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Enhancing STEM preservice teachers' interdisciplinary teaching competence and instructional design innovation ability through cognitive conflict in community of practice

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Abstract

Purpose – Preservice teachers (PSTs) often face challenges in STEM teaching, including cognitive conservatism, limited collaboration experience and weak innovation capacity. To address this, based on cognitive conflict and collaborative innovation theories, this study aims to propose the Cognitive Conflict in Community of Practice (CCCP), following an "Activation-Reinforcement-Diversification" pathway. Anchored in a university–school–enterprise collaboration, the model aims to explore effective support mechanisms and assess its impact on STEM PSTs' Interdisciplinary Teaching Competence (ITC) and innovative design ability.

Design/methodology/approach – A mixed-methods approach was used, combining quasi-experimental design and qualitative analysis. Centered on the CCCP, interdisciplinary teaching practices were implemented to assess its impact. Questionnaires measured ITC improvement between experimental and control groups, while interviews and textual analysis explored the development of instructional design innovation.

Findings – The model significantly improved PSTs' ITC and fostered innovative awareness in a STEM course, facilitating a shift from idealized to practical design. It also promoted cognitive interaction and professional growth among in-service teachers, supporting a mutually empowering development pathway.

Originality/value – This study presents an innovative integration of cognitive conflict theory and multidimensional collaboration, offering a practical and scalable framework for interdisciplinary teacher education. It contributes to the theoretical understanding of cognitive conflict transformation in pedagogical contexts and provides actionable guidance for PSTs course reform.

Keywords Cognitive conflict, Collaborative community, Instructional design innovation ability, Interdisciplinary teaching competence, STEM preservice teachers

Paper type Research paper

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1. Introduction

In the context of global educational transformation and the accelerated integration of knowledge systems, the traditional discipline-centered model of talent cultivation is facing increasing challenges. Confronted with the complexity of real-world problems, single-discipline knowledge is often insufficient to address them independently. Interdisciplinary teaching, with its emphasis on multidisciplinary integration and real-world problem orientation, has gradually emerged as a key pathway for promoting educational innovation (Zhan and Niu, 2023). As a critical pathway to pedagogical transformation, interdisciplinary education – particularly within STEM education – helps learners establish connections across disciplinary boundaries, fostering integrated understanding and systemic thinking (Zhan *et al.*, 2023). STEM education, which centers on the integrated application of science, technology, engineering and mathematics to solve complex real-world problems, thus serves as a preferred context for implementing interdisciplinary instructional practices (Zhan *et al.*, 2022a, 2022b). However, the integration of interdisciplinary knowledge often disrupts existing cognitive frameworks, triggering conceptual tensions and conflicts – a process that serves as a key mechanism for facilitating deep learning and cognitive restructuring. According to Piaget's theory of social cognitive conflict, cognitive disequilibrium arises when learners' preexisting understandings are challenged by conflicting perspectives or experiences of others. To resolve this disequilibrium, learners actively retrieve prior knowledge, reexamine and question their own views and attempt to assimilate others' cognitive experiences to restore balance. The evolution of cognitive structures is thus driven by an ongoing process of conflict and resolution (De Lisi *et al.*, 1999). Therefore, how to effectively trigger and scaffold meaningful cognitive conflict in interdisciplinary teaching has become a central concern in interdisciplinary instructional design.

As in STEM education, teachers serve as key organizers and facilitators in interdisciplinary instruction (Liu, 2020; Li *et al.*, 2025). However, current preservice teacher (PST) preparation and in-service teacher development programs still exhibit significant shortcomings in terms of practical components and authentic teaching experience (Huang *et al.*, 2022). On the one hand, traditional teacher education models predominantly rely on university-led, discipline-centered training, often resulting in a lack of hands-on teaching experience. This leaves PSTs underprepared for real-world educational contexts and creates a substantial disconnect between theory and practice (Li *et al.*, 2025). On the other hand, during interdisciplinary instructional design and implementation, PSTs commonly encounter challenges such as cognitive conservatism, limited collaborative experience and insufficient motivation for innovation (Van Ingen and Ariew, 2015; Kostiainen *et al.*, 2018). These challenges call for more operationalized and practically grounded support strategies within teacher education systems. Prior research has shown that social interaction and interpersonal relationships are essential to PSTs' professional development (Daly *et al.*, 2014). In learning environments characterized by social motivation and collective cohesion, learners are more open to heterogeneous perspectives, which can stimulate deeper cognitive conflict and foster cognitive transformation (Mugny *et al.*, 1978).

Within this context, collaborative innovation theory offers a promising framework for addressing these challenges. By constructing collaborative communities involving multiple stakeholders, it becomes possible to activate cognitive diversity, trigger constructive cognitive conflicts and achieve knowledge reconstruction through cooperative negotiation – ultimately establishing a pathway for cognitive transformation that is oriented toward practice and innovation. The innovation of collaboration mechanisms within interdisciplinary teaching teams not only enhances the quality of integrated instructional practices but also has the potential to fundamentally reshape school organizational structures, making them more adaptable to the evolving demands of interdisciplinary integration. Such structural transformation provides institutional support for cultivating talent with interdisciplinary vision and comprehensive innovation capabilities (Zhu *et al.*, 2025). Research has also shown that while cognitive conflict can directly promote team innovation, if not effectively managed, it may escalate into emotional conflict, which can negatively impact team dynamics and creativity (He *et al.*, 2014). Therefore, how to strategically activate, manage and resolve cognitive conflict within collaborative communities – thereby supporting knowledge restructuring – remains an open question requiring further theoretical exploration and empirical validation.

