

Job Shadowing Across Boundaries: Collaborative Learning between Chemistry Pre- and In-Service Teachers

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ABSTRACT

This case study examined a job shadowing intervention embedded within a Community of Practice (CoP) involving pre-service and in-service chemistry teachers in Germany. The aim was to explore job shadowing as a boundary-crossing learning format in teacher education and to analyse participants' perceived learning, collaboration, and awareness of systemic interconnections within the educational ecosystem. A mixed-methods case study design was used, combining Likert-scale questionnaires with qualitative open-ended responses. Findings indicated that participants experienced job shadowing as highly valuable, characterised by eye-level exchange, reciprocal perspective-taking, and strong mutual engagement. Pre-service teachers reported enhanced professional identity and career orientation, while in-service teachers highlighted reflective renewal and new instructional perspectives. Both groups emphasised the importance of cross-institutional networking between university, school, and Science, Technology, Engineering, and Mathematics -related contexts. A key contribution was a recursive multi-level model integrating micro (individual learning), meso (CoP interaction), and macro (educational ecosystem) levels. The results suggested that these levels interact through feedback loops, producing a self-reinforcing learning system rather than linear knowledge transfer. The study sought to advance research on CoP and boundary crossing by showing how job shadowing can foster connected, multi-level teacher professional development.

KEY WORDS: Continuous professional development, job shadowing, STEM education teachers

INTRODUCTION

In Germany, teacher education is traditionally divided into three distinct phases: University-based teacher education, the preparatory training (*Referendariat*), and the subsequent professional practice as an in-service teacher, often accompanied by requirements for continuing professional development (CPD). Although this multi-phase structure aims to ensure comprehensive professional preparation and lifelong learning, a central challenge lies in the fragmentation of responsibilities across these phases. Different institutions, stakeholders, and governance structures are responsible for each stage of teacher education, often resulting in limited coordination and communication between them. This fragmentation is particularly critical because professional learning in teacher education depends on cooperation, exchange, and shared reflection across institutional settings (Gräsel et al., 2006).

Furthermore, the organization and implementation of these phases differ considerably between the federal states (*Bundesländer*), leading to heterogeneous structures, varying standards, and inconsistent opportunities for professional exchange. As a consequence, overlaps and repetitions in content may occur, while at the same time important connections between theory, practice, and professional development remain underdeveloped. Exchange between the phases is often not

systematically intended and may even be perceived as having limited practical value by the actors involved. Sustained cooperation and shared experiences across phases can support continuous professional identity development and strengthen theory-practice integration (Wenger, 1998).

Against this background, the present study seeks to address and suggest idea to overcome these structural barriers. The case study aims to establish meaningful connections between the different phases of teacher education and to explore how collaboration and exchange across institutional boundaries can create mutual benefits for all participants involved. By fostering dialogue and shared learning between university-based education, preparatory training, and in-service professional development, the study contributes to discussions on coherence and continuity in teacher professionalization.

Theoretical Background

The concept of Communities of Practice (CoP) has become increasingly relevant in discussions about teacher professionalization, particularly in contexts where educational systems are characterized by institutional fragmentation and limited collaboration between different phases of teacher education (Gräsel et al., 2006). In Germany, teacher education is traditionally divided into phase 1: University studies, phase 2: Preparatory training, and phase 3: Subsequent in-service professional development. While these phases are intended

to support continuous professional growth, they are often institutionally separated and only loosely connected. Given these hurdles, CoP provides a promising theoretical framework for understanding how collaborative learning structures can overcome institutional boundaries and foster coherence across different stages of teacher education.

