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DEVELOPING CHEMISTRY PRESERVICE TEACHERS' PEDAGOGICAL CONTENT KNOWLEDGE (PCK) THROUGH THE LEARNING BY COLLABORATIVE DESIGN (LBCD) CURRICULUM MODEL

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Abstract. *Pedagogical Content Knowledge (PCK) is crucial for effective teaching, but it is a complex and implicit knowledge, especially in chemistry education. Therefore, this study explores the use of the LBCD (Learning by Collaborative Design) model to support PCK development among pre-service chemistry teachers. This study adopted a one-group pretest-posttest experimental design, conducting the intervention with 210 participants. After data collection, the study first conducted exploratory and confirmatory factor analyses on the pre-and post-test data, confirming the good reliability and validity of the designed chemistry PCK questionnaire. Additionally, paired sample t-tests were used to measure pre-service teachers' PCK development in dimensions of CTO, KOA, KOC, KOL, and KOS. Furthermore, unstructured interviews helped to further clarify the participants' views of the effectiveness of the LBCD curriculum. The results showed that the developed chemistry PCK questionnaire and the LBCD model had a significant statistical impact on the PCK elements development among pre-service teachers, although the development of these elements was not balanced. Finally, the study provides suggestions for the measurement of PCK elements, as well as chemistry teacher education, such as applying the LBCD model to different teacher groups and testing PCK element models using the methods of this study.*

Keywords: *chemistry preservice teachers, experimental design, LBCD curriculum model, PCK development*

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Introduction

Pedagogical content knowledge (PCK) refers to the professional knowledge and skills that a teacher possesses in a particular subject or content area and is key to ensuring effective teaching. As Park and Oliver (2008) point out, pedagogical content knowledge is a core element of a teacher's professional competence. It includes an understanding of concepts, principles, theories, skills, and methods related to a specific discipline, as well as knowledge and skills related to the teaching process (e.g., understanding instructional strategies, teaching methods, student learning characteristics, assessment techniques, and classroom management), the interplay between content and instructional methods, and an awareness of student learning difficulties and misconceptions (Shulman, 1986; Shulman, 1987; Neumann et al., 2019). Teachers need to have a deep understanding of not only subject matter knowledge but also relevant pedagogical methods and skills. This integration of 'pedagogical content knowledge' and 'pedagogical methodological knowledge' enables teachers to truly excel in their profession and provide quality educational services to their students (Castellano & Mikeska, 2023).

Scholars have different definitions of PCK categorization (Berry et al., 2015). Shulman (1986) initially identified two components of teacher expertise: content knowledge and (general) pedagogical knowledge. Magnusson et al. (1999) proposed the widely used five-component model of PCK, which includes orientation to science teaching (OST), knowledge of the curriculum (KoC), knowledge of the learner (KoL), knowledge of strategies (KoS), and knowledge of assessment (KoA) (Koberstein-Schwarz et al., 2022; Park, 2021). Gess- Newsome et al. (2019) hypothesized three internal structures of content knowledge (CK), pedagogical knowledge (PK), and contextual knowledge (CxK). Despite differences in the definition of PCK, scholars have emphasized

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the importance of teacher expertise (Pilous et al.) It represents a deep understanding and mastery of the content taught in the classroom, bridges the gap between subject-matter expertise and instructional practice, and is an essential component of effective teaching and learning (Forsler et al.) By enhancing PCK, teachers can provide students with a more effective and impactful learning experience for students, giving them the knowledge and skills they need to succeed (Kleickmann et al., 2015; He et al., 2021).

Research Problem

PCK is a complex and implicit form of knowledge in teachers' cognitive structures (Pilous et al., 2023). While teachers can perceive, experience, and develop PCK, expressing and formally transmitting PCK through language, text, or symbols poses challenges (Barendsen & Henze, 2019). Due to the implicit nature of PCK, the development and assessment of PCK have become challenging. Nevertheless, researchers have developed various PCK assessment tools, such as CoRe (Content Representations) and PaP-eRs (Pedagogical and Professional Experience Reports) developed by Loughran et al. (2007), PCK ERT (PCK Evidence Reporting Table) and PCK assessment standards developed by Park and Oliver (2008), and assessment tools developed by Leader-Janssen et al. (2013), TSPCK (PCK Evidence Reporting Table), and PCK assessment standards. Jang et al. (2013) explored pre-service teachers' PCK through workshops, mid-term and final evaluations, and teacher interviews. Aydeniz and Kirbulut (2014) developed an assessment tool for pedagogical content knowledge for secondary school science teachers. Kirschner et al. (2016) developed a paper-and-pencil test tool for physics teachers' PCK. Großschedl et al. (2019) developed a tool to measure pre-service biology teachers' pedagogical content knowledge using the Rasch model. These assessment tools mainly collect qualitative data through open-ended questionnaires, classroom observations, interviews, and two-stage questionnaires, with only a few researchers attempting to develop quantitative tools for evaluating teachers' PCK. In chemistry education, there is no widely influential quantitative assessment tool for teachers' PCK development.