Therefore, this study integrates collaborative innovation theory and cognitive conflict theory to propose a Cognitive Conflict in Community of Practice (CCCP). It uses empirical research to examine the effectiveness of this practice in enhancing Interdisciplinary Teaching Competence (ITC) and instructional design innovation ability among STEM PSTs. Specifically, this study adopts the definition of K-12 teachers' ITC proposed by Zhan *et al.* (2025), which emphasizes the integration of values, motivation, knowledge structures and ability systems that teachers need to possess. These qualities and competencies are essential for understanding, designing, implementing, evaluating and researching interdisciplinary teaching practices, all aimed at cultivating students' core competencies through problem-solving-oriented instruction. In addition, instructional design innovation ability is defined as teachers' comprehensive capacity to creatively integrate instructional objectives, content, methods, media and evaluation within systematic instructional design. This ability enables teachers to transcend conventional models and foster students' critical thinking, creativity and life skills (Umamah *et al.*, 2020; Umamah *et al.*, 2021). Based on this, the study aims to provide both theoretical grounding and practical pathways for STEM PST education reform in the new era, as well as meaningful references for interdisciplinary education. It seeks to address the following research questions:

(1) How can the CCCP be constructed to foster collaborative innovation among PSTs and in-service teachers, and support the development of ITC and instructional design innovation ability in STEM PSTs?

(2) To what extent is the CCCP effective in improving STEM PSTs' ITC and instructional design innovation ability?

2. Literature review

2.1 Collaborative innovation

Collaborative innovation is a complex process involving the systematic optimization and joint innovation of various stakeholders. At its core, it is a dynamic system that evolves along the logic of communication–coordination–cooperation–collaboration (Serrano and Fischer, 2007). From the dual dimensions of integration and interaction, collaborative innovation emphasizes the mutual exchange and integration of information, technology, knowledge and other resources. Synergistic effects – where the whole exceeds the sum of its parts (i.e. $1 + 1 > 2$) – are achieved through coordination and joint action among system components (Weidlich, 1984). Its essence lies in cooperation and interaction among multiple actors (Liu, 2024). Collaborative innovation is seen as an effective organizational response to changing external environments, aimed at enhancing innovation performance (Soeparman *et al.*, 2009). From a resource-based view, stakeholders engage in collaboration to access complementary resources that help overcome their individual capability limitations (Zhang *et al.*, 2018). Modern universities play a central role in knowledge creation and dissemination, making them critical actors in innovation systems and technological advancement (Fischer *et al.*, 2019). As the main sites for teacher preparation, universities are under growing pressure to move beyond traditional discipline-based systems. With the ongoing advancement of interdisciplinary education and educational informatization, there is an urgent need to foster resource integration and collaborative innovation among diverse stakeholders in cultivating future teachers with comprehensive literacy and innovative capacity.

In this context, the construction of educational communities offers an effective path toward the integrated cultivation and high-quality development of PSTs (Bush and Cook, 2016). Currently, collaboration in teacher education is primarily based on university–school (U–S) partnerships, which have expanded to include university–enterprise (U–E) and university–school–enterprise (U–S–E) models. Among these, the U–S–E collaborative model integrates the strengths of universities, enterprises and K-12 schools to establish a three-dimensional support system that connects theoretical instruction, practical teaching contexts and technological platforms. This model provides contextualized and interdisciplinary support, particularly within C-STEAM instructional practices (Lyu *et al.*, 2024). Within this framework, universities serve as the central actors, providing PSTs with systematic educational theories and interdisciplinary teaching approaches. Enterprises contribute technological support and facilitate platforms for interaction between PSTs and in-service teachers. PSTs offer innovative ideas in interdisciplinary instructional design, while in-service teachers share practical teaching strategies and contextual insights. Through sustained interaction, all parties integrate and exchange knowledge and resources, thereby advancing collaborative innovation.

2.2 Cognitive conflict

Cognitive conflict theory builds upon Piaget's (1964) *Equilibration Theory* and Festinger's (1957) *Cognitive Dissonance Theory* and has become a foundational theoretical framework for explaining conceptual change in education (Hewson and Hewson, 1984). According to Piaget, when individuals encounter contradictions between new information and their existing cognitive schemas, they undergo a process of assimilation–accommodation–re-equilibration, which drives cognitive development through schema restructuring. In this process, external stimuli act as triggers, while assimilation and accommodation serve as both prerequisites and internal motivators for the formation of new cognitive patterns (Wang, 2014). Vygotsky pointed out that the driving force of psychological development lies in the contradiction and tension between internal mental structures and the sociocultural environment. When spontaneous and scientific concepts meet and create disequilibrium, the individual reorganizes meanings to achieve cognitive development—a process resonant with the later notion of cognitive conflict (Vygotsky, 1986). Lee *et al.* (2003) defined this phenomenon as a state of cognitive dissonance, in which individuals perceive tension due to misalignment between their existing mental frameworks and real-world situations. Thus, the essence of cognitive conflict lies in the perceived imbalance, and cognitive development occurs as individuals attempt to resolve this tension and restore equilibrium (Piaget, 1977). Prior studies have shown that cognitive conflict can significantly enhance creative output and innovative thinking. Exposure to divergent knowledge sources contributes to innovation success (Cummings, 2004) and even when only a few individuals in a team experience cognitive conflict, the overall group tends to become more creative (Van Dyne and Saavedra, 1996).

In educational practice, cognitive conflict is widely employed to disrupt students' preconceptions, facilitating the development of deeper understanding and innovative thinking. Making students explicitly aware of the conflict between their existing knowledge and new concepts is a key prerequisite for effective conflict resolution and cognitive growth. Research highlights that cognitive development is highly context-dependent (Bao and Redish, 2006). Well-designed conflict scenarios can break habitual thinking patterns and stimulate active exploration. Variations in theoretical knowledge versus practical skills, mismatched expectations, preparation gaps or questioning strategies can all generate cognitive conflict within the Zone of Proximal Development (Li *et al.*, 2021). Cognitive conflict is particularly prevalent in STEM education. STEM emphasizes real-world problem-solving and interdisciplinary integration, requiring learners to continuously question, reconstruct and transfer knowledge within complex contexts (Nabila *et al.*, 2025). Within this framework, collaborative learning environments offer richer social mechanisms to both trigger and resolve cognitive conflict. Differences in perspectives and practical experience among members of a learning community often serve as catalysts for conflict. Through collaborative dialogue and meaningful negotiation, learners can dissolve such conflict and engage in higher-order knowledge construction and shared decision-making (Wang *et al.*, 2021). For example, through interactive activities such as discussions, experiments or instructional design practices, learners integrate diverse resources and perspectives, facilitating conceptual transformation, resolving conflicts and achieving a new state of cognitive equilibrium. To further support this process, learning designers may adopt either a confrontational approach – presenting clear and challenging content to directly address misconceptions – or a guided approach, which encourages learners to explore, construct and revise their mental models autonomously through interaction with the environment (McDougall, 2002). Both approaches aim to foster meaningful engagement and cognitive restructuring.