The concept of CoP has been originally developed by Lave and Wenger (1991) and later expanded by Wenger (1998). CoPs are groups of individuals who share a common domain of practice and engage in collective learning through ongoing interaction. Within CoPs, learning is not confined to formal instruction but emerges through participation, dialogue, and shared experience (Wenger, 1998; Brown and Duguid, 1991). A central assumption of this perspective is that learning is fundamentally social and situated within authentic contexts rather than occurring solely as an individual cognitive process (Brown et al., 1989). From this perspective, situated learning plays a key role in professionalization: learning takes place through participation in real professional practices, where meaning is constructed in interaction with more experienced members of the community (e.g., Farnsworth et al., 2016). In this process, learners move from legitimate peripheral participation toward more central forms of participation. In teacher education, this means that pre-service teachers gradually develop a more realistic and practice-oriented understanding of the profession by engaging in authentic teaching contexts. In-service teachers play a crucial role in this process, acting as gatekeepers of practice and as translators between theoretical knowledge and its practical application in schools (Alvarez Alvarez, 2015). According to Wenger (1998), CoP consists of three core dimensions: domain, community, and practical experience. The domain refers to a shared area of interest or expertise, such as Science, Technology, Engineering, and Mathematics (STEM) education or pedagogical development. In teacher education, this domain may include STEM teaching, inclusive education, or innovative pedagogical approaches. The community describes the social relationships that enable mutual engagement, while practical experience refers to the shared repertoire of routines, tools, and strategies that develop over time through joint activity. Building on this perspective, the concept of Boundary Crossing and Boundary Objects (Akkerman and Bakker, 2011) adds an important analytical dimension for understanding collaboration between different institutional contexts such as universities, schools, and industry. These contexts represent distinct practice fields with their own logics, norms, and expectations. In this framework, activities such as job shadowing can be understood as boundary-crossing processes, where participants jointly move across institutional and epistemic boundaries. Within such processes, boundary objects (e.g., structured observation tasks, reflective prompts, or guided discussion formats) serve as mediating tools that enable communication and shared understanding across different contexts. However, research emphasizes that the quality of boundary-crossing is crucial: Only when this is supported by structured reflection and

meaningful interaction does it lead to genuine learning, rather than remaining at a purely observational level. This emphasis on reflection is further supported by Experiential Learning Theory (Kolb, 1984), which conceptualizes learning as a cyclical process consisting of four stages: concrete experience, reflective observation, abstract conceptualization, and active experimentation. In the context of teacher education, this model highlights the importance of systematically processing practical experiences. In-service teachers as well as university educators can play a key role in structuring and deepening these reflection processes, ensuring that classroom observations and teaching experiences are transformed into professional knowledge rather than remaining isolated events (Cuddapah and Clayton, 2011).

In addition to these theoretical perspectives, the role of Mentoring and Co-Learning is essential for understanding collaborative learning across different phases of teacher education. Unlike traditional hierarchical mentoring models, contemporary approaches emphasize co-constructive relationships, in which both parties contribute to and benefit from the exchange. Student teachers gain orientation, professional socialization, and access to practical knowledge, while experienced teachers benefit from new perspectives, up-to-date theoretical input, and critical reflection on their own practice. This reciprocal learning process further strengthens the idea of CoP as spaces of mutual development rather than one-directional transmission of knowledge (Wenger, 1998).

Within STEM education, CoPs have gained increasing attention as mechanisms for promoting educational reform and professional innovation. STEM education is inherently interdisciplinary and often requires collaboration across traditional subject boundaries. As a result, teachers frequently face challenges related to integrating knowledge, pedagogical approaches, and disciplinary cultures. CoP can support teachers in navigating these complexities through collaborative learning and collective reflection. Townley (2020) argues that CoPs can function as professional learning communities that support the development of integrated STEM education. According to the author, STEM education involves multiple intersecting epistemologies and professional cultures, making collaboration essential for meaningful integration. CoPs provide spaces in which teachers can negotiate shared understandings, develop interdisciplinary teaching approaches, and collectively address challenges related to STEM implementation.

Further evidence for the effectiveness of CoPs in STEM contexts was provided by Tomkin et al. (2019), who examined how faculty CoP influenced the implementation of active learning approaches in higher education STEM courses. Their findings indicated that participation in collaborative professional communities increased the adoption of evidence-based teaching practices and promoted long-term pedagogical change. Rather than relying solely on isolated workshops or top-down reforms, CoPs created sustainable structures for professional exchange and mutual accountability. Kezar

and Gehrke (2017) additionally demonstrated that STEM-focused CoPs could contribute to broader educational reform processes by fostering institutional collaboration and scaling innovative pedagogical practices. Their study identified several mechanisms through which CoPs supported sustainable change, including disciplinary exchange, institutional networking, and cross-sector collaboration. Such findings were particularly relevant for contexts like German teacher education, where institutional fragmentation often hindered systematic collaboration across phases.

Recent research also emphasized the role of CoP in teacher identity development within STEM education. A study by Yang et al. (2025) found that teachers who actively participated in STEM CoP developed stronger professional identities and greater confidence in interdisciplinary teaching. Participation in collaborative curriculum development, case discussions, and reflective exchange supported teachers in redefining their professional roles and competencies. Another important aspect of CoP was their potential to create sustainable professional learning environments. Traditional professional development formats were frequently criticized for being short-term, externally imposed, and disconnected from teachers' everyday practices. In contrast, CoPs emphasized ongoing participation, peer support, and collaborative knowledge production. Research on STEM faculty development showed that CoPs foster long-term engagement and encourage participants to continuously refine and share their pedagogical practices.

