2018; Vanderlinde et al., 2021).

The empirical background is a 4-year longitudinal study (2022-2025) of an emerging interorganizational network of PLCs in the field of science teacher education in Denmark called *Naturfagsakademiet* (NAFA) (English translation: *Danish Academy of Science Education* - For a short English introduction see the homepage: About NAFA - NAFA). NAFA is a national program supported by Novo Nordisk Fonden and VILLUM FONDEN with more than 25 million Euros in the period from 1st August 2021 to summer 2028. The main objective of NAFA is to enhance knowledge sharing and knowledge creation among science teaching professionals at different educational levels, both teacher education and primary and lower secondary schools. A central part of this is the organising of local and national PLCs at all the six university colleges in Denmark. In NAFA, a PLC is defined *as a committed and systematic inquiring community between a group of educators, who share experiences and knowledge from practice through inquiry and reflective dialogues focused on students' learning.* We will use NAFA as a case to analyse and discuss the following two research questions:

How is it possible to organize professional learning communities for science teacher educators?

How do science teacher educators experience their participation in such professional learning communities?

Method

Theoretically we build on a practice theoretical approach and a Routine Dynamics lens (Feldman, 2021; Kiær & Albrechtsen, 2024) to understand, how the science teacher educators in NAFA enact the new organizational routines in the form of 'PLC-routines' (Spillane et al., 2016). PLC-routines have a function as 'coupling mechanisms' (Spillane et al., 2011) in and between university colleges and are routines meant to support the professional learning of the science teacher educators (Horn & Little, 2010)

We explore how the idea and the actual performance of the PLC-routines constitute each other, and how different artifacts play a role in this creation of routines, using the analytic framework of Feldman & Pentland (2003). The empirical material in this paper stems from an ongoing ethnographic study that began in 2023 where we follow and observe the enactment of the PLC-routines at both online and physical meetings among the science teacher educators. Currently we have collected 61 hours audio- and video-recordings, and we have 2318 pages of transcribed data, including fieldnotes. We have also interviewed some of the science teacher educators (N=7) asking them about their experiences of participating in the PLCs of NAFA. In our paper presentation we will analyse and discuss these observations and interviews to understand how the PLCs – as defined in NAFA – are enacted in practice as new organizational routines.

Preliminary Findings

Our preliminary findings show how there is an ongoing process of building the new PLC-routines where there are examples of science teacher educators trying to find balance between the ostensive and performative aspects of the PLC-routines. The Routine Dynamics perspective enables us to describe and understand these processes in depth. We see a potential in using this approach for further investigation of the organization of professional learning opportunities for science teacher educators (see also Wolthuis et al., 2022). Our analysis of the empirical material from our observations and interviews also show how different artifacts are used to organise the PLCs and establish the new routines such as the use of a Teams platform with different folders, inspirational materials, collaboration agreements, theme reports, meeting agendas etc. The

interviewed science teacher educators explain how they work together, when and how often they meet, facilitate the meetings, invite experts to the meetings, include pre-service and in-service students in their activities, plan instruction, make decisions and communicate with science teacher educators from other university colleges. The PLC meetings we have observed are quite different in how they are enacted although they all work with the same overall theme (such as technological literacy) and we also see how the part of doing inquiries together seems limited. In the paper presentation we will discuss the possible implications of the findings for the further development of PLC-routines for science teacher educators.

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Fostering STEM Teacher Identity Development In Primary And Secondary Science Education

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Integrated STEM (Science, Technology, Engineering, and Mathematics) education is promoted as an approach that equips students to address complex real-world challenges. Its implementation, however, requires teachers to move beyond single-subject instruction and adopt interdisciplinary roles and practices. This study examines the development of STEM teacher identity among primary and secondary science teachers participating in a 7-month professional development programme. Guided by the Dynamic Systems Model of Role Identity (DSMRI), the research explores shifts in teachers' self-perceptions, beliefs, goals, and perceived action possibilities. Twenty-four in-service teachers engaged in collaborative curriculum design, reflective activities, and classroom implementation of STEM modules, supported by mentors within learning communities. Data were collected through questionnaires, reflective journals, and recordings of community meetings. Findings revealed differentiated trajectories of professional identity development. Many teachers, particularly at the secondary level, underwent transformational change, marked by expanded perceived action possibilities, more integrated epistemic understandings of STEM, and greater use of design-oriented, inquiry-driven practices. Others followed a more elaborative trajectory, extending existing practices with interdisciplinary elements while retaining aspects of prior disciplinary orientations. Across both groups, self-perceptions remained comparatively stable, suggesting that changes in professional self-understanding may require more sustained identity-focused support.

Keywords: STEM education, Teacher education

Introduction

Contemporary global challenges are increasingly understood as complex, wicked problems characterized by the interaction of environmental, technological, and social factors. Addressing such challenges in educational settings requires interdisciplinary teaching approaches that highlight the critical links between distinct disciplines and provide opportunities for students to apply knowledge and relevant skills to complex problem situations in ways that mirror the interconnected nature of scientific, technological, and societal decision-making (Schpakow & Zambak, 2025).