Collectively, these studies underscore the importance of integrating cognitive conflict and collaborative innovation to enhance interdisciplinary teaching practices, providing a robust foundation for the development of the proposed model.

3. Concept model

Grounded in both collaborative innovation theory and cognitive conflict theory, this study constructs a conceptual model from two dimensions. Structurally, it is based on the U–S–E collaborative community for STEM PST training, establishing a synergistic mechanism linking universities, schools and enterprises. Process-wise, it centers on the stimulation, dissolution and rebalancing of cognitive conflict, revealing the dynamic trajectory of PSTs' pedagogical cognitive development within this multistakeholder collaboration. Section 3.1 will focus on the structural construction of the U–S–E collaborative community, while Section 3.2 will further examine the evolutionary mechanisms and transformation logic of cognitive conflict driven by this framework.

3.1 U-S-E collaborative community

The "university–school–enterprise" model, as a key mechanism linking universities, schools and enterprises, has gradually become an effective approach to advancing PSTs education reform and fostering practical skills development (Lyu *et al.*, 2024). Research indicates that this model facilitates the integration of diverse educational resources, bridges the gap between university-based training and frontline teaching practice and provides PSTs with a more authentic and interactive learning environment (Zhan *et al.*, 2022a, 2022b; Li *et al.*, 2023). Building on the theory of collaborative innovation, this study constructs a U-S-E collaborative community centered on PST training, involving active participation from university faculty (University), frontline teachers (School) and enterprise professionals (Enterprise). This tripartite collaboration focuses on interdisciplinary instructional design, forming a multiactor, multidimensional synergistic educational ecosystem (see Figure 1). Within this community, PSTs achieve a cognitive transition from theoretical understanding to practical application through embedded, task-oriented learning.

In the early stage of the course, university faculty are responsible for delivering theoretical instruction and methodological guidance. By designing problem-based scenarios

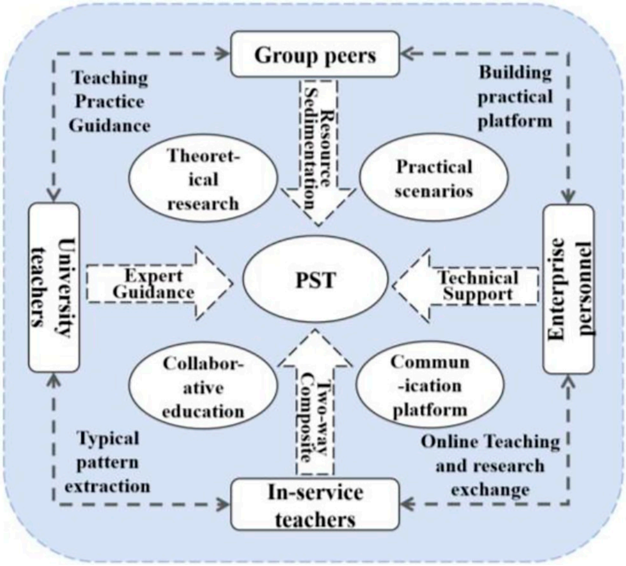

Figure 1. U-S-E collaborative community
Source: Authors' own work

and facilitating group discussions, they guide PSTs in identifying conceptual differences and design misconceptions, thereby stimulating initial cognitive conflict and providing theoretical foundations to support subsequent knowledge construction. In-service teachers become involved primarily in the mid-to-late stages, offering feedback on PSTs' instructional designs based on authentic classroom needs. They highlight key instructional points and learner differences, enabling PSTs to iteratively revise their plans through a "feedback–adjustment–optimization" cycle, thereby enhancing practical adaptability and feasibility. Enterprise professionals contribute by providing tool support and resource assurance through collaborative lesson-planning platforms, interactive teaching-research systems and authentic teaching scenarios. Their participation not only addresses technological shortcomings but also extends the practical boundaries of interdisciplinary teaching.

Within the U-S-E collaborative community, PSTs engage in continuous interaction with multiple stakeholders through the process of cognitive conflict – initiation, resolution and balance – thereby achieving a cognitive transition from theoretical understanding to practical transformation (see Figure 2). Differences in experience among peers generate disagreements in topic selection and design conception; theoretical guidance from university faculty and teaching assistants highlights the gap between "knowing" and "doing"; classroom feedback from in-service teachers reveals contextual constraints; and technical testing by enterprise professionals exposes an overreliance on formalized methods. Together, these factors constitute multiple triggers of cognitive conflict. Through ongoing communication and collaborative revision, the theoretical clarification provided by university faculty, the practical adjustments offered by in-service teachers, the technological feedback from enterprise professionals and the group negotiation among PSTs jointly contribute to the resolution of conflicts, which are ultimately transformed into a deeper