In the context of the present study, CoPs serve as a theoretical lens for understanding how barriers between the phases of teacher education can be reduced. By creating collaborative structures that include university educators, pre-service teachers, and in-service teachers, the study seeks to establish spaces for shared reflection, mutual learning, and professional exchange. Rather than treating the different phases of teacher education as isolated institutional domains, the CoP approach conceptualizes them as interconnected parts of an ongoing professional learning process. This perspective is particularly valuable because it shifts the focus from institutional separation toward collective participation and shared professional development. CoP may therefore contribute not only to improving communication between the phases of teacher education but also to strengthening professional identity, reducing fragmentation, and fostering sustainable innovation in STEM education.

Job Shadowing as a Format of CoP

Job shadowing is a workplace learning approach in which individuals acquire knowledge through structured observation of experienced practitioners in authentic work settings. Within contemporary organizations, it serves as an important mechanism for experiential learning, knowledge transfer, and organizational development. Thus, we explore job shadowing as a learning practice and examine its integration into CoPs as a means of strengthening collective learning and supporting the exchange of tacit knowledge (Lave and Wenger, 1991; Eraut, 2004).

In modern work environments characterized by increasing complexity and dynamic knowledge requirements, formal training alone is often insufficient to develop professional competence. Job shadowing addresses this gap by enabling situated learning, where individuals observe real-time work processes, decision-making, and professional judgment in context. Unlike instructional or classroom-based approaches, job shadowing emphasizes learning through participation and observation in everyday practice (Lave and Wenger, 1991).

From an individual perspective, job shadowing supports career orientation by providing realistic insights into roles and responsibilities, thereby enabling more informed career decisions. It also facilitates knowledge transfer by making tacit dimensions of work visible, including implicit decision-making processes, prioritization strategies, and adaptive problem-solving behaviors (Eraut, 2004; Nonaka and Takeuchi, 1995). Furthermore, it plays an important role in onboarding processes by accelerating the integration of new employees into organizational practices and reducing the risk of early-stage errors.

At the organizational level, job shadowing contributes to learning by enhancing cross-functional understanding and strengthening awareness of interdependent workflows. It allows organizations to surface and disseminate effective practices across teams, thereby supporting continuous improvement. In addition, it fosters skill development not only in technical domains but also in communication, collaboration, and behavioral competencies, which are often best learned through observation rather than instruction (Swap et al., 2001).

A typical job shadowing process can be structured into four interconnected phases. The first phase, preparation, involves defining clear learning objectives and selecting appropriate practitioners to observe. The second phase, observation, consists of accompanying professionals during their daily work activities and systematically observing tasks and interactions. The third phase, reflection, includes structured debriefing sessions aimed at interpreting observations and identifying key learning outcomes. The final phase, transfer, focuses on applying the acquired insights to the learner's own professional context.

In the context of teacher education and CPD, job shadowing is increasingly recognized as a valuable approach, particularly in STEM education, where it supports the development of both pedagogical and content-related competencies (Yang et al., 2025). Research indicates that when (pre-service and in-service) teachers engage in structured job shadowing experiences in STEM-related environments (e.g., research institutions, engineering firms, or technology-driven organizations), they broaden their understanding of the real-world relevance of STEM. These experiences contribute to a stronger professional identity and encourage teachers to critically reflect on and adapt their instructional approaches in order to better connect classroom learning with authentic STEM practices (Cavas and Mercan, 2025). Furthermore,

studies on classroom observation and professional learning in STEM education suggest that observing expert practitioners enhances teachers' professional noticing skills, particularly in relation to how complex problem-solving processes, modeling activities, and inquiry-based practices are enacted in authentic contexts (Amador and Gillespie, 2025). This form of observational learning closely aligns with the core principles of job shadowing, where attention is directed not only at what is done but also at how and why decisions are made in situ. Additional research on lesson observation in STEM teaching highlights that structured observation processes can serve as a foundation for collaborative reflection among teachers, thereby supporting collective professional learning within school-based communities and professional learning networks (Casabianca et al., 2015). Thus, the literature suggests that job shadowing functions as a powerful bridge between formal teacher education and authentic STEM practice environments. It enables teachers to connect theoretical pedagogical knowledge with real-world applications of STEM, thereby fostering more reflective, context-sensitive, and practice-oriented teaching approaches.