The integrated STEM (Science, Technology, Engineering, and Mathematics) approach operationalizes this interdisciplinarity in classroom practice. Integrated STEM denotes instructional designs that deliberately interconnect disciplinary and interdisciplinary knowledge and practices around authentic, real-world problems (Kelley & Knowles, 2016). Despite variation across frameworks, descriptions of integrated STEM tend to converge on a set of core pedagogical principles, emphasizing learning through inquiry and problem-based processes, engaging students in authentic STEM practices, and positioning engineering design as a central organizing structure for instruction (Johnson & Czerniak, 2023; Roehrig et al., 2021). When coherently enacted, integrated STEM enables students to apply interdisciplinary knowledge across contexts and supports competencies necessary for addressing complex challenges such as systems thinking, problem framing, and evidence-informed decision making.

Implementing integrated STEM requires teachers to move beyond subject-matter knowledge. This, in turn, calls for targeted professional development that supports pedagogical design, collaboration, and work with open-ended problems. In this study we position teacher identity as

the principal analytic lens for understanding professional development (Avraamidou, 2014). Compared with purely knowledge-centred or competence frameworks, an identity lens is more inclusive; it encompasses teachers' beliefs, self-perceptions, and motivations, thereby acknowledging the personal and professional meanings teachers attach to instructional change (Russ, et al., 2016). Although there is no universally accepted definition of what teaching identity consists of, the literature consistently portrays it as encompassing the ways teachers understand and position themselves in relation to teaching, learning, and subject matter, while also being shaped by how they are recognized by others within their professional contexts (Avraamidou, 2014). Rather than a fixed personal attribute, teaching identity is understood as a dynamic and evolving construct that develops over time through experience. It comprises multiple, interacting sub-identities formed through engagement with diverse social, institutional, and disciplinary contexts, and it plays a significant role in shaping teachers' instructional choices (Beauchamp & Thomas, 2011; Capps, Crawford, & Constas, 2012).

From the perspective of identity, in order for teachers to effectively implement the integrated STEM teaching approach they must develop a strong STEM teacher identity; that is, a professional stance that goes beyond teaching subjects in isolation and instead embraces the integration of knowledge, practices, and purposes across disciplinary boundaries (El Nagdi et al., 2018). A teacher with a strong integrated-STEM identity is characterized by a coherent professional self-image as an educator who works across STEM disciplines and is recognized as such within their professional community. This identity is further reflected in strong self-efficacy for designing and implementing inquiry-driven STEM learning experiences, as well as in a redefinition of their role from content delivery toward the facilitation of student-centred problem solving. Moreover, teachers who enact such an identity demonstrate a willingness to experiment, tolerate ambiguity in their instructional practice, and engage in sustained collaboration with colleagues across grades and disciplinary boundaries, practices that are essential in interdisciplinary and design-oriented learning environments (El Nagdi et al., 2018, Galanti & Holincheck, 2022).

A tool that in this study helped us operationalize this complex identity construct is the Dynamic Systems Model of Role Identity (DSMRI; Garner & Kaplan, 2019). The model starts from a socio-cultural view of learning emphasizing the importance of the particular social and educational context in shaping teachers' identity. DSMRI conceptualizes identity as a dynamic system composed of five interacting components: (i) teachers' ontological and epistemological beliefs - in other words, assumptions about knowledge and learning; (ii) purposes and goals teachers set for their instruction; (iii) self-perceptions and role definitions - including perceived competence and self-image; (iv) perceived action possibilities - the behaviours and strategies teachers consider feasible in their context and (v) action which represents the enactment of identity in practice. In this context, STEM education professional development will manifest itself in the enrichment of STEM teacher identity components with new elements, as teachers encounter new practices, expectations, and forms of collaboration. Depending on the number and strength of these changes, shifts in identity are characterized as transformation, elaboration or stagnation (Gunersel et al., 2016).

Building on the conceptualization of teacher identity as a dynamic construct, this study aims to explore how primary and secondary science teachers develop a STEM teacher identity while participating in a professional development program focused on climate-change education. In particular, we examine how this development is reflected across the components of the DSMRI model and how identity tensions emerge, are negotiated, and potentially mediate or constrain these processes of change.

To address this aim, the study is guided by the following central research question:

What shifts occur in the ways teachers manifest aspects of STEM teacher identity during the aforementioned professional development program?

Methodology

Research Context And Design

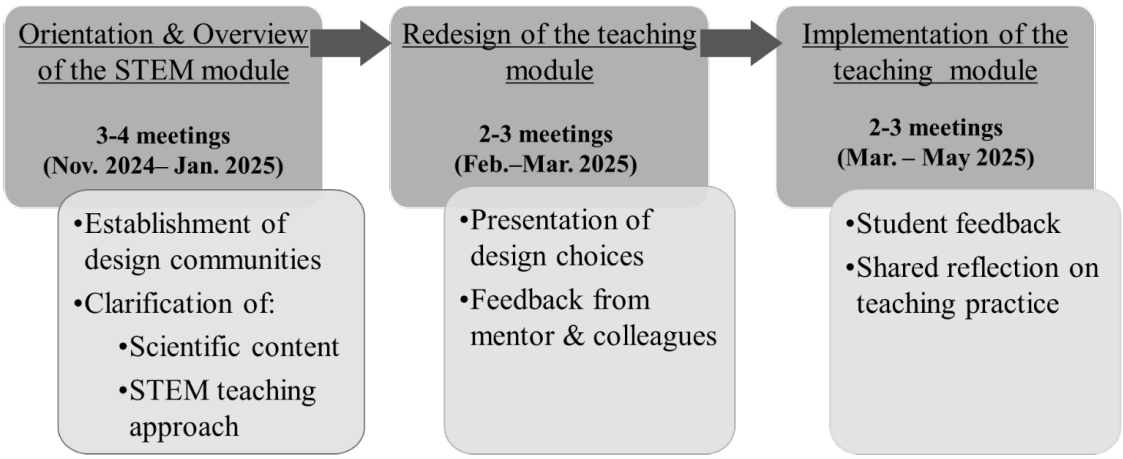
This study was conducted within the STEM-id project (https://stem-id.edc.uoc.gr/en/) aimed at supporting teachers in integrating STEM approaches with climate-change content into coherent classroom lessons across educational levels. The project was structured in two interrelated phases that combined material development with teacher professional learning.