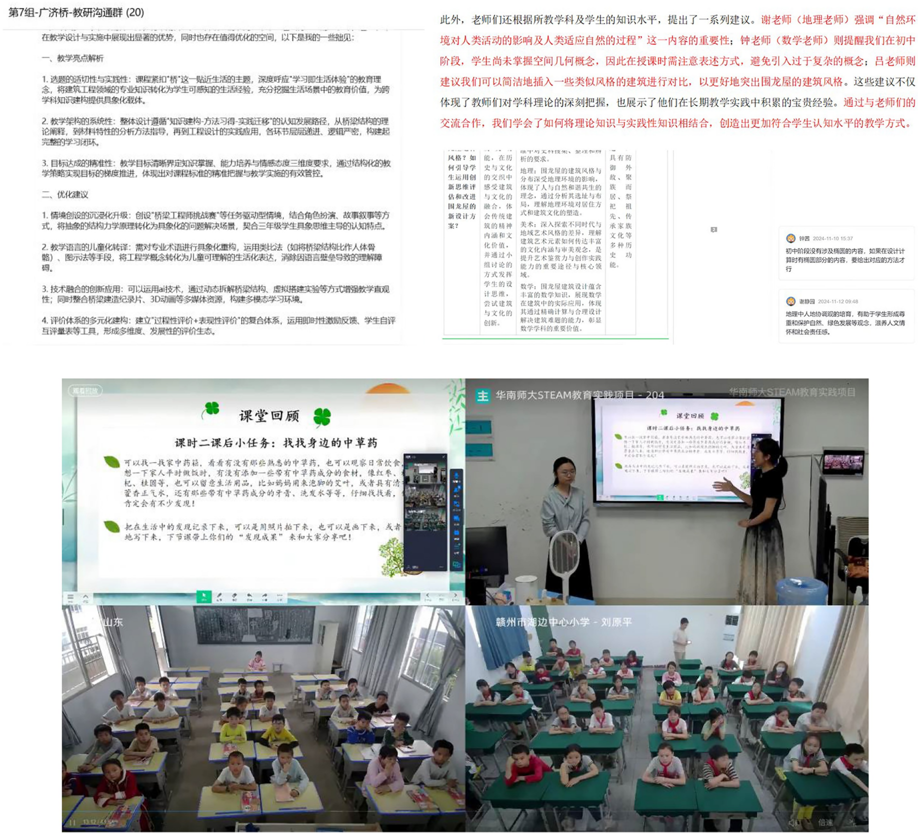

Figure 2. U-S-E collaborative community practice
Source: Authors’ own work

understanding of interdisciplinary teaching. At the balance stage, PSTs gradually develop a practical cognition that “pursues innovation while accommodating contextual feasibility.” They learn to actively apply theoretical frameworks to examine and revise their designs, incorporate technological feasibility into pedagogical considerations and move from merely “knowing how to do” to “understanding why it should be done.” Meanwhile, other community members also experience reciprocal learning and internalization through interaction: in-service teachers are inspired by novel design ideas and experiment with them in their own classrooms; university faculty reflect on the appropriateness of their theoretical instruction based on PSTs’ difficulties; and enterprise professionals, by providing technical support, deepen their understanding of educational needs and gradually develop optimization strategies tailored to teaching contexts.

3.2 Cognitive conflict in community of practice

Lee *et al.* (2003) proposed a “Cognitive Conflict Model” that divides cognitive conflict into three stages: preliminary, conflict and resolution. The model emphasizes that learners gradually resolve conflict through cognitive reevaluation and judgment after perceiving the conflict, leading to the generation of new cognition. Building on this theoretical foundation and integrating the practical context of STEM PST education and collaborative learning, this study further develops a three-stage strategy – "cognitive conflict triggering, conflict resolution and cognitive stabilization" – which better reflects the actual process of collaborative knowledge construction in interdisciplinary teaching and learning. This strategy seeks to enhance PSTs' ITC and instructional design innovation ability by activating individual cognitive differences, inducing cognitive conflicts and facilitating knowledge reconstruction and cognitive transformation through deep collaboration and multifaceted interaction within a multistakeholder collaborative community (see Figure 3).

3.2.1 Difference activation and cognitive conflict triggering. Cognitive conflict is a critical driver of cognitive development, arising from differences in learners' knowledge structures, backgrounds and thinking styles (Mugny *et al.*, 1978). Both Piaget and Vygotsky emphasized that cognitive development involves not only individual knowledge construction but also meaning negotiation within social interactions (De *et al.*, 1999). Accordingly, this study proposes a cognitive conflict triggering pathway termed "difference activation," aiming to stimulate learners' cognitive differences through problem-based scenarios and the exposure of cognitive biases, guiding them into deeper cognitive conflict via social collaboration. This pathway comprises three sequential steps: Activation (creating problem contexts), Reinforcement (revealing cognitive biases) and Diversification (introducing social cognitive cues). By combining contextual triggers with social interaction, this approach provokes and deepens cognitive dissonance, laying the groundwork for subsequent cognitive transformation and equilibrium.

In the Activation stage, challenging and open-ended authentic problems are designed to expose learners' knowledge gaps and limitations when facing complex tasks, thereby

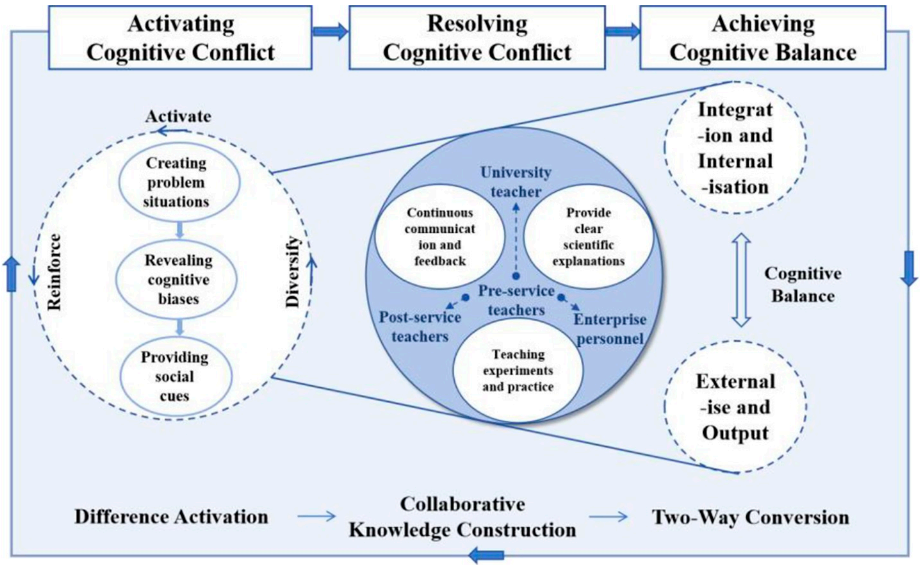

Figure 3. Cognitive conflict in community of practice
Source: Authors' own work

eliciting latent cognitive differences (Calleja and Formosa, 2020). In practice, instructors present real teaching tasks close to authentic settings, prompting students to preliminarily conceptualize teaching content, structure and methods based on prior experience. In the implementation of the course, teachers often begin with authentic instructional tasks – such as "designing a teaching activity centered around an interdisciplinary big idea" – to prompt students to develop initial ideas based on their prior knowledge. However, students tend to resort to traditional, discipline-specific and linear thinking patterns, making it difficult to achieve disciplinary integration or structural elaboration of concepts. As a result, a misalignment arises between their approach and the holistic, interconnected demands of interdisciplinary teaching. For instance, in the initial design of the "Cloud Laboratory" project, students treated interdisciplinary knowledge as a mere combination of subjects, neglecting the internal connections among them. Classroom discussions and feedback revealed this limitation: university faculty highlighted the lack of conceptual integration, while in-service teachers stressed the need to match content with students' cognitive levels. These critiques triggered a cognitive conflict that led students to recognize the shortcomings of their initial approach and prepared them for deeper reflection and reconstruction.