The concept of CoPs provides a particularly relevant framework for extending the value of job shadowing. When embedded within CoPs, job shadowing evolves from an individual learning activity into a collective learning practice. One key contribution lies in the facilitation of peer-to-peer learning, where members observe each other's work across roles and levels of experience. This horizontal learning dynamic reduces dependency on hierarchical knowledge transfer and encourages mutual exchange (Wenger, 1998). Another important aspect is the externalization of tacit knowledge. Much of professional expertise is embedded in practice and difficult to articulate explicitly. Job shadowing makes such knowledge observable, enabling members of a CoP to gain insight into different approaches to similar tasks. Over time, this contributes to a shared understanding of effective practice within the community (Nonaka and Takeuchi, 1995). Furthermore, repeated engagement in job shadowing activities supports the development of shared practices. As members observe and reflect on each other's work, implicit norms and standards begin to emerge, leading to greater alignment in how work is performed. This process also strengthens trust and collaboration, as direct exposure to colleagues' work fosters empathy and reduces siloed thinking (Brown and Duguid, 1991). Finally, job shadowing can be integrated into continuous learning cycles within CoPs. When combined with structured reflection formats such as retrospectives, peer discussions, or knowledge-sharing sessions, it becomes part of an ongoing organizational learning system rather than a 1-time intervention (Eraut, 2004).

In conclusion, job shadowing represents a simple yet powerful approach to workplace learning. Its integration into CoP enhances its impact by connecting individual experiential learning with collective knowledge creation. Through observation, reflection, and shared practice, organizations

can leverage job shadowing as a sustainable mechanism for making tacit knowledge visible and strengthening collaborative learning cultures (Nonaka and Takeuchi, 1995; Wenger, 1998).

Research Questions

In this case study, pre- and in-service chemistry teachers were brought together in a structured job shadowing format within a CoP framework. The initiative aimed to explore how job shadowing could function as a boundary-crossing learning approach across different phases of teacher education in Germany, particularly between university-based preparation and in-service professional practice. By embedding the activity in a CoP perspective, the study sought to examine how mutual observation and participation in authentic teaching contexts could support knowledge exchange, professional learning, and the development of shared practices between experienced and future teachers. In addition, a central focus was placed on participants' perceptions of the job shadowing experience, including its perceived value, challenges, and learning outcomes.

Following research questions are the core of the study:

1. How does job shadowing within a CoP support boundary crossing between pre-service chemistry teacher education and in-service teaching practice?
2. What types of professional knowledge and insights do chemistry teachers and pre-service teachers gain from observing each other's practice?
3. How do participants perceive the value and relevance of job shadowing for their own professional development?
4. In what ways does job shadowing contribute to the development of shared practices and mutual understanding within the CoP?
5. What challenges and opportunities emerge when implementing job shadowing across different phases of teacher education?

Thus, the primary aim was to explore how structured job shadowing across different phases of teacher education could facilitate boundary-crossing between university-based preparation and in-service school practice.

METHODS

This study employed a mixed-methods case study design to investigate a job shadowing intervention implemented within a CoP framework. The intervention brought together chemistry teachers and pre-service chemistry teacher students in Germany ($n = 6$).

Sample

Participants included in-service chemistry teachers and pre-service chemistry teacher education students who were invited to participate jointly in a structured job shadowing format. The design explicitly paired both groups in order to enable reciprocal observation and exchange of perspectives. The setting included authentic teaching and learning environments relevant to chemistry education, allowing participants to

engage with real-world professional practice. The study involved three in-service STEM teachers, including chemistry as a teaching subject, with teaching experience ranging from 5 to 30 years. This range reflected different stages of professional development, from relatively early-career teachers to highly experienced practitioners with long-term expertise in school-based STEM education. The second participant group consisted of three pre-service chemistry teachers enrolled in a secondary school teacher education program (Gymnasium level). These students were in their advanced stages of study, corresponding approximately to master's level qualifications. Chemistry was their teaching subject besides biology. This composition ensured that participants represented both ends of the professional continuum in chemistry teacher education, enabling structured comparison and exchange within the job shadowing intervention.

During the 3-day program of the present Job Shadowing program, participants had the opportunity to gain insights into different areas of science education, research, and industry collaboration.

On the 1st day, the event began with a welcoming reception followed by an introduction to the LMUchemlab, which was a local student laboratory focusing on inclusive chemistry education. In the afternoon, participants visited the company F-select, where they learned about innovative approaches and practical applications in the scientific and industrial sector.

The second day focused on educational exchange and networking. A presentation about Science on Stage introduced participants to the international network that promoted innovative STEM teaching practices across Europe. This was followed by a discussion round in which ideas and experiences related to science education were shared. Afterwards, the group also visited CRELUX, a company specializing in research and laboratory services, providing insights into modern scientific workflows and collaboration between industry and research institutions.