In Phase A, eight mentor teachers engaged in a community of practice with STEM education and climate science researchers. Within this collaborative setting, they were introduced to key principles of integrated STEM and climate change education and jointly developed an integrated STEM teaching module on climate change. The teaching module was deliberately designed as a flexible, educative resource. Its modular structure allowed teachers to select, reorder, combine, or omit activities according to their classroom context. It also included prompts for adaptation, optional extensions, and differentiation strategies across grade levels.

Building on this groundwork, Phase B — which constituted the context of this study — engaged twenty-four teachers (twelve primary and twelve secondary) in a structured professional development program focused on STEM teacher identity. The program was centred on the module developed in Phase A and supported by the mentors within design communities. Participating teachers varied in teaching experience (between 3 and 18 years) and none had prior formal training in climate education or integrated STEM approach.

The professional development program lasted approximately seven months and was organized around a series of synchronous community meetings complemented by asynchronous design and reflection activities. Training occurred within designing communities, where the teachers worked collaboratively and received ongoing support from the eight mentors. An overview of this sequence of collaborative activities - from initial orientation, through redesign of teaching materials, to classroom implementation and reflection - is presented in Figure 1.

Figure 1. Phased structure of the professional development programme.



More specifically, the program began with group meetings aimed at clarifying key scientific concepts, introducing the integrated STEM approach, and familiarizing teachers with the module. Teachers then selected activities, designed and synthesized their own lesson plans, received

feedback from mentors and peers, and subsequently implemented those plans in their classrooms, allowing them to iteratively connect design decisions with classroom realities.

Data Collection

To capture teachers' perspectives and evolving understandings throughout this process, multiple qualitative data sources were collected. Primary data included teachers' open-ended initial questionnaires and the reflective journals they kept throughout the professional development process. The initial questionnaires elicited teachers' prior experiences, beliefs, and expectations regarding STEM and climate-change teaching, thereby providing a baseline for identity-related analysis. The reflective journals captured teachers' ongoing sense-making, challenges, and evolving perceptions of their role during the design and implementation phases. In addition, learning community meetings were audio-recorded, capturing discussions and feedback among mentors and teachers, as well as moments of negotiation, uncertainty, and emerging shared understandings.

All participants provided informed consent for their participation and for the recording of meetings, and all data were anonymized prior to analysis.

Data Analysis

Table 1. Coding scheme identifying manifestations of DSMRI identity components.

DSMRI Components	Subcategories
Ontological & Epistemological beliefs	Statements expressing knowledge & beliefs about: - Scientific content of Climate change - S-T-E-M disciplines connections - STEM teaching approach - Students
Self-perceptions	Statements on: - Teaching role (facilitator/mentor) - Self-efficacy for STEM teaching
Purpose & Goals	Statements expressing teaching objectives: - Learning scientific content - Solving real-world problems - Applying knowledge - Environmental awareness - Sustainability values
Perceived action possibilities	Statements expressing: - implementation of experimental activities - engineering design activities - use of ICT

For data analysis we used qualitative content analysis methods with an abductive coding strategy, combining theory-driven and data-driven codes to iteratively refine categories (Bryman, 2016). For coding we used DSMRI components and related subcategories. These categories captured

teachers' oral or written statements about ontological and epistemological beliefs, self-perceptions, purposes and goals, and perceived action possibilities, as summarized in Table 1.

To examine identity development over time, we characterized the level of change in each DSMRI component as radical, moderate, or no change, following an adaptation from Gunersel et al. (2016). Radical change denotes a component that was initially limited or absent and later became extensively developed; moderate change denotes an initially developed component that became more elaborated; no change denotes no meaningful difference across time, based on comparisons between early and later data sources for each teacher.

Combining these component-level judgments produced an overall profile for each teacher that reflects the pattern and intensity of change across DSMRI components. These profiles, summarized in Table 2, enabled cross-case comparison while preserving attention to individual developmental trajectories.

Table 2. Criteria used to characterise the overall pattern of identity change.

Identity change	Description
Transformation	At least 4 radical change occurs in a DSMRI component
Elaboration	At least 4 moderate changes occur in DSMRI components
Stagnation	No change or fewer than 4 moderate changes occur in DSMRI components

Results

Changes in STEM Teacher Identity Components

Table 3. Distribution of primary and secondary teachers by level of change across DSMRI identity components.