The Reinforcement stage intensifies learners' perception of cognitive dissonance, amplifying conflicts between their prior understanding and actual contexts. Instructors reveal misconceptions in knowledge application – such as flawed learner analysis, partial concept grasp, or impractical design – helping learners recognize gaps between their cognitive structures and real-world problems. This awareness prompts proactive engagement in cognitive conflict (Khoeriah *et al.*, 2024). For instance, in the "Weilong House" project, PSTs initially sought to integrate history, architecture, influencing factors and cultural connotations into a single lesson. However, in-service teachers provided feedback that such an ambitious design would obscure key points and overload students, triggering a cognitive conflict between idealized planning and classroom feasibility.

Finally, the Diversification stage introduces others' perspectives, social cues and collaborative interactions to broaden learners' viewpoints and stimulate deeper cognitive conflict (Mugny *et al.*, 1978). For example, in the initial stage of topic exploration, nearly all seven groups selected themes from the humanities and social sciences. This reflected a cognitive bias among PSTs, who perceived these areas as easier to integrate with other disciplines. Such a phenomenon required timely intervention from university faculty to guide students in understanding interdisciplinary design methods for natural science topics, thereby breaking their one-sided cognitive mindset.

3.2.2 Collaborative knowledge construction and cognitive conflict resolution. Once cognitive conflicts are effectively triggered, the instructional focus shifts to guiding students to interpret, reflect upon and integrate these conflicts within a collaborative framework, facilitating cognitive restructuring and deepening. Building on McDougall's (2002) approach and leveraging the constructed U-S-E collaborative community, this study refines the confrontational and guided methods into three core pathways: Scientific Explanation – Continuous Feedback – Practice Validation, which systematically advance the resolution of cognitive conflicts and foster a dynamic process of knowledge construction.

In the Scientific Explanation phase, confrontational guidance is used to explicitly present cognitive discrepancies, stimulating deep critical thinking. Teachers clarify cognitive biases and partial understandings revealed during conflicts by using precise academic language, theoretical frameworks and representative cases (Kera, 2024). For example, in its initial design, the Cloud Laboratory group treated science and art as two separate domains by arranging distinct sessions on "the morphological characteristics of clouds" and the "cloud-making experiment," resulting in a fragmented approach of "scientific demonstration plus artistic add-on." Through the instructor's analysis of the connotation and design methodology of the interdisciplinary big idea, grounded in textbooks and relevant literature, the students were guided to recognize that interdisciplinary teaching requires the conceptual integration of knowledge rather than parallel juxtaposition. Following in-depth discussion and iterative revision, the group refined their design to embed artistic exploration within scientific inquiry: during the "cloud-making experiment," students were prompted to observe and record the dynamic changes of clouds while simultaneously analyzing their aesthetic features. This adjustment enabled the organic integration of scientific inquiry and artistic expression, transforming the activity from a disciplinary patchwork into a coherent interdisciplinary learning experience.

The Continuous Feedback phase constitutes the core of cognitive adjustment and meaning negotiation. In collaborative learning, individuals iteratively refine their understanding through ongoing communication and feedback, gradually aligning their cognitive structures (Calleja and Formosa, 2020). Cognitive conflict resolution is not a solitary internal process but a dynamic, collaborative construction of knowledge. Within the U-S-E community, sustained support enables systematic conflict resolution through ongoing cognitive feedback and resource sharing. For example, when some groups were unable to implement the planned interactive activities, discussions with enterprise professionals helped PSTs realize that for upper-grade students, simple functions such as using a paintbrush tool could effectively replace the minigames they had designed-achieving the intended outcome while avoiding excessive instructional burden. At the same time, feedback from in-service teachers enabled PSTs to align their idealized designs more closely with classroom realities. For instance, the "Weilong House" group initially attempted to cover multiple dimensions – including history, structure and culture, but was advised that the content was overly complex and difficult to digest. After further discussion, the group refined their design to focus on two core components: "architectural modeling" and "cultural connotations," thereby achieving greater clarity and feasibility.

Finally, the Practice Validation phase grounds cognitive restructuring in authentic teaching scenarios. Through iterative cycles of practice, feedback and adjustment, students test theoretical knowledge in real contexts and refine cognitive frameworks by addressing practical challenges, establishing a "learning from conflict" praxis (Calleja and Formosa, 2020). In the program's later stages, PSTs iteratively revise instructional designs, conduct field trial lessons and implement teaching on platforms, continuously validating and refining their pedagogical concepts. For example, in the first lesson implementation, one group encountered difficulties as students struggled to understand due to overly broad content coverage. Based on feedback from in-service teachers and students, the members realized that their objectives were too scattered. In the second lesson, they refocused on core concepts, eliminated redundant content and guided students to gradually construct knowledge through inquiry-based tasks. The classroom effectiveness improved significantly, reflecting a deeper understanding of the rationality of instructional goals.

Another group experienced a similar adjustment regarding technology use. Their initial draft included multiple interactive game activities, but during teaching these led to a sluggish classroom pace and distracted student attention. After consulting with enterprise professionals and in-service teachers, the group recognized the principle that "technology should serve pedagogy." Ultimately, they retained only one interactive activity closely aligned with the core concept. This decision not only ensured smoother lesson flow but also enhanced learning effectiveness, reflecting a rational balance between "technological feasibility" and "instructional effectiveness." These cases demonstrate that the feedback–revision cycle in practice not only strengthened PSTs' contextual awareness and reflective capacity but also facilitated the deep internalization of teaching philosophies through the interplay of theory and practice.