On the last day, participants visited the Museum Mensch und Natur (Human and Nature) and the BIOTOPIA Laboratory, where they explored interactive scientific exhibitions and educational concepts connecting science, sustainability, and society. The program concluded with a closing discussion reflecting on the experiences and key takeaways of the event.

During the job shadowing visits, pre-service and in-service teachers regularly exchanged views with one another. This exchange occurred largely spontaneously and arose directly out of the shared observation; only in a few instances was it guided or structured by university staff. On their own initiative, participants used the observation visits to discuss the application of knowledge as well as the insights gained during the job shadowing, and to consider together how these could be applied or used in their own (future) teaching. Further cooperation was left to the participants.

Instrumentation

Data were collected using two parallel, structured questionnaires: One for pre-service teachers and one for in-service teachers. Both instruments consisted of quantitative Likert-scale items and qualitative open-ended questions.

The quantitative section used a six-point Likert scale ranging from 1 (strongly disagree) to 6 (strongly agree), covering four categories:

- **Collaboration and Communication:** Items assessed the quality of exchange, opportunities for interaction, and the perceived value of joint reflection between participants. (4 items)
- **Learning and Knowledge Gain:** Items focused on perceived learning outcomes, including insights into chemistry-related professional contexts, the connection between theory and practice, and the development of new perspectives. (4 items)
- **Transfer and Usefulness:** This dimension captured perceived relevance for academic studies (students) or teaching practice (teachers), as well as the applicability of insights gained through job shadowing. (4 items)
- **Organisation and Practical Conditions:** Items evaluated the perceived quality of organizational preparation, time structure, and feasibility of the format. (3 items).

The qualitative section consisted of seven open-ended questions designed to capture more in-depth reflections on the experience. These included participants' perceptions of collaboration, perceived benefits, challenges, key learning experiences, and suggestions for improvement. In addition, teachers were asked whether they would recommend the format for future use.

The use of parallel questionnaires on the meaning of triangulation, for both groups enabled a comparative perspective on how job shadowing was experienced by different actor groups within the CoP. Combining structured Likert-scale items with open-ended questions allowed for both measurable evaluation of the intervention and in-depth qualitative insights into participants' experiences. This design was particularly suitable for exploring boundary-crossing learning processes between pre-service and in-service phases of teacher education.

Data Analysis

Quantitative data were analysed descriptively to identify patterns in participants' perceptions across the four thematic dimensions. Qualitative responses were analysed using thematic content analysis, focusing on recurring categories related to collaboration, learning processes, boundary crossing, and perceived value of the job shadowing experience.

RESULTS

Quantitative Results

Both groups – pre-service chemistry teachers and in-service chemistry teachers – showed a uniform response pattern in the

quantitative section of the questionnaire. Across the Likert-scale items, participants consistently reported high levels of agreement, resulting in ceiling-level ratings for all dimensions (collaboration and communication, learning and knowledge gain, transfer and usefulness, as well as organisation and framework conditions). Overall, the quantitative responses suggested a highly positive perception of the job shadowing format.

Qualitative Results

The qualitative data provided deeper insight into how participants experienced the job shadowing intervention within the CoP framework. Across both groups, several consistent thematic patterns emerged, particularly regarding collaboration, perspective-taking, and perceived value of the exchange.

Collaboration and equality in exchange

Pre-service teachers repeatedly described the interaction with in-service teachers as equal, open, and highly constructive. The exchange was perceived as being on “eye-level,” characterised by mutual interest in each other’s perspectives and experiences. Participants highlighted the value of dialogue and reflection with teachers as a key aspect of the experience, enabling them to meaningfully engage with real-world school practice.

Similarly, in-service teachers emphasised open, transparent, and productive communication with pre-service. Both groups reported that the exchange enabled meaningful perspective-taking and mutual understanding. The interaction was frequently described as pleasant, respectful, and purposefully oriented toward shared learning.

Perspective expansion and learning opportunities

A dominant theme across responses was the exposure to a wide range of perspectives and learning opportunities. Pre-service teachers particularly valued the diversity of experiences encountered during the job shadowing, noting that it allowed them to explore multiple dimensions of educational and professional practice. It was highlighted that the program enabled them to understand different educational pathways and career options, reinforcing or confirming their professional choice.

In-service teachers in this study also reported gaining new perspectives, particularly through engagement with pre-service teachers. The exchange was seen as an opportunity for mutual learning, where both groups contributed different forms of knowledge and experience. In particular, participants emphasised that they remained “up to date” and gained fresh ideas through interaction with students.