Identity components	Radical change		Moderate change		No Change	
	Prim	Sec	Prim	Sec	Pri	Sec
Ontological & Epistemological beliefs	5	2	6	4	4	3
	Total: **7**		*Total:* **10**		*Total:* **7**	
Purpose & goals	2	4	8	6	2	2
	Total: **6**		*Total:* **14**		*Total:* **4**	
Perceived action possibilities	4	8	5	2	3	2
	Total: ***12***		*Total: 7*		*Total:* **5**	
Self-perceptions	2	2	5	3	5	7
	Total: **4**		*Total:* **8**		*Total:* **12**	

This section presents the findings concerning changes in teachers' STEM teacher identity as they participated in the professional development program. Guided by the DSMRI framework, the analysis focuses on how different components of role identity were manifested and reconfigured over time.

Table 3 presents the distribution of teachers who manifested shifts in STEM teacher identity across the DSMRI components. Each component shows a different degree of change, reflecting both teachers' initial identity configurations and the extent of reorientation required to engage with the integrated STEM approach.

Examination of these distributions reveals three notable patterns. First, the largest number of radical changes occurred in perceived action possibilities - twelve teachers in total - and these radical shifts were concentrated among secondary teachers (eight of twelve). This pattern suggests that many secondary teachers reconsidered what forms of classroom activity they viewed as feasible, moving toward more complex and design-oriented STEM practices. For example, a secondary teacher moved from a constrained, low-effort plan (just to show a video) to a concrete classroom enactment involving student data collection and iterative testing. In the initial questionnaire she stated:

> As I teach in a high school and class time is very limited, I have not taught anything related [to climate change] before. I would probably show a video to give them some food for thought.

In contrast, during the redesign phase she wrote in her reflection journal:

> For the climate change solutions, students will build a system to measure real-time CO_2 emissions so they can test the effectiveness of their constructions.

In DSMRI terms, this illustrates an expansion of perceived action possibilities, as the teacher envisioned and intended hands-on, authentic STEM tasks that students can carry out within class time, rather than only passive exposure. At the same time, this shift in lesson planning implies a redefinition of her instructional role, from content deliverer toward facilitator of student-centred inquiry, a transition that aligns closely with the identity of an integrated-STEM teacher.

A second pattern concerns shifts in ontological and epistemological beliefs, observed in seven teachers, the majority of whom were primary educators, suggesting a reorientation in how they conceive what STEM teaching is for and how knowledge is produced in those lessons. For example, one teacher initially defined STEM as "all about the educational robotics competitions the kids take part in". After collaborative design meetings he reframed STEM as:

> It's not enough to know Math, Physics, etc; you must support students in their constructions within the engineering design cycle so they can apply what they know.

This contrast points to a shift from associating STEM primarily with discrete activities toward viewing it as a learning process that involves guided design and the application of knowledge.

In addition to these more pronounced transformations, numerous teachers exhibited moderate shifts in their instructional purposes and related beliefs. These changes often took the form of extending existing goals - such as content understanding - to include broader aims related to problem solving, real-world relevance, or environmental awareness, while still retaining elements of their prior instructional orientation.

By contrast, self-perceptions emerged as the most stable DSMRI component, with twelve cases showing no change, and secondary teachers particularly reporting stable, high STEM teaching self-efficacy. This relative stability may reflect the resilience of self-evaluative beliefs, which are

often less susceptible to short-term change, or a tendency toward optimistic self-assessment in self-reported data.

Patterns Of STEM Teacher Identity Change

When considering the aggregated patterns of identity change across DSMRI components, most identity shifts were classified as Transformation, with secondary teachers comprising the larger share of those transformations - consistent with the concentration of radical changes we saw in action possibilities and epistemic framing.

Table 4. Overall patterns of STEM teacher identity change among participating teachers.

Types of identity change	Primary	Secondary	Total
Transformation	5	8	13
Elaboration	6	3	9
Stagnation	1	1	2

Primary teachers more often followed an Elaboration trajectory, which may be associated with their prior use of cross-domain and project-based practices that could be extended rather than fundamentally replaced. In contrast, secondary teachers - often working within more rigid disciplinary structures and curriculum constraints - appeared to undergo more visible reconfigurations of their instructional repertoires, resulting in Transformation profiles.

Finally, two teachers showed no detectable change across components. These cases point to the importance of examining contextual constraints, such as workload or school-level support, as well as strongly held prior beliefs that may limit engagement with identity-related change processes.

Discussion

The findings of this study point to two distinct trajectories of teacher identity development within the professional development context. In the *Transformation* profile, teachers deepened their science knowledge, gained confidence with engineering, and adopted interdisciplinary STEM conceptions. Moreover, they reframed their instructional goals from knowledge acquisition toward skills development such as systems thinking and problem solving (Eilam, 2022), and introduced experiential and engineering, design-based activities for climate problems - a move consistent with calls to foreground engineering design as a central organizing practice in integrated STEM (Stohlmann et al., 2012). These shifts suggest a reconfiguration not only of classroom practices but also of the underlying purposes and epistemic orientations that frame teaching and can enable more coherent forms of integrated practice (Ennes et al., 2021).