In addition, the development of PCK is a continuous process that requires ongoing professional learning and reflective practice (Nilsson & Vikström, 2015; Tal et al., 2021). In chemistry education, pre-service teachers need to develop a solid foundation of chemistry content knowledge, pedagogical knowledge, and skills related to chemistry teaching (Padilla & Van Driel, 2011; Ekiz-Kiran et al., 2021). They must understand effective teaching strategies, assessment methods, and classroom management techniques to promote student engagement, critical thinking, and active learning (Can-Kucuk et al., 2022). Researchers have proposed various intervention models to facilitate the effective development of PCK in authentic teaching contexts for pre-service chemistry teachers. Combined with the comprehensive PCK consensus model proposed by Hume et al. (2019), the paths followed by researchers in designing PCK intervention models can be roughly divided into three categories, as shown in Figure 1. The first category directly impacts the practice of PCK within personal PCK, such as case studies and students serving as cooperative teachers (Schultze & Nilsson, 2018). The second category directly influences the planned PCK within personal PCK, aiming to promote the development of chemistry teachers' planned PCK, including instructional design, lesson planning, and curriculum development (Gess-Newsome et al., 2019). This can be achieved through curriculum analysis, lesson plan development, and peer collaboration (Nilsson & Vikström, 2015). The third category focuses on the collective professional knowledge component of PCK, aiming to enhance the development of collective professional knowledge within the chemistry teacher community, thereby promoting the development of individual professional knowledge (including planned professional knowledge and enacted professional knowledge). Examples in this area include professional learning communities (PLCs) and collaborative CoRe (Content Representations) design with mentors (Hume & Berry 2013). Currently, the first two intervention paths are more frequent, while research on the third path is relatively limited.

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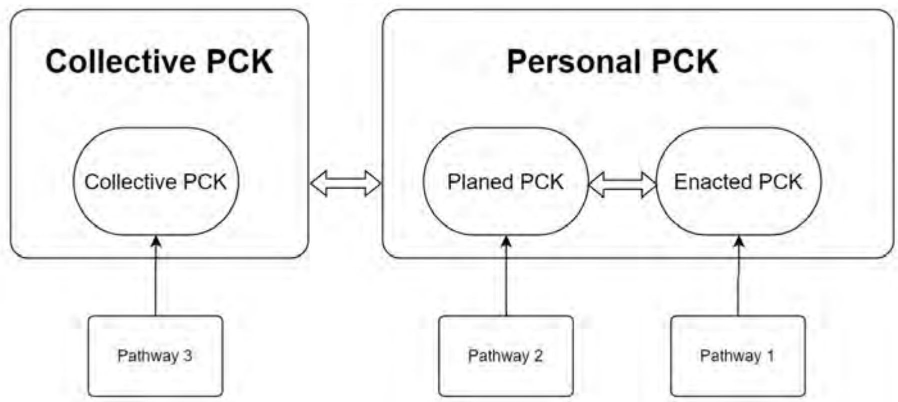
Figure 1
Pathways for PCK Development



Research Focus

Based on these analyses, there is little research related to the third pathway of PCK development and there is a need for a more standardized quantitative tool to assess the impact of intervention programs on pre-service chemistry teachers PCK. To address this problem, the intervention model of this study aimed to focus on the pathway of directly impacting collective PCK development to promote individual PCK development (Path 3). The Learning by Collaborative Design (LBCD) model is an innovative approach to education that emphasizes collaborative learning (Koehler et al.) The LBCD model emphasizes the creation of solutions to real-world problems through collaborative design, engaging learners in the active construction of knowledge (Stammes et al., 2020). In this model, pre-service teachers engage in the process of designing and solving problems in small groups, interacting, discussing, and collaborating. The LBCD model also encourages pre-service teachers to incorporate digital tools, simulations, and other resources into their teaching practices (Herodotou et al., 2022) to facilitate their collaborative learning and deepen their understanding of chemistry concepts (Yeh et al., 2021). Furthermore, to meet the need for a more valid questionnaire for quantitative measurement of PCK, this study developed a chemistry PCK scale based on the 5-element PCK model (Magnusson et al., 1999) and examined its quality. On this basis, this study measured the impact of LBCD on pre-service chemistry teachers' PCK development and verified the effectiveness of curriculum design in promoting chemistry PCK development.

Research Questions

This study aimed to address the following research questions:

1) Does the newly developed Chemistry PCK questionnaire, based on the 5-components PCK model, valid measure the PCK in pre-service chemistry teachers?
2) To what extent does the LBCD curriculum effectively promote the development of PCK among chemistry pre-service teachers?