3.2.3 Bidirectional transformation to achieve cognitive equilibrium. Following the activation and collaborative resolution of cognitive conflicts, students' cognitive development enters the stage of rebalancing, which centers on integrating and transferring constructed knowledge. This process promotes both the internal assimilation of knowledge and its external behavioral manifestation, thereby achieving a dynamic cognitive equilibrium (Piaget and Inhelder, 1969; Calleja and Formosa, 2020).

First, integration and internalization mark key indicators of cognitive stability. Through ongoing explanation, feedback and practical validation in earlier stages, students progressively synthesize newly acquired knowledge with existing cognitive schemas, forming a more systematic and stable understanding. By composing course reflections and revision notes, learners continuously reinterpret and generalize issues arising from cognitive conflicts, transforming fragmented experiences into structured cognitive frameworks. Guided by the *U-S-E Collaborative Community*, PST deepen their reflection on the intrinsic relationships between interdisciplinary teaching concepts and design logic, enabling a cognitive leap from "knowing how" to "understanding why." For example, in their reflection report, the Weilong House group systematically reviewed the adjustment process of "focusing on core concepts – reducing content – restructuring activities," through which they gradually came to understand the necessity of "selection" and "focus" in interdisciplinary instructional design.

Second, externalized output reflects the effective transformation and transfer of knowledge. PSTs demonstrate mastery by applying constructed knowledge flexibly across new tasks and contexts. Through implementing their interdisciplinary teaching plans in authentic classrooms, they translate theoretical understanding into observable teaching behaviors. Real-time interaction not only tests the practicality of their designs but also enables the enactment of knowledge in practice. Furthermore, PSTs disseminate their cognitive gains through teaching reports, academic presentations and online platform sharing. For example, after refining their plans, the groups implemented teaching through co-taught lessons or offline practicum sessions. This not only externalized the transfer from cognitive frameworks to instructional practice but also allowed them to gradually validate and consolidate their understanding of the rationality of interdisciplinary instructional design through authentic classroom feedback, thereby achieving a dynamic state of cognitive balance.

4. Method

4.1 Participants

This study used a quasi-experimental design to examine the impact of a CCCP on PSTs' ITC within the course *Interdisciplinary Teaching and Project-based Learning* (see Figure 4). Participants were 72 second-year undergraduate students majoring in Educational Technology at a normal university, with 33 assigned to the experimental group and 39 to the control group. Both groups had no prior systematic training in interdisciplinary teaching theory or practice before the course.

4.2 Procedure

The 16-week course centers on the core theme of "Interdisciplinary Instructional Design and Implementation" and is divided into three phases: theoretical learning, instructional design and simulation. The control group followed a traditional STEM teaching approach, where university instructors delivered knowledge through lectures and PSTs primarily engaged in

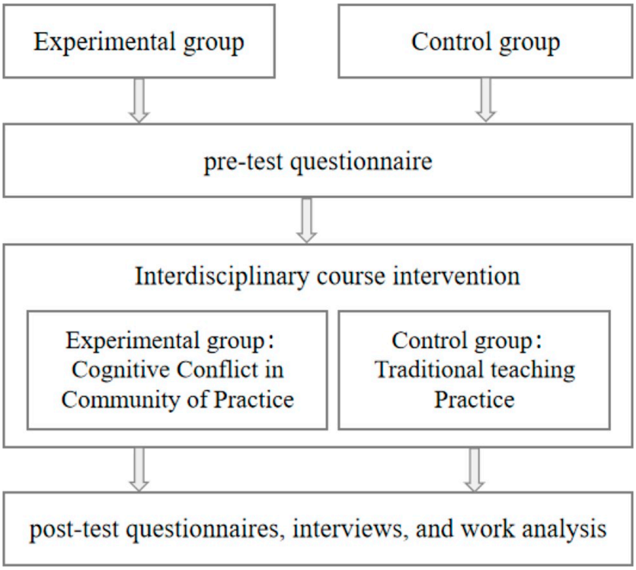

Figure 4. Experimental procedure
Source: Authors' own work

passive learning. In the later phase, students independently completed interdisciplinary instructional design tasks, which were then evaluated through simulated teaching sessions. The experimental group was taught using the CCCP. During the theoretical learning phase, university instructors guided students to actively trigger cognitive conflicts through group discussions and opinion clashes within authentic problem scenarios, enhancing their understanding and critical examination of interdisciplinary teaching concepts.

In the design and implementation phase, both groups were assigned equivalent instructional design tasks in terms of topic, scope and learning objectives to ensure comparability, while experimental group students collaborated in small teams to complete instructional design tasks. They engaged in multiple rounds of cognitive conflict through online exchanges with in-service primary and secondary school teachers, collective lesson planning and teaching research feedback. Through continuous communication, clear scientific explanations and practical teaching experiments, the joint involvement of in-service teachers and peers facilitated the gradual resolution of cognitive conflicts. Through iterative reflection and collaboration, students reorganized and balanced their cognitive structures by integrating theoretical knowledge with practical experience, thereby internalizing and enhancing their teaching concepts and design skills.

4.3 Measuring instruments

This study used a mixed-methods design, integrating questionnaires and interviews for data collection. Quantitative data were obtained through pretest and posttests measuring changes in PSTs' ITC. Qualitative data – including instructional design plans, reflection reports and interview transcripts – provided complementary insights. The data collection instruments are described as follows:

4.3.1 Survey of interdisciplinary teaching competence. This study primarily draws on the ITC model for teachers proposed by Zhan *et al.* (2025), which conceptualizes competence as a dynamic structure comprising four interrelated dimensions: Interdisciplinary Teaching Knowledge (content knowledge across disciplines, pedagogical knowledge for integration and technological knowledge for interdisciplinary teaching), Interdisciplinary Teaching Affection (recognition of interdisciplinary value, confidence and motivation to engage in interdisciplinary practice), Interdisciplinary Instructional Ability (skills in designing, implementing and evaluating interdisciplinary teaching) and Interdisciplinary Professional Development Ability (reflection, research capacity and collaboration for ongoing professional growth). The ITC scale includes 24 items across these four dimensions, with an overall reliability coefficient of 0.918, indicating high reliability and strong construct validity.