By contrast, teachers classified under the *Elaboration* profile demonstrated more incremental forms of change, where mostly moderate and a few radical changes were concentrated in teachers' perceived action possibilities and in purposes and goals, while beliefs often retained disciplinary anchors that were enriched with interdisciplinary elements. In these cases, teachers expanded their instructional goals toward application and problem solving yet frequently continued to rely on established knowledge-centred routines. Such a pattern aligns with research describing additive pathways to integrated STEM, in which teachers integrate new practices into existing professional identities rather than fundamentally replacing them (Guzey et al., 2016). From an

identity perspective, this trajectory may reflect a process of negotiation, where elements of integrated STEM are accommodated within pre-existing frameworks of meaning and practice.

Across both profiles, self-perceptions appeared comparatively stable, as only a few teachers revised how they saw their role as STEM educators. The relative persistence of this component is consistent with literature suggesting that shifts in self-perception often require more explicit and sustained identity work than changes in practices or goals alone (Rushton et al., 2023).

Conclusions

Overall, this study contributes to a growing body of research that conceptualizes teacher change in integrated STEM education not merely as the adoption of new practices, but as a dynamic process of identity development shaped by the interaction between beliefs, goals, perceived possibilities for action, and professional self-perception.

In conclusion, the findings of this study suggest three interrelated implications for teacher practice and the design of professional development in integrated STEM education. First, when teachers reconceptualize STEM learning from a focus on disciplinary content toward processes and transferable skills, corresponding shifts tend to occur in classroom practice, including greater use of engineering design tasks and iterative forms of inquiry. The enactment of such practices, particularly when they were experienced as feasible and pedagogically valuable, appears to reinforce and further reshape teachers' epistemic beliefs and instructional goals, suggesting a mutually reinforcing relationship between changes in practice and teachers' developing professional identities.

Second, shifts in teachers' self-perceptions as STEM educators seem to require more targeted and explicit forms of support, such as structured reflective activities, opportunities for social recognition within professional communities, and sustained mentoring relationships.

Finally, the identification of multiple identity development trajectories highlights the need for professional development models that combine short-term support for instructional redesign with longer-term processes of identity work. Such models should be responsive to teachers' starting points, acknowledging that primary and secondary teachers may differ in their prior experiences with interdisciplinary practice, curricular flexibility, and disciplinary identification.

Ultimately, supporting teachers in adopting integrated STEM approaches requires recognizing professional learning as an ongoing process of identity development, in which changes in practice, beliefs, and self-perceptions evolve in mutually reinforcing ways over time. Future research may further illuminate how these identity trajectories are sustained across longer time scales and varied educational contexts.

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Didactic Dimension Of The Professional Identity Of Tunisian Physics And Chemistry Teachers

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This research explores determinants of teachers' action and the didactic dimension of professional identity in physics and chemistry teaching. Drawing on the Joint Action Theory in Didactics (Sensevy & Mercier, 2007; Sensevy, 2011), we analyse in situ classroom practices to characterise this didactic dimension. Our analytical approach combines a pragmatic analysis of teaching activity with a didactic perspective on knowledge construction. The study is based on six qualitative case studies involving Tunisian secondary school teachers, combining classroom video recordings, interviews, and curriculum analysis, with students aged 15 to 19. Results reveal recurrent instructional configurations across cases: teacher-controlled knowledge progression structured by Initiation–Response–Evaluation interactions, student activity mainly oriented towards participation, strong reliance on curricular resources, and an empirico-inductive practical epistemology.

These shared configurations are interpreted both as determinants of instructional action and as indicators of the didactic dimension of professional identity. This dimension is characterised through recurrent ways of organising knowledge, student activity, and instructional progression. The study suggests that this didactic dimension is not only constructed through classroom practices, but also contributes to orienting teachers' instructional choices, in relation with practical epistemology and joint didactic action.

Keywords: Professional identity; Joint Action Theory; Science teaching

Introduction

Research in science education has consistently shown that students' attitudes towards science—particularly physics—tend to decline during secondary schooling, affecting motivation, engagement, and learning outcomes (Osborne et al., 2003; Adesoji, 2008). These attitudes are considered a central component of scientific literacy and are closely related to students' beliefs about science and their perceived competence (OECD, 2007). Among the factors influencing these attitudes, teaching practices play a decisive role (Gauthier et al., 2005; Blazar & Kraft, 2017). Understanding how teachers organise classroom activity and introduce disciplinary knowledge therefore constitutes a major research issue.

In parallel, research on teachers' professional identity has highlighted its dynamic and situated character, constructed through practice and shaped within institutional frameworks (Dubar, 1994; Cattonar, 2001; Lasky, 2005). Professional identity both guides classroom action and is reshaped by it. In science education, several studies have underlined the influence of disciplinary epistemologies on teaching practices, particularly in physics and chemistry (Robert & Robine, 1989; Boilevin, 2013). However, relatively little attention has been paid to the didactic dimension of professional identity—that is, the way teachers relate to disciplinary knowledge and organise its transmission in classroom interactions.

The present study addresses this gap by focusing on Tunisian secondary school physics and chemistry teachers. We adopt the Joint Action Theory in Didactics (JATD; Sensevy, 2012) as an analytical framework to examine classroom practices as joint actions between teachers and students organised around knowledge. This perspective allows us to move beyond descriptive accounts of teaching activity and to infer macroscopic determinants of teacher action from

recurrent instructional configurations, including practical epistemologies and institutional framing through curricula and textbooks.