Research Methodology

Context

This study employed a one-group pre-test and post-test research design to survey and intervene with pre-service chemistry teachers from a renowned teacher training institution in Guangdong, China, during the first semester of 2022. The institution focuses on preparing pre-service teachers for primary and secondary schools in China. The study was approved by the Chemistry Education Committee at the University. Before implementing the intervention, an advertisement was sent to all pre-service chemistry teachers. Participation was voluntary. Confirmed participants signed up with the lecturer and completed a consent form. During the intervention, the

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preservice teachers participated in the LBCD curriculum. Before and after the intervention, participants were required to complete a pre-and post-test PCK questionnaire.

Participants

Regarding the selection of the sample size for this study, since the study mainly involves an instructional intervention and adopts a pre-post questionnaire format, as well as conducting CFA and EFA analysis, the choice of sample size needs to consider multiple factors. Comrey and Lee (2013) proposed that for factor analysis, a sample size of 50 is considered very poor, 100 is poor, and 200 is acceptable, and this criterion has been widely used. Furthermore, Anderson and Gerbing (1984) conducted a Monte Carlo simulation and reached similar conclusions, indicating that when each latent variable has 3 indicators and the sample size is > 200, the probability of convergence failure is almost zero, and there are no incorrect solutions. Considering the current number of pre-service teachers of chemistry education in the university and the practical feasibility of the intervention, invitations were sent to all relevant students who had completed foundational courses in higher education chemistry, including inorganic, organic, analytical, physical, and structural chemistry, as well as education-related courses such as educational psychology, but had yet to receive specific training in chemistry teaching methods, pedagogical skills, or advanced topics in chemistry education. Ultimately 210 pre-service chemistry teachers (aged 20-22 years) volunteered to serve as participants, forming the formal sample size for this study. These included 108 females and 102 males. Also, to further gain a specific understanding of the impact of the LBCD curriculum on PCK, 30 students were randomly selected to participate in unstructured interviews as supplementary data of students' views of the effectiveness of the LBCD curriculum on their PCK development.

Design of the LBCD Curriculum

The Learning by Collaborative Design (LBCD) curriculum model comprises five phases, as depicted in Figure 2: (1) Collaborative Design Analysis: Teachers provide resources related to the theory of chemistry teaching design. Working in groups, preservice teachers discuss PCK components and their connections in the context of specific chemistry teaching topics. (2) Collaborative Design Guidance: Facilitated by instructors, preservice teacher groups engage in classroom discussions and interactions to address doubts and questions about teaching design. (3) Collaborative Design Construction: Preservice teacher groups collaborate and divide responsibilities to search for and organize teaching resources related to a specific topic. They then discuss and construct the group's teaching design. (4) Collaborative Design Refinement: Preservice teacher groups sequentially present their group teaching designs in the classroom and make further revisions based on feedback from instructors and other groups. (5) Collaborative Design Reflection: Preservice teachers share their refined group teaching designs and present their learning reflections. These five phases are interconnected and form a continuous cycle of collaborative design-reflection-revised collaborative design-revised reflection (Brennan & Gorman, 2023). This iterative process aims to develop the collective PCK of preservice teacher groups and, in turn, promote the development of individual PCK among preservice teachers (Lantz-Andersson et al., 2018).

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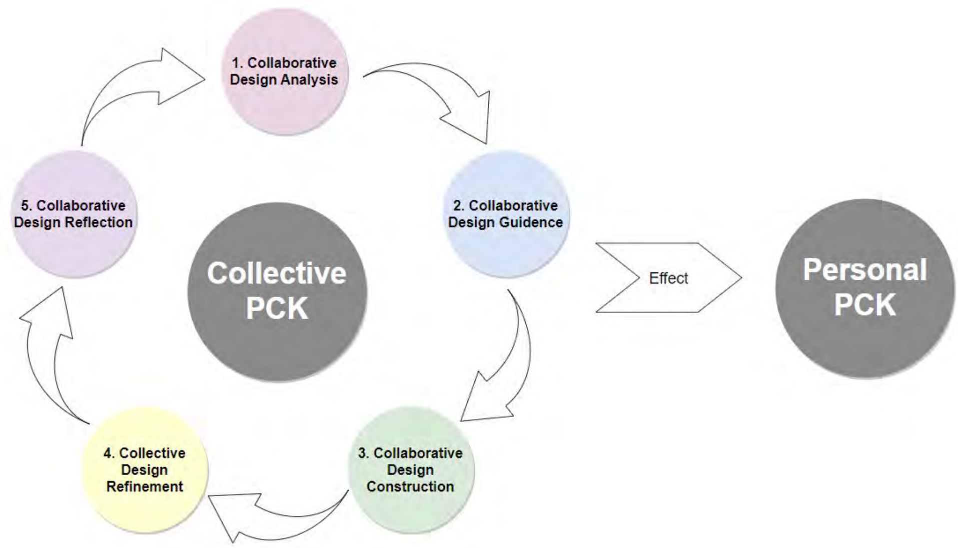
Figure 1
LBCD Curriculum Model



Development of Chemistry PCK Questionnaire

The process from questionnaire development to formal measurement involved four steps. Step 1 is defining the Components and Content of PCK. In this step, the PCK five-component model was used as the theoretical framework (Aydin et al., 2014).