Networking and system-level awareness

A recurring theme was the importance of networking and communication across educational sectors. Participants highlighted the value of connecting university, school, and industry contexts, particularly within STEM education.

The exchange was seen as an opportunity to strengthen collaboration between institutions and stakeholders involved in education.

Several responses explicitly emphasized that educational improvement depended on stronger communication and networking structures. Participants expressed the belief that many actors shared the common goal of advancing education, but that these efforts needed to be more systematically connected.

Relevance for career orientation and professional development

Pre-service teachers frequently reported that the experience reinforced their perception of being in the “right profession” and supported their motivation to complete their studies. The job shadowing experience was described as inspiring and beneficial for their academic and professional development.

In-service teachers, on the other hand, highlighted the professional relevance of the experience, particularly in terms of gaining insights into external STEM-related fields and receiving input that could inform their teaching practice. Some noted that while certain subject-specific industry information was challenging to fully grasp, the overall experience still broadened their professional horizon.

Organizational aspects and suggestions for improvement

Last but not least, the organisation of the program was consistently evaluated positively. Participants described the structure as well-designed, well-communicated, and enabling exposure to multiple perspectives. The variety of offered activities was particularly appreciated.

At the same time, participants provided suggestions for improvement, including an increase in the number of offerings and opportunities to participate more frequently in such formats. One recurring suggestion was the integration of additional contemporary topics, such as artificial intelligence in education, as a future extension of the program.

DISCUSSION AND IMPLICATIONS

The findings of this exploratory case study suggest that job shadowing, when embedded within a CoP, can function as a promising boundary-crossing mechanism between pre-service chemistry teacher education and in-service teaching practice. The convergence of quantitative and qualitative results indicates a consistently positive evaluation of the intervention across both participant groups, suggesting a high degree of perceived relevance, acceptance, and professional value.

From a quantitative perspective, the uniformly maximal ratings across all dimensions (collaboration and communication, learning and knowledge gain, transfer and usefulness, and organizational conditions) indicate a ceiling effect. While this limits statistical differentiation, it is analytically meaningful

in that it reflects a shared perception of strong effectiveness and relevance of the format across roles. The absence of variance between groups further suggests that the intervention succeeded in aligning participant experiences, thereby reducing perceptual distance between institutional phases of teacher education.

The qualitative findings provide deeper explanatory insight into these results. A central theme is the experience of “eye-level” collaboration between chemistry pre- and in-service teachers. This indicates a temporary flattening of traditional hierarchical structures within teacher education, consistent with CoP theory, which emphasizes mutual engagement and shared participation in practice (Wenger, 1998). The participants describe the exchange as constructive, respectful, and mutually enriching, highlighting the importance of relational equality for meaningful learning.

A second key finding related to reciprocal perspective transformation. Pre-service teachers gained authentic insights into school-based practice and professional requirements, while in-service teachers reported gaining fresh perspectives, updated ideas, and renewed awareness of educational developments. This bi-directional learning dynamic suggested that job shadowing was not a unidirectional training tool but rather a symmetrical learning environment in which both groups function simultaneously as learners and contributors. This suggested that reflection played an important role in transforming observational experiences into professional learning (Kolb, 1984).

Third, the study highlights the emergence of boundary-crossing awareness. Participants repeatedly emphasise the importance of stronger networking between university, school, and external STEM-related contexts. This indicates that job shadowing extends beyond individual learning outcomes and contributes to a systemic understanding of education as an interconnected ecosystem. In this sense, the intervention acts as a boundary object that enabled coordination and shared meaning-making across institutional domains.

Fourth, the findings indicate significant implications for professional identity development. Pre-service teachers report increased confidence in their career choice and a stronger sense of belonging to the profession. This aligns with situated learning perspectives, according to which identity formation is closely linked to participation in authentic practice contexts (Lave and Wenger, 1991).

Finally, participants expressed a strong desire for institutional scaling of the format, including more frequent offerings and integration of contemporary topics such as artificial intelligence in education. This suggested that job shadowing was not only perceived as valuable but also as underutilized within current teacher education structures.

The integrated analysis of both data strands suggests that the intervention produces three interconnected meta-effects: universal positive valuation, reciprocal learning symmetry, and

boundary dissolution. These effects are not independent but are structurally produced through the recursive interaction of the three levels described above (Authors).

In particular, the ceiling effects in the quantitative data can be interpreted not merely as an artefact of measurement, but as an indicator of systemic alignment of meaning structures. The qualitative data confirm this interpretation by showing that both groups converge on similar interpretations of value, learning, and relevance. The job shadowing format therefore appears to function as a boundary object, enabling shared meaning-making across institutional roles.