Our research is based on six qualitative case studies combining classroom video recordings, interviews, and curriculum analysis. Rather than concentrating on individual teaching styles, we identify recurrent features of practice across cases in order to characterise shared determinants of instructional action and to examine how the didactic dimension of professional identity both emerges from teaching activity and contributes to structuring it.

The study addresses the following research questions:

1. How do common characteristics of classroom practices allow us to infer determinants of teacher action in physics and chemistry teaching?
2. How do these determinants contribute to the didactic dimension of teachers' professional identity, and in what ways does this dimension act as a structuring principle of instructional action?

By articulating classroom practices with professional identity through a didactic lens, this study aims to clarify how stabilised ways of relating to knowledge and student activity organise teaching in physics and chemistry classrooms.

Theoretical Framework

Professional Teaching Identity And Its Didactic Dimension

Over the past two decades, professional identity has emerged as a major focus in educational research, conceptualised as a dynamic and situated process shaped through practice and social interactions (Knowles, 1992; Connelly & Clandinin, 1999; Dubar, 1994). Professional identity enables teachers to recognise themselves as members of a profession while being recognised as such by others (Cattonar, 2001). It encompasses shared professional norms as well as individual trajectories, negotiated within institutional and contextual constraints.

From this perspective, identity is not understood as a fixed attribute but as continuously constructed through teaching activity. It both guides classroom action and is reshaped by it (Lasky, 2005). Previous studies in subject-specific didactics have shown that disciplinary knowledge plays a central role in this construction, influencing how teachers interpret curricular prescriptions and organise learning situations (Robert & Robine, 1989; Boilevin, 2013).

In this study, we focus on the *didactic dimension* of professional identity, defined as the way teachers conceive disciplinary knowledge and organise its transmission in classroom interactions. This dimension includes teachers' epistemological orientations, their positioning in relation to knowledge, and the instructional strategies through which scientific content is made accessible to students. Rather than approaching identity through declared beliefs, we examine it through recurrent classroom practices, considering these practices as observable manifestations of underlying professional dispositions.

Joint Action Theory In Didactics

To analyse classroom practices, we adopt the Joint Action Theory in Didactics (JATD; Sensevy & Mercier, 2007; Sensevy, 2011), which conceptualises teaching and learning as a joint action between teachers and students organised around knowledge. Within this framework, didactic activity is understood as the functioning of a system composed of three interdependent components: teacher, students, and knowledge.

JATD provides conceptual tools for analysing how knowledge emerges and evolves during classroom interactions. Central among these are the notions of didactic contract and didactic

milieu (Brousseau, 1980). The didactic contract refers to the implicit expectations governing teacher–student interactions, while the milieu designates the set of material and symbolic resources that support learning activity. Changes in one necessarily imply adjustments in the other.

Didactic action is further characterised through the processes of mesogenesis (construction of knowledge objects), chronogenesis (temporal organisation of learning), and topogenesis (distribution of epistemic responsibility between teacher and students) (Sensevy, 2012). These concepts allow us to analyse how teachers structure classroom activity and position students with respect to knowledge.

In JATD, classroom activity can be modelled as a succession of learning games, during which teachers and students jointly engage with specific knowledge stakes. Learning is understood as the progressive acquisition of epistemic capacities through participation in these games.

Methodology

This study adopts a qualitative multiple case study design focusing on six secondary school physics and chemistry teachers in Tunisia. The teachers were selected to reflect variability in teaching experience, grade levels, and school contexts. Their classes involved students aged between 15 and 19 years.

Data Collection

Data were collected through a combination of classroom video recordings, teacher interviews, and document analysis. For each case, full teaching sessions were filmed, covering both theoretical lessons and practical activities. These recordings constituted the primary empirical corpus.

In addition, pre- and post-lesson interviews were conducted with each teacher in order to clarify instructional intentions and refine the interpretation of classroom interactions. Official curriculum documents and textbooks were also analysed to account for institutional framing of teaching practices.

Analytical Approach

Following a clinical approach of ordinary classrooms, the analysis aimed to identify recurrent features of practice rather than individual teaching styles. Video data were fully transcribed and organised using Transana software, allowing segmentation of classroom interactions into instructional sequences and interaction patterns.

The analytical process proceeded in four stages. First, each lesson was examined to characterise dominant modes of interaction and task structures. Second, practices were compared across cases to identify recurring patterns. Third, these patterns were interpreted in terms of didactic strategies and practical epistemologies. Finally, we inferred macroscopic determinants of teacher action—such as epistemological orientations and institutional constraints—and examined how these determinants contribute to the didactic dimension of professional identity.

In line with the Joint Action Theory in Didactics, particular attention was paid to the distribution of epistemic responsibility between teachers and students, the nature of tasks proposed, and the ways scientific knowledge was introduced and stabilised during classroom activity.

Rather than relying on teachers' declared beliefs alone, this methodology prioritises observable classroom practices as empirical indicators of professional dispositions. By triangulating video data, interviews, and curriculum materials, the study seeks to establish robust links between recurrent instructional practices and shared components of professional identity.

Results

Analysis of the six classroom case studies reveals recurrent patterns of instructional practice across physics and chemistry lessons. These patterns concern classroom discourse, the nature of student tasks, and the way scientific knowledge is constructed. Rather than isolated teaching styles, they point to shared modes of organising teaching and learning.