The original Orientations to Science Teaching (OST) mainly refers to the field of science education, in this study, we are focusing on chemistry pre-service teachers, so it has been modified to Chemistry Teaching Orientation (CTO) to be more in line with the subject matter. The revised specific content of the five components is as follows:

Table 1
Contents and Dimensions of the PCK

Dimensions	Descriptions
CTO	Values and orientation of chemistry teachers towards the chemistry teaching process.
KoC	Chemistry teachers' understanding of curriculum standards and textbooks.
KoL	Chemistry teachers' understanding of students' prior knowledge and learning difficulties.
KoS	Chemistry teachers' understanding of chemistry teaching methods and representational means.
KoA	Chemistry teachers' understanding of the dimensions and methods of chemistry teaching evaluation.

Based on the contents and dimensions of the PCK components, the Chemistry PCK Questionnaire was initially developed. The questionnaire consisted of 20 self-report items, utilizing a 7-point Likert scale. Higher scores indicated a higher degree of agreement (1=strongly disagree, 7=strongly agree). After the initial development of the questionnaire, a chemistry education expert assessed the relevant questionnaire items. The assessment criteria included the scientific nature of each component dimension, the accuracy and appropriateness of item design, and the correctness and standardization of item statements. The modified questionnaire, based on expert opinions, was used in the study.

1) Reliability test

After the data collection, the reliability analysis of the questionnaire was conducted using Cronbach's α

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reliability coefficient in the pre-test and post-test phases. In the pre-test, the Cronbach's α values for each factor exceeded .91 (> .70), and in the post-test, the Cronbach's α values for each factor exceeded .87 (> .70), indicating good reliability of the questionnaire.

2) Exploratory Factor Analysis (EFA)

Exploratory factor analysis was first performed separately on the data from the 20 items in both the pre-test and post-test using SPSS 23.0 software, resulting in the identification of 5 factors. Specifically, the appropriateness of factor analysis was initially tested for all items. The results showed that in the pre-test, the KMO (Kaiser-Meyer-Olkin) value was .94 (> .80), and Bartlett's sphericity test $\chi^2 = 3838.36$, $p < .001$. In the post-test, the KMO value was .94 (> .80), and Bartlett's sphericity test $\chi^2 = 3186.35$, $p < .001$. These findings indicate that both pre-test and post-test data were suitable for factor analysis. The total explained variance for the 5 factors obtained in the pre-test was 82.14%, and in the post-test, it was 77.71%, both exceeding 70% (see Table 2 for the variance explained by each factor), indicating their strong explanatory power for PCK. Additionally, as shown in Table 2, the exploratory factor loadings for each item in the pre-test ranged from .66 to .87, and in the post-test, they ranged from .68 to .87, all exceeding .50, suggesting good initial validity for each item.

Table 2
Results of EFA

Component	Item	Pre-test		Post-test	
		Factor loading	Variance (%)	Factor loading	Variance (%)
CTO	Students' opinions are important and should be taken seriously	.82 (.85)	17.31	.87 (.84)	16.17
	Effective chemistry teaching should encourage more student discussion and hands-on practice	.85 (.89)		.84 (.83)	
	Studying chemistry means students have plenty of opportunities to explore, discuss and express their ideas	.87 (.88)		.81 (.82)	
	A good chemistry classroom should have a democratic and free atmosphere to promote students' thinking and communication	.82 (.80)		.77 (.80)	
KoC	I am familiar with the course objectives in the chemistry curriculum standards	.79 (.84)	17.16	.73 (.73)	14.46
	I am familiar with the content standards required in the chemistry curriculum standards	.82 (.88)		.68 (.87)	
	I am familiar with the distribution of modules in chemistry textbooks	.80 (.90)		.75 (.77)	
	I am familiar with the connection and continuity of contents in chemistry textbooks (junior/high school, compulsory/elective)	.72 (.84)		.71 (.79)	
KoL	I know the student's prior chemistry knowledge or learning experience	.74 (.87)	15.02	.78 (.83)	15.77
	I understand students' prior core literacy in chemistry	.77 (.89)		.83 (.87)	
	I understand possible learning difficulties or inadequacies in students' abilities	.66 (.88)		.70 (.84)	
	I understand possible misconceptions or misunderstandings that students may have	.73 (.82)		.73 (.83)	