4.3.2 Survey of innovative ability in teaching design. The study explored PSTs' interdisciplinary instructional design innovativeness through semi-structured interviews. Following course completion, the research team conducted interviews with experimental group PSTs and the in-service teachers involved in the collaboration. The interviews focused on the interdisciplinary knowledge and skills acquired by PSTs, the interaction between PSTs and in-service teachers and the development of PSTs' instructional design innovation. This qualitative data aimed to provide multifaceted support for interpreting the effectiveness of the instructional practice.

4.4 Data analysis

Questionnaire data were analyzed using SPSS software. Independent samples t-tests and paired samples t-tests were employed to compare score differences between the experimental and control groups before and after the intervention. Specifically, paired samples t-tests examined within-group changes from pretest to posttest, while independent samples *t*-tests assessed between-group differences at both pretest and posttest stages. This analytical approach enables a comprehensive evaluation of each group's progress over time and the comparative effectiveness of the intervention.

5. Results

5.1 Interdisciplinary teaching competence

A pretest assessing ITC was administered to both groups prior to instruction. Independent samples *t*-tests (see Table 1) revealed no significant differences across all dimensions ($p > 0.05$), indicating baseline equivalence between the experimental and control groups.

The independent samples *t*-test on the post-test data revealed that the experimental group showed significant improvement in overall ITC compared to the control group (see Table 2).

Table 1. Comparison of pretests between experimental and control groups

Dimension	Experimental group M	Experimental group SD	Control group M	Control group SD	T	*p*
Interdisciplinary teaching affection	4.182	0.463	4.098	0.551	−0.689	0.493
Interdisciplinary teaching knowledge	3.556	0.593	3.312	0.688	−1.593	0.116
Interdisciplinary instructional ability	3.662	0.617	3.509	0.592	−1.072	0.288
Interdisciplinary professional development ability	3.899	0.529	3.697	0.596	−1.512	0.135
Interdisciplinary teaching competence	15.298	1.948	14.615	2.109	−1.417	0.161

Source(s): Authors' own work

Table 2. Comparison of posttests between experimental and control groups

Dimension	Experimental group M	Experimental group SD	Control group M	Control group SD	T	*p*
Interdisciplinary teaching affection	4.348	0.362	4.120	0.528	−2.104	0.039*
Interdisciplinary teaching knowledge	4.182	0.334	3.842	0.481	−3.422	0.001**
Interdisciplinary instructional ability	4.187	0.338	3.543	0.558	−5.793	0.000**
Interdisciplinary professional development ability	4.242	0.384	3.739	0.547	−4.430	0.000**
Interdisciplinary teaching competence	16.960	1.235	15.244	1.759	−4.706	0.000**

Note(s): **indicates that the *p*-value is less than 0.01, representing a statistically significant difference, while *indicates that the *p*-value is less than 0.05, representing a difference that is not statistically significant at the stricter level
Source(s): Authors' own work

Specifically, Interdisciplinary Teaching Knowledge, Interdisciplinary Teaching Ability and Interdisciplinary Professional Development Ability improved significantly ($p < 0.01$), while the Interdisciplinary Teaching Affection also showed a statistically significant increase ($p < 0.05$), though with a comparatively lower level of significance. Overall, the CCCP effectively enhanced the experimental group's ITC across multiple dimensions.

5.2 Innovative design

To explore the enhancement of PSTs' innovative ability in teaching design within this program, while also considering the development of in-service teachers' instructional capabilities, semi-structured interviews were conducted following the teaching intervention. Analysis revealed that the Cognitive Conflict in Community of Practice effectively stimulated teaching innovation awareness among multiple stakeholders and fostered the development of innovative teaching design skills within the synergistic "preservice and in-service" collaborative environment.

5.2.1 STEM preservice teachers: generating innovation through reflection and iteration. PSTs demonstrated significant growth in instructional design innovation, transitioning from initially idealized, theory-driven plans to more feasible and practice-oriented designs. Several groups reported multiple rounds of iteration and refinement in areas such as learning objectives, instructional tools and activity formats. Key improvements included:

- restructuring learning objectives around core disciplinary competencies;
- incorporating inquiry-based tasks to enhance student engagement; and
- transforming knowledge delivery into interactive and enjoyable learning experiences.

One PST shared in the interview, "This was my first close experience with teaching. Revising lesson plans under time pressure after trial instruction pushed me to rethink lesson relevance and explore innovative solutions to real teaching challenges."

In addition, feedback from in-service teachers played a pivotal role in driving these iterative improvements. As another PST reflected, "An in-service teacher pointed out that our originally designed experiment was too difficult for third graders and noted our misjudgment of the students' actual learning situation. We then revised the experiment to be more relatable and practical."

5.2.2 In-service teachers: reflection and inspiration from the "new vision". In-service teachers generally perceived the collaboration with PSTs as transcending traditional experience-sharing teaching and research activities, resembling more of a reciprocal learning process. During interviews, several teachers noted that although PSTs still exhibited shortcomings in classroom implementation, their innovative thinking at the instructional design level was refreshing. Particularly noteworthy were their strengths in pedagogical tools, activity planning and interdisciplinary integration, demonstrating robust theoretical grounding alongside creative practice.

One in-service teacher remarked, "Our previous lessons were relatively conventional, but the PSTs brought fresh perspectives – such as integrating art with science in unexpected ways – that made me reflect on how to better engage students in my own teaching."

Another commented, "Seeing them was like seeing my younger self. Some of their ideas are truly worth learning from, even for us veteran teachers. While we tend to focus on practical concerns, they are more capable of thinking beyond conventional frameworks."

6. Discussion

6.1 CCCP as an effective mechanism for enhancing interdisciplinary teaching competence

This study systematically investigated the effectiveness of the CCCP as a core pedagogical intervention to enhance PSTs' ITC. Quantitative results revealed that the experimental group significantly outperformed the control group in the post-test across four dimensions: Interdisciplinary Teaching Affection, Interdisciplinary Teaching Knowledge, Interdisciplinary Instructional Ability and Interdisciplinary Professional Development. This indicates that the model positively impacts PSTs' ITC.