Teacher-Controlled Knowledge Progression: Dominance Of The IRE Pattern

Across all six cases, classroom interactions predominantly followed an Initiation–Response–Evaluation (IRE) structure (Sinclair & Coulthard, 1992). Teachers initiated exchanges through closed questions, students provided brief responses, and teachers evaluated or reformulated these answers before moving on.

In this dialogic lecture format, the progression of knowledge remained largely under teacher control. Students' contributions were mainly limited to completing expected statements or recalling previously introduced information. For example, during a chemistry lesson on acid–base titration, the teacher guided students step by step towards the expected formula, leaving little space for alternative reasoning or conceptual elaboration.

Excerpt 1 (P6, titration lesson). The interaction follows an IRE pattern in which knowledge progression is tightly controlled by the teacher

T: We performed a titration… for example… you titrated an acid with a base. What exactly are we determining when we titrate the acid? (1:32:51)

Class: …

T: At equivalence, what do we have? (1:32:55)

Class: …

T: What relation do we have? (1:33:00)

S: The number of moles. (1:33:04)

T: Yes… yes, yes. What do we have then? (1:33:10)

Class: …

T: Earlier… what did we say? (1:33:17)

Class: …

T: At equivalence, we have… as a relation… if it's a monobasic acid and a monobasic base. (1:33:24)

Class: …

T: So we say CAVA equals… (1:33:27)

Class: CbVb

T: CAVA equals CbVb. Then, from this relation, what are we going to determine? (1:33:35)

S: The number of moles of acid.

This interactional pattern ensured curriculum coverage but restricted opportunities for students to engage in deeper conceptual discussions. In this configuration, epistemic responsibility remained largely on the teacher's side, with students positioned primarily as respondents rather than as contributors to knowledge construction.

Low Epistemic Demand Of Student Tasks

A second recurrent feature concerns the nature of tasks proposed to students. In both physics and chemistry lessons, activities mainly involved reproducing experimental protocols already designed by the teacher or described in textbooks. Students carried out basic measurements

(volume, mass), mixed reagents, or observed predefined phenomena, but rarely participated in designing experiments or formulating investigative questions.

Although students were kept active through frequent questioning and hands-on manipulation, their engagement remained largely procedural. Tasks required execution rather than interpretation, and conceptual demands were limited. As a result, student activity was equated with participation, without necessarily involving knowledge construction. This procedural orientation is illustrated in Excerpt 2.

Excerpt 2 (P1, practical work). Student action is largely constrained to reproducing a protocol already prepared by the teacher

T: This is [T points with finger] sodium bicarbonate.

Scheima: Should I put it all?

T: Just a small amount.

T: Bilel, add a few drops of the sulfuric acid solution. [Bilel picks a test tube at random, the teacher intervenes] No, no, a flask [an Erlenmeyer]. You need to read the labels.

Classroom observations showed that students followed step-by-step instructions with little opportunity to modify procedures or explore alternative explanations. This organisation supported technical familiarity with laboratory practices but offered few occasions to engage with scientific inquiry as a process of hypothesis generation and testing. Overall, student engagement was high in terms of participation, yet its epistemic value remained low: being active does not necessarily mean building knowledge.

Empirico-Inductive Construction Of School Science

Across cases, scientific knowledge was systematically introduced through observation-based situations drawn from experiments, textbook activities, or videos. Lessons typically began with concrete phenomena, such as chemical reactions (e.g., zinc and copper sulfate), stoichiometric transformations illustrated by indicator colour change, inertia observed through space-probe videos, wave propagation via elastic-string vibration, concentration through tasting sugar solutions, or acids–bases through everyday examples (heartburn and antacids).

These activities were followed by teacher-led generalisations, during which scientific relations or definitions were formalised. Students were expected to move from observation to accepted conclusions, without being invited to formulate hypotheses, explore alternative explanations, or engage in theoretical modelling. Across the six classrooms, opportunities for questioning results, comparing interpretations, or examining underlying assumptions remained limited. As a consequence, scientific knowledge was presented primarily as a set of established facts derived from empirical observation rather than as a process involving uncertainty, argumentation, and conceptual construction.

Taken together, these recurrent instructional configurations point to an empirico-inductive epistemology in which knowledge appears to emerge directly from observable phenomena and experimentation. Within this framework, science is framed as stable and authoritative, constraining students' engagement with scientific reasoning as a dynamic and dialogical practice.

Recurrent Classroom Practices

Taken together, the six case studies reveal four recurrent features of classroom practice:

- a dialogic lecture format structured by IRE interactions;

- teacher-driven progression of knowledge;
- student tasks characterised by low epistemic demand;
- inductive construction of school science based on experiments or textbook examples.

These shared patterns suggest common ways of organising teaching and learning in physics and chemistry classrooms, beyond individual differences between teachers.

Taken together, these recurrent classroom practices point to shared ways of organising knowledge, student activity, and instructional progression. In line with our analytical framework, we now move from the description of these practices to the identification of macroscopic determinants of teacher action, in order to examine how they contribute to the didactic dimension of professional identity.