Thus, a central theoretical contribution of this study is the development and empirical grounding of a recursive multi-level model of job shadowing within CoP. The model conceptualizes learning processes across three interdependent levels: Micro (individual learning), meso (CoP-mediated interaction), and macro (educational ecosystem awareness) (Figure 1).

The model supports the findings of this study showing the need for multi-level STEM education which supports equality and social justice between the different levels.

Thus, the cross-level synthesis of findings demonstrates that these levels do not operate independently but form a recursive learning system:

- At the micro level, individuals experience identity development, cognitive expansion, and professional confirmation through direct exposure to authentic practice contexts
- At the meso level, the CoP acts as a mediating structure that enables reciprocity, dialogue, and the dissolution of hierarchical boundaries

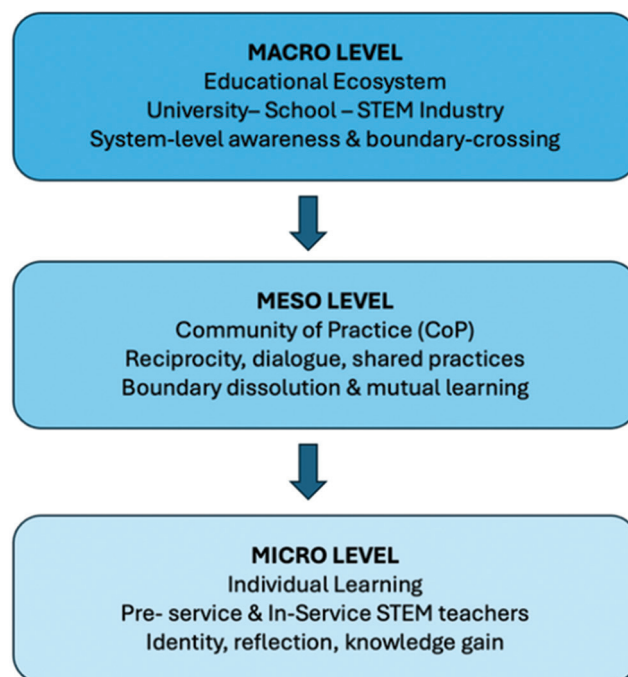


Figure 1: Recursive multi-level model of job shadowing in communities of practice

- At the macro level, participants develop an expanded awareness of the educational ecosystem, linking university education, school practice, and external STEM environments.

Crucially, these levels interact dynamically rather than linearly. Micro-level experiences stimulate openness to interaction, meso-level social processes amplify and stabilise these experiences, and macro-level reflections reframe individual learning within broader systemic contexts. This recursive circulation between levels explains the observed consistency across quantitative and qualitative findings and provides a possible explanation for the highly positive perceptions reported by participants of the intervention.

While these findings suggest the relevance of recursive learning processes across levels, the proposed model needs to be understood as an exploratory conceptual framework grounded in the present case study rather than as a fully validated explanatory model.

The case study extends existing research on CoP (Wenger, 1998; Lave and Wenger, 1991) by demonstrating that CoPs in teacher education can be operationalized as multi-level recursive learning systems rather than purely social interaction spaces. While prior research has emphasised participation and identity formation, this study indicates how these processes are embedded within a broader system of cross-level feedback loops that connect individual learning, social negotiation, and systemic awareness. Furthermore, the findings contribute to boundary-crossing theory by showing that job shadowing does not simply enable transfer between contexts, but actively produces a dynamic integration of contexts. This shifts the conceptualization of teacher education from a sequential model (university → school) to a relational and recursive model of continuous interaction.

From a practical perspective, the results suggest that job shadowing should be systematically integrated into teacher education as a recurring, structured format rather than an isolated experience. Its effectiveness depends not only on exposure to practice but on its embedding within a CoP that enables reflection and reciprocity. For teacher education institutions, this implies the need to design learning environments that explicitly support cross-phase interaction and sustained dialogue. For schools and teachers, it highlights the value of opening practice to external perspectives as a form of professional development. For STEM education in particular, the model underscores the importance of linking school-based learning with broader scientific and industrial ecosystems.

In conclusion, this study shows that job shadowing within a CoP operates as a recursive multi-level learning system that integrates individual, social, and systemic dimensions of professional learning. This recursive structure not only explains the observed empirical patterns but also provides a novel theoretical lens for understanding boundary-crossing processes in teacher education. The proposed model advances existing CoP and boundary-crossing frameworks by emphasising dynamic feedback loops across levels, thereby offering a

more comprehensive explanation of how professional learning emerges in complex educational ecosystems.