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Component	Item	Pre-test		Post-test	
		Factor loading	Variance (%)	Factor loading	Variance (%)
KoS	I can use different teaching methods for different chemistry modules	.75 (.93)	16.83	.69 (.82)	15.38
	I can use various activities to enhance students' interest in learning chemistry	.77 (.89)		.73 (.85)	
	I can use real-life examples to explain chemistry concepts and/or principles	.78 (.85)		.80 (.85)	
	I can explain concepts and/or principles through demonstrations (e.g., physical objects, experi-ments)	.79 (.86)		.80 (.84)	
KoA	I know how to evaluate students' understanding and application of chemistry knowledge	.70 (.87)	15.82	.73 (.87)	15.93
	I know how to assess student's learning abilities in chemistry	.75 (.81)		.68 (.89)	
	I know how to evaluate students' attitudes and values toward chemistry	.77 (.84)		.75 (.86)	
	I know how to assess students' core competency levels in chemistry	.77 (.84)		.71 (.83)	

Note 1: Inside and outside the brackets are confirmatory factor loadings and exploratory factor loadings respectively.
Note 2: CTO: Chemistry Teaching Orientation; KoC: Knowledge of Curriculum; KoL: Knowledge of Learners; KoS: Knowledge of Strategies; KoA: Knowledge of Assessment

3) Confirmatory Factor Analysis (CFA)

To further assess the structural validity, convergent validity, and discriminant validity of the questionnaire, CFA was conducted using AMOS 22.0.

Model fit was first assessed to evaluate the adequacy of the structural model in this study. The fit indices for both the pre-test and post-test are reported below (Table 3). These results indicate that the model exhibited good structural validity in both the pre-test and post-test (Yaşlioğlu & Yaşlioğlu, 2020). The χ^2/df was below the recommended threshold of 3.00, suggesting a good fit between the model and the observed data. The RMSEA and SRMR values were also below the cutoff of .08, indicating a close fit of the model to the data. Additionally, the NFI, IFI, TLI, and CFI values were all above the minimum threshold of .90, further supporting the model's adequacy. The model fit results provide evidence that the proposed structural model adequately represents the relationships among the observed variables in the study.

Table 3
Model Fit

Test Type	χ^2/df	RMSEA	SRMR	NFI	IFI	TLI	CFI
Pre-Test	2.06	.07	.05	.92	.96	.95	.95
Post-Test	1.50	.05	.04	.93	.97	.97	.97

Note: χ^2/df: Chi-square/degrees of freedom; RMSEA: Root Mean Square Error of Approximation; SRMR: Standardized Root Mean Square Residual; NFI: Normed Fit Index; IFI: Incremental Fit Index; TLI: Tucker-Lewis Index; CFI: Comparative Fit Index

Composite reliability and convergent validity were assessed to evaluate the reliability of the measurement tool in this study. As presented in Table 2, confirmatory factor loadings were calculated for each item in both the pre-test and post-test. The loadings ranged from .80 to .90 in the pre-test and from .73 to .89 in the post-test, all surpassing the threshold of .50. This indicates that each item adequately represents its respective factor. To fur-

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ther examine the reliability of the factors, the average variance extracted (AVE) and construct reliability (CR) were computed for each factor. In the pre-test, AVE values ranged from .71 to .77, exceeding the recommended value of .50. Additionally, CR values ranged from .91 to .93, surpassing the minimum threshold of .70. Similar results were obtained in the post-test, with AVE values ranging from .62 to .75 and CR values ranging from .87 to .92. The high factor loadings, along with the AVE and CR values exceeding the recommended thresholds, provide evidence for the robustness and consistency of the measurement tool used in this study (Cheung et al., 2023).

Discriminant validity was assessed to examine the distinctiveness of the factors in the questionnaire. The correlation matrix presented in Table 4 shows that all correlations between factors in both the pre-test and post-test were statistically significant ($p < .01$). The correlation coefficients ranged from .39 to .76 in the pre-test and from .47 to .67 in the post-test. To evaluate discriminant validity, the square root of the average variance extracted (AVE) for each factor was compared to the Pearson correlation coefficients. The results revealed that all correlation coefficients were lower than the square root of the corresponding AVE in both the pre-test and post-test (Rönkkö & Cho, 2022). This indicates that while there was some interrelation between the factors, they also demonstrated sufficient discriminant validity.

Table 4
Results of Discriminant Validity

	KoC	KoL	KoS	KoA	CTO
KoC	.75 (.62)				
KoL	.68** (.65**)	.75 (.71)			
KoS	.66** (.65**)	.66** (.64**)	.77 (.70)		
KoA	.61** (.67**)	.76** (.65**)	.65** (.59**)	.71 (.75)	
CTO	.49** (.40**)	.51** (.45**)	.53** (.50**)	.39** (.47**)	.73 (.67)
$\sqrt{AVE}$	.86 (.79)	.87 (.84)	.88 (.84)	.84 (.87)	.85 (.82)

Note 1: The inside and outside brackets are post-test and pre-test respectively, the diagonal is AVE, **p < 0.01.
Note 2: CTO: Chemistry Teaching Orientation; KoC: Knowledge of Curriculum; KoL: Knowledge of Learners; KoS: Knowledge of Strategies; KoA: Knowledge of Assessment

The results of the CFA mentioned above indicate that there are significant correlations among the first-order factors of PCK in both the pre-test and post-test phases (see Figure 3). Based on the PCK five-component model, a second-order structural model was established (see Figure 4), and its fit to the data was examined through higher-order confirmatory factor analysis. The model fit of the pre-test and the post-test can be seen in Table 5. These results suggest that the second-order structural model is a good fit for the data (Yaşlioğlu & Yaşlioğlu, 2020). Additionally, the factor loadings of the first-order factors in the pre-test ranged from .60 to .90 (> 0.5), and in the post-test, they ranged from .59 to .89 (> .5). This indicates that the lower-order factors have high explanatory power for the higher-order factor, which further supports the validity of the second-order structure.