Discussion

The results make it possible to move beyond the description of classroom practices to infer shared determinants of teacher action across the six cases. These determinants concern teachers' relationship to knowledge, their conception of student activity, the institutional framing of teaching through official curricula and textbooks, and their practical epistemology. Together, they constitute central components of the didactic dimension of professional identity.

First, teachers position themselves primarily as holders and transmitters of knowledge. This is evidenced by the dominance of IRE interactions and teacher-controlled progression of scientific content. Within the Joint Action Theory in Didactics, this configuration corresponds to a topogenesis in which epistemic responsibility remains largely on the teacher's side. Students are invited to respond but rarely to initiate or transform the knowledge at stake. Teaching is thus organised around ensuring that prescribed content is introduced and formalised, reinforcing a transmission-oriented model of instruction.

Second, student activity is consistently valued, but mainly in the sense of participation rather than inquiry. Classroom practices show that being "active" is equated with answering questions, manipulating materials, or following procedures. However, this activity carries limited epistemic weight, as tasks rarely require hypothesis formulation, interpretation, or argumentation. Student engagement therefore functions primarily as an indicator of participation rather than as a driver of knowledge construction.

Third, instructional practices are strongly structured by official curricula and textbooks. Teachers closely follow prescribed sequences and experiments, which contributes to the stabilisation of classroom routines across cases. From a didactic perspective, this institutional framing shapes both the didactic milieu and the didactic contract, orienting the organisation of tasks and the progression of knowledge.

Finally, teaching practices are underpinned by an empirico-inductive practical epistemology. Scientific knowledge is introduced through observation and experimentation and presented as a set of established relations derived from empirical evidence. Students are rarely invited to engage with theoretical modelling, alternative explanations, or the tentative character of scientific knowledge. This epistemological orientation positions science as something to be revealed through experience rather than constructed through inquiry, debate, and abstraction.

Taken together, these four determinants—teacher-centred knowledge transmission, student activity conceived primarily as participation, institutional framing through curricula and textbooks, and empirico-inductive practical epistemology—form a coherent system organising classroom action. These determinants are not interpreted here as individual teacher preferences,

but as shared professional dispositions enacted in ordinary teaching situations. Moreover, they do not only emerge from classroom practices; they also orient teachers' instructional action by stabilising recurring ways of organising knowledge and student activity. The didactic dimension of professional identity—understood as teachers' relationship to knowledge, student activity, and instructional organisation—functions as a structuring principle of teaching. It orients teachers' choices, stabilises recurring instructional configurations, and guides the way scientific content is introduced and formalised

In this sense, professional identity appears not as a set of declared beliefs, but as a stabilised configuration of practices and orientations produced and reproduced through everyday didactic activity. The didactic dimension of professional identity emerges through recurrent ways of organising knowledge, positioning students, and responding to curricular constraints. These findings support the view that professional identity both guides instructional action and is continuously shaped by it.

Conclusion And Implications

This study examined the didactic dimension of professional identity among Tunisian secondary school physics and chemistry teachers through the analysis of classroom practices using the Joint Action Theory in Didactics. By focusing on recurrent features of teaching activity across six case studies, we identified four shared determinants of instructional action: teacher-centred knowledge transmission, student activity conceived primarily as participation, institutional framing through curricula and textbooks, and an empirico-inductive practical epistemology.

These determinants are inferred from recurrent instructional configurations and constitute shared components of the didactic dimension of professional identity. They structure classroom interactions and stabilise particular ways of engaging with scientific knowledge beyond individual teaching styles. Professional identity thus appears as a stabilised configuration of didactic practices enacted in ordinary teaching activity and continuously reproduced through recurrent ways of introducing knowledge, distributing epistemic responsibility, and positioning students with respect to scientific inquiry. Importantly, the didactic dimension of professional identity does not merely emerge from teaching activity; it also acts as a determinant of instructional action. Through shared orientations towards knowledge, student participation, and epistemic responsibility, teachers mobilise stabilised professional dispositions that organise classroom activity and shape the progression of scientific content. From a theoretical perspective, this study contributes to research on teacher professional identity by grounding it in observable didactic practices and by showing how macroscopic determinants of action can be inferred from classroom interactions. The JATD framework proved useful in linking instructional organisation with practical epistemologies, offering a situated account of identity construction in science teaching. The findings also have important implications for teacher education and professional development. Making these determinants explicit may support teachers in reflecting on their epistemological orientations and instructional routines. Professional learning initiatives could build on such reflexive work to foster alternative ways of engaging students in knowledge construction, particularly by strengthening inquiry-based approaches and promoting greater epistemic diversity in classroom discourse. In this perspective, teacher–researcher cooperation within design-based approaches, such as cooperative didactic engineering (Sensevy & Bloor, 2019), offers promising avenues for supporting professional evolution while remaining coherent with curricular requirements.

Several limitations must be acknowledged. The study is based on a limited number of cases within a single national context, restricting generalisability. Future research could extend this approach to comparative studies across educational systems to examine how different institutional

configurations shape the didactic dimension of professional identity. Longitudinal and intervention-based designs would also help clarify how these determinants evolve over time and how targeted professional development might support more inquiry-oriented science teaching practices. By articulating recurrent classroom practices with practical epistemologies and institutional framing, this study contributes to a didactic understanding of how professional identity is constructed—and how it structures teaching activity—in physics and chemistry classrooms.

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