Previous research (Cheng and Sun, 2025) has demonstrated that introducing cognitive conflict strategies in university classrooms can significantly enhance students' knowledge reconstruction and metacognitive skills. The present study further confirms that the CCCP effectively overcomes the limitations of passive knowledge reception typical of traditional STEM instruction, enabling students to engage in deeper knowledge construction within authentic problem contexts.

From the perspective of teaching practice, the Cognitive Conflict in Community of Practice effectively stimulated students' questioning and reconstruction of interdisciplinary instructional designs by setting challenging tasks, guiding cognitive conflicts across disciplines and facilitating role-based collaboration. For instance, through interactions with in-service teachers, PSTs recognized idealized elements in their designs. They then shifted focus toward better alignment among learning situation analysis, task difficulty and instructional tools. This process of "calibrating theory through practice" not only advances the applicability of pedagogical knowledge but also fosters self-renewal through reflective teaching, thereby expanding students' professional development pathways. This aligns strongly with findings from Rojas-Avilez *et al.* (2023), who highlighted interdisciplinary collaboration as a driver for pedagogical knowledge generation and reengineering in teacher professional learning communities.

Although the increase in scores on the Interdisciplinary Teaching Affection was relatively modest, the improvement was statistically significant. This suggests that cognitive conflict strategies positively influence students' affective and value-attitude domains while simultaneously stimulating higher-order cognition. Related studies focusing on STEM education emotions have noted that cognitive conflict promotes the activation of higher-order thinking and influences learning attitudes (Bao *et al.*, 2014). Therefore, it is plausible that this CCCP subtly shapes students' affective values alongside fostering cognitive and competency development in interdisciplinary teaching. Further refinement of assessment instruments may be needed in future research to capture these nuanced affective changes more precisely.

6.2 CCCP as an intrinsic driver of innovation generation

Another key finding of this study is that cognitive conflict not only facilitates knowledge reconstruction within collaborative instructional practices but also serves as a crucial mechanism driving the generation of innovative instructional designs. Interview data revealed that PSTs consistently encountered feedback and challenges from peers, in-service teachers and authentic teaching contexts during their instructional design process. Such feedback compelled them to critically reexamine their original ideas, thereby fostering more creative and practicable teaching plans. The transition from "idealized design" to "practice-adapted design" was achieved through the guidance and negotiation inherent in cognitive conflicts.

Simultaneously, in-service teachers experienced cognitive stimulation through reciprocal interactions with PSTs. Many reported that the fresh perspectives brought by PSTs' designs were "refreshing," prompting them to reflect on the limitations of their own established teaching strategies. This bidirectional cognitive exchange, based on an "experience-innovation" dynamic, offers a new pathway for professional growth across generations of educators.

Theoretically, this study further validates Piaget's and Mugny *et al.*'s model of "cognitive disequilibrium–reconstruction–equilibrium" (Piaget, 1985; Mugny *et al.*, 1975–1976). Coupled with collaborative innovation theory, it highlights that in multiagent teaching communities, cognitive conflict not only triggers conceptual change within individual learners but also acts as a key driver for creativity generation and overcoming bottlenecks in group collaboration. Particularly in interdisciplinary design tasks, PSTs must integrate knowledge and tools from diverse disciplines and coordinate role division collaboratively, forming a creative pathway characterized by "negotiation emerging from conflict" and "construction emerging from negotiation." This process significantly enhances their openness to innovative design and problem-solving abilities.

The findings resonate with prior research. For instance, Adnyani (2020) identified cognitive conflict as a critical mechanism for stimulating higher-order thinking; Li *et al.* (2021) argued that cognitive conflict enhances students' motivation and curiosity while emphasizing its role in knowledge construction and conflict facilitation within interdisciplinary synergy; Susilawati *et al.* (2019) found that inducing cognitive conflict significantly improved students' lateral thinking skills. This study extends the functional scope of cognitive conflict, underscoring that in PSTs' interdisciplinary training, cognitive conflict should be viewed not merely as a pedagogical challenge but as a valuable "resource" and "catalyst" in the instructional design process.

7. Conclusion

Grounded in the theory of collaborative innovation, this study constructed and implemented the CCCP to explore its effectiveness in enhancing PSTs' ITC and instructional design innovation ability in a STEM course. The model follows a core pathway of "conflict initiation–conflict resolution–cognitive rebalancing," embedded within a tripartite collaborative community involving university educators, in-service teachers and industry professionals. This structure fosters difference activation, collaborative knowledge construction and two-way transformation.

Quantitative analysis revealed that PSTs in the experimental group significantly outperformed those in the control group across all four measured dimensions: Interdisciplinary Teaching Affection, Teaching Knowledge, Instructional Ability and Professional Development. This indicates that the CCCP effectively promoted deeper engagement throughout theoretical learning, instructional design and simulated teaching. Qualitative data – drawn from interviews, reflective journals and design documents – further highlighted the pivotal role of cognitive conflict in deepening pedagogical reflection and stimulating instructional innovation. The CCCP not only facilitated the shift of PSTs from theoretical understanding to classroom practice but also inspired in-service teachers to reexamine and update their own instructional strategies. The two-way interaction led to mutual growth, enabling a new form of intergenerational professional development.

In addition to validating the CCCP's efficacy, this study expands theoretical understanding of how cognitive conflict can serve as a trigger for conceptual transformation when supported by multiagent collaboration. The CCCP offers a scalable and systematic framework for interdisciplinary curriculum design, with important implications for STEM PSTs education reform. Future STEM PSTs preparation programs should place greater emphasis on integrating multistakeholder collaboration, practice-based learning and cognitive adaptability. Constructing structured conflict scenarios and offering timely feedback mechanisms can effectively foster deep learning and innovative ability among PSTs in a STEM course. In addition, the model can be adapted to educational contexts beyond STEM through appropriate modifications, further broadening its applicability and impact.

Given the limitations in the scope and duration of the current study, future research could expand the sample size, extend the intervention period and incorporate multimodal data sources – such as social network analysis, learning analytics or eye-tracking technology – to further examine the mechanisms and boundaries of the "cognitive conflict–innovation generation" pathway. Such efforts will provide more robust empirical evidence to inform STEM PSTs development models.

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