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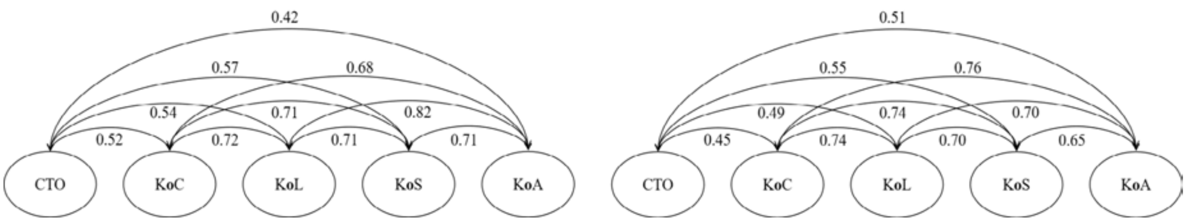
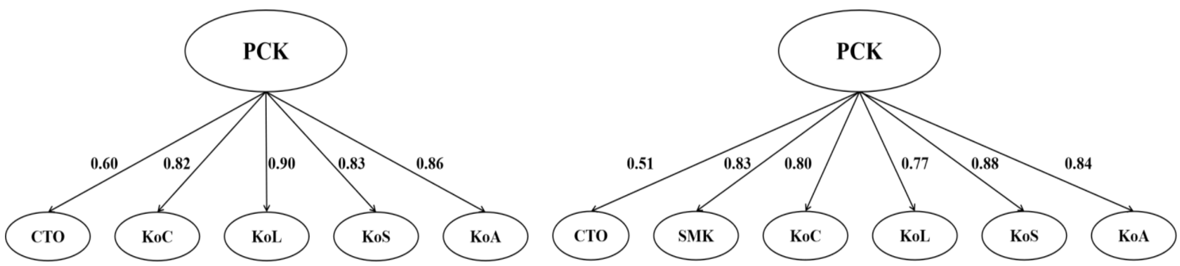
Figure 3
First-order Pairwise Correlation Structure of PCK



Note 1: The left side is the pre-test, and the right side is the post-test.
Note 2: CTO: Chemistry Teaching Orientation; KoC: Knowledge of Curriculum; KoL: Knowledge of Learners; KoS: Knowledge of Strategies; KoA: Knowledge of Assessment

Figure 4
Second-order Structure of PCK



Note 1: The left side is the pre-test, and the right side is the post-test.
Note 2: CTO: Chemistry Teaching Orientation; KoC: Knowledge of Curriculum; KoL: Knowledge of Learners; KoS: Knowledge of Strategies; KoA: Knowledge of Assessment

Table 5
Model fit

Test Type	χ^2/df	*RMSEA*	*SRMR*	*NFI*	*IFI*	*TLI*	*CFI*
Pre-Test	2.14	.07	.05	91	.95	.94	.95
Post-Test	1.53	.05	.05	.92	.97	.97	.97

Note: χ^2/df: Chi-square/degrees of freedom; RMSEA: Root Mean Square Error of Approximation; SRMR: Standardized Root Mean Square Residual; NFI: Normed Fit Index; IFI: Incremental Fit Index; TLI: Tucker-Lewis Index; CFI: Comparative Fit Index

Unstructured Interviews

After the intervention, 30 participants were randomly selected for interviews to find out their views of the effectiveness of the intervention and the deep reasons behind these views. The interview questions mainly covered topics such as "How did you complete the various sections of your teaching design before the course?", "How did you complete the various sections of your teaching design after the course?", "What were the reasons for the changes in your teaching design method before and after the course?", and "In your opinion, what impact does group collaboration in teaching design have on your learning?"

Data Analysis

First, after the development of the chemistry PCK questionnaire, Exploratory Factor Analysis (EFA) and Confirmatory Factor Analysis (CFA) were used to assess the quality of the questionnaire. EFA was employed to assess

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the goodness of fit of the PCK five-component model (a first-order model with pairwise correlations). Based on the strong correlations among the first-order factors of the questionnaire, high-order CFA was conducted to assess the goodness of fit of the "second-order" structure of the questionnaire. Besides, Paired-Samples t-tests were also used to compare the levels of individual PCK components among preservice chemistry teachers before and after the intervention. Additionally, interview data were utilized to explain further changes in the levels of PCK components and the reasons behind these changes. This study employed SPSS 23.0 and AMOS 22.0 software for data analysis.