LIMITATIONS OF THE STUDY

Despite the promising findings, several limitations need to be considered when interpreting the results of this study. The study is based on a single case design involving a relatively small and context-specific sample of pre-service chemistry teachers and in-service chemistry teachers. This limits the generalisability of the findings beyond the specific institutional and disciplinary context in which the job shadowing intervention is implemented.

The quantitative data show a pronounced ceiling effect across all measured dimensions. While this indicates a very positive overall evaluation of the intervention, it also reduces variability in responses and limits the ability to detect more subtle differences between participant groups or dimensions of experience. This may be related to social desirability bias, novelty effects, or the strong voluntary engagement of participants in the program. In addition, the voluntary nature of participation may have resulted in self-selection effects, as participants with particularly positive attitudes toward collaboration and professional exchange may have been more likely to participate.

In addition, the study relies primarily on self-reported data. Although the combination of quantitative Likert-scale items and qualitative open-ended responses provides methodological triangulation, the findings remain based on subjective perceptions rather than direct measures of learning outcomes, behavioral change, or long-term professional development.

Considering the context of the case study, the data collection captures only immediate or short-term reflections after the job shadowing experience. As such, the study does not provide insights into the long-term sustainability of learning effects, the actual transfer of insights into teaching practice, or the persistence of changes in professional identity or collaboration patterns.

Finally, the study focuses on chemistry education within STEM. While this provides a well-defined disciplinary context, it may limit transferability to other subject areas or educational settings without further adaptation.

Thus, future research should address these limitations by adopting more robust and diversified methodological approaches. Larger-scale studies across multiple institutions and subject areas are needed to examine the generalisability of job shadowing within CoP in teacher education. Comparative studies across disciplines (e.g., biology, physics, mathematics, or non-STEM subjects) would be particularly valuable. Further, future studies should incorporate longitudinal designs to investigate the long-term impact of job shadowing on professional development, teaching practice, and identity formation. This would allow researchers to determine whether the observed positive effects persist over time and translate into sustained behavioral or instructional change.

We also recommend the integration of additional data sources beyond self-reports. Observational data, reflective journals,

classroom practice analysis, or peer feedback could provide more objective indicators of learning transfer and professional growth. Mixed-methods designs combining qualitative, quantitative, and behavioral data would strengthen the evidence base.

Future research could explore variations of the job shadowing format itself. For example, comparative studies could examine differences between one-directional shadowing (student observing teacher), reciprocal shadowing (mutual observation), and multi-site shadowing involving external STEM environments such as industry or research institutions.

And finally, further theoretical development could be needed to better understand the mechanisms underlying boundary crossing in CoP. In particular, future work could integrate perspectives from boundary crossing theory, identity theory, and professional vision research to develop more fine-grained explanatory models of how job shadowing influences learning at micro-, meso-, and macro-levels.

CONCLUSION

This exploratory case study demonstrates that job shadowing, when embedded within a Community of Practice, functions as more than an isolated professional development activity: it operates as a recursive, multi-level learning system that connects individual, social, and systemic dimensions of teacher education. The convergence of quantitative and qualitative findings—reflected in both the ceiling effects and the recurring qualitative themes of eye-level collaboration, reciprocal perspective-taking, and boundary-crossing awareness—supports a model in which learning at the micro, meso, and macro levels does not occur in isolation but reinforces itself through ongoing feedback between levels.

Theoretically, the study extends Community of Practice and boundary-crossing frameworks by showing that such formats can actively produce integration across institutional contexts rather than merely enabling transfer between them, reframing teacher education as a relational and recursive process rather than a sequential one (university → school). Practically, the findings suggest that job shadowing should be institutionalised as a recurring, structured element of teacher education, deliberately embedded in a CoP that supports reflection and reciprocity, rather than offered as a one-off experience.

At the same time, these conclusions must be read in light of the study's exploratory, single-case design, its reliance on self-reported data, and the short-term nature of the data collection, all of which limit the generalisability of the findings and their claims about sustained change. The proposed recursive multi-level model should therefore be understood as a conceptual starting point rather than a validated explanatory theory. Future research—particularly larger-scale, cross-disciplinary, and longitudinal studies incorporating observational and behavioural data—will be needed to determine whether the positive effects observed here persist over time and translate

into lasting change in teaching practice and professional identity. Nonetheless, the study offers a novel lens for understanding how professional learning emerges through the dynamic interplay of individual, social, and systemic processes in complex educational ecosystems.

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