Research Results

Pre-service Teachers' Chemistry PCK Performance

Before and after the intervention, the normality test was performed on the pre and post-test results. Based on the data conforming to the normal distribution, descriptive statistics and paired sample t-tests were conducted on the scores of PCK in the pre-test and post-test to examine the effectiveness of the LBCD curriculum model in promoting the development of PCK components. The results (Table 6) showed that there are significant differences in the mean of PCK components, including CTO, KoC, KoL, KoS, and KoA, between the pre-test and post-test. Comparing the post-test to the pre-test, there were improvements in the mean scores of all PCK components. The degree of improvement, from highest to lowest, is ranked as follows: KoL (0.59), KoA (.53), KoC (.49), KoS (.45), and CTO (.44). This suggests that the LBCD curriculum model has a statistically significant positive effect on the development of PCK components, and the development of each component shows some degree of unevenness.

Table 6
Results of Descriptive Statistics and Paired Sample t-test

Component	Paired	*M*	*SD*	*t*	*df*	*p*
CTO	CTO pre-test	4.85	1.19	-4.17	209	<.01
	CTO post-test	5.29	.90			
KoC	KoC pre-test	4.56	1.35	-4.20	209	<.001
	KoC post-test	5.05	.98			
KoL	KoL pre-test	4.34	1.30	-5.28	209	<.001
	KoL post-test	4.93	1.01			
KoS	KoS pre-test	5.02	1.43	-3.60	209	<.01
	KoS post-test	5.47	.92			
KoA	KoA pre-test	4.29	1.20	-4.73	209	<.001
	KoA post-test	4.82	1.06			

Note: CTO: Chemistry Teaching Orientation; KoC: Knowledge of Curriculum; KoL: Knowledge of Learners; KoS: Knowledge of Strategies; KoA: Knowledge of Assessment

Pre-service Teachers' Perceptions of the Effectiveness of the LBCD Curriculum

A detailed analysis of the improvement in the levels of PCK components based on individual questionnaire items was provided, and further explanation was based on the responses of preservice teachers to interview questions (see Table 7).

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Table 7
Example of Interview Results

Interview Questions	Sample interview responses for preservice teachers
1. How did you complete the writing of each part of the instructional design before studying the course?	*Student 5 Before class, my understanding of chemistry classes was based on the traditional model of teachers lecturing and students listening. My knowledge of curriculum standards and textbooks is limited to the outdated textbooks I used in high school. I have heard about curriculum standards, but I don't fully understand them. When analyzing students' learning, I mainly rely on my observations and personal experiences, or I refer to the literature.* *Student 11: For activity design, I learned some teaching methods during my sophomore year, such as question and answer methods, experimental methods, etc., as well as teaching tools like pictures and videos. However, when it comes to lesson planning and teacher activities, I usually rely on my intuition or use existing teaching materials. In terms of evaluation, I primarily assess students' understanding of chemistry knowledge and help them reinforce and check their understanding through exercises and tests after class.*
2. How did you complete the writing of each part of the instructional design after studying the course?	*Student 5:I have a better understanding of the new textbooks and curriculum standards when analyzing them. It's important to examine the content and organization of the teaching materials and outline the topics to be covered in class. While curriculum standards are consistent nationwide, textbooks may vary.* *Student 13: I understand the significance of conducting a well-founded analysis of students' learning. This analysis should summarize students' existing knowledge, identify their learning difficulties, and evaluate their abilities, conceptual understanding, and literacy. It should be based on references to textbooks, curriculum standards, and empirical research papers. However, it's important to avoid directly quoting literature conclusions and instead provide an analysis that considers the specific context.* *Student 11: In terms of activity design, I feel more comfortable with designing teaching situations, selecting teaching methods, and utilizing different teaching representation techniques. The design of learning tasks and activities should be logical and structured, incorporating various teaching representation methods effectively. It's important to prioritize the scientific and appropriate use of these methods.* *Student 17: I have learned various evaluation tools and methods such as concept maps and evaluation rubrics.*
3. What are the reasons for the change in your method of writing instructional design before and after studying the course?	*Student 3: In my case, the change occurred when I studied the instructional designs of other groups in class. Although all the groups delivered excellent presentations, my group presented later in the class. As we listened to the presentations of other groups, we made modifications to our designs. We learned from the strengths of other groups and took the opportunity to self-assess and correct any shortcomings.* *Student 16: The main reasons were the teacher's constructive feedback during each class and the comments from other groups. These suggestions also triggered our group's reflection and promoted our continuous revision.* *Student 28: This change came about through an iterative process of revisions, driven primarily by the teacher's guidance. After one of our group presentations, the teacher asked us about how we planned to implement the evaluation objectives. When our group was unable to provide a satisfactory response, it prompted us to reflect deeply on the selection and design of the evaluation tool. Following this feedback, our group refined the evaluation tool to better address this aspect.*
4. What effect do you think working in groups on instructional design has on your learning?	*Student 9: Working side by side with the team members did help a lot. It was really difficult for me to persevere through revision after revision.* *Student 13: Our group was a productive community. Everyone was willing to help each other while discussing and modifying our design products.* *Student 22: When we compared our work with other groups, we often realized our shortcomings. This motivated us to further revise our work. The more we revise, the better our understanding becomes.*

CTO (Chemistry Teaching Orientation). Before and after the intervention, preservice chemistry teachers showed an improvement in the average scores for all items related to CTO. The items with the greatest improvement, in descending order, were "studying chemistry means students have plenty of opportunities to explore, discuss and express their ideas" (.64), "Effective chemistry teaching should encourage more student discussions and hands-on practice" (.42), "A good chemistry classroom should have a democratic and free atmosphere to promote student thinking and communication" (.38), and "Student perspectives are very important and should be taken seriously" (.32). Based on the responses of preservice teachers to interview questions 1 and 2, Many preservice teachers mentioned in the interviews that their impressions of classroom organization in chemistry before the intervention were based on a teacher-centric model where the teacher talks and students listen. After the intervention, preservice teachers had a deeper understanding that the classroom should be student-centered, providing students with more opportunities for exploration, discussion, and expression in chemistry classes.

KoC (Knowledge of Curriculum). Before and after the intervention, preservice teachers also showed improvement in the average scores for all items related to KoC. The items with the greatest improvement were "I am familiar

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with the content standards required in the chemistry curriculum standards" (.55) and "I am familiar with the connection and continuity of contents in chemistry textbooks" (.55). On the other hand, the items with relatively smaller improvements were "I am familiar with the distribution of modules in chemistry textbooks" (.44) and "I am familiar with the course objectives in the chemistry curriculum standards" (.44). It was revealed through interviews that preservice teachers had not studied courses related to the analysis of chemistry curriculum standards or the analysis of middle school chemistry textbooks before the intervention, and their awareness of curriculum standards was limited, mostly based on their experiences in middle and high school. After the intervention, preservice teachers became more familiar with the distribution and connection of textbook content, as well as the course objectives and content standards in the curriculum.

KoL (Knowledge of Learners). Before and after the intervention, preservice teachers improved the average scores for all items related to KoL. The items with the most significant improvement, in descending order, were "I understand possible misconceptions or misunderstandings that students may have" (.70), "I understand possible learning difficulties or inadequacies in students' abilities" (.59), "I understand students' prior core competencies in chemistry" (.56), and "I know students' prior chemistry knowledge or learning experience" (.52). According to the interviews, preservice teachers' knowledge about student learning before the intervention was mainly based on their learning experiences, literature, and educational materials. After the intervention, preservice teachers recognized the need to analyze students' knowledge and learning difficulties based on curriculum standards, textbooks, and empirical papers with specific data from various dimensions, including knowledge, skills, methodological abilities, and conceptual literacy.

KoS (Knowledge of Strategies). Before and after the intervention, preservice teachers demonstrated improvement in the average scores for all items related to KoS. The items with the greatest improvement were "I can use real-life examples to explain chemistry concepts and/or principles" (.54) and "I can use various activities to enhance students' interest in learning chemistry" (.49). On the other hand, the items with relatively smaller improvements were "I can use different teaching methods for different chemistry modules" (.39) and "I can explain concepts and/or principles through demonstrations (e.g., physical objects, experiments)" (.36). Many preservice teachers mentioned in the interviews that they had studied educational courses before the intervention, so they had some understanding of teaching methods and teaching representation methods, although their understanding was relatively vague. After the intervention, preservice teachers had a deeper understanding of the selection of chemistry teaching methods, the design of learning task activities, and the application of teaching content representation methods.

KoA (Knowledge of Assessment). Before and after the intervention, preservice teachers showed improvement in the average scores for all items related to KoA. The items with the greatest improvement were "I know how to evaluate students' attitudes and values towards chemistry" (.60) and "I know how to assess students' core competency levels in chemistry" (.56). In comparison, the items with relatively smaller improvements were "I know how to assess student's learning abilities in chemistry" (.51) and "I know how to evaluate students' understanding and application of chemistry knowledge" (.47). It was revealed through interviews that, influenced by the current emphasis on assessing students mainly in terms of knowledge and skills and the predominant use of paper-and-pencil tests as the primary assessment method in secondary school chemistry education, preservice teachers before the intervention had limited considerations for evaluating students from higher dimensions such as core competencies in chemistry, fundamental concepts, etc. After the intervention, preservice teachers began to develop an awareness of designing assessment objectives based on various dimensions, including knowledge, skills, methodological abilities, conceptual literacy, etc., and selecting or developing assessment tools.

Besides, based on the responses of preservice teachers to interview questions 3 and 4, the facilitating effect of the LBCD curriculum model on the development of PCK components was explained (see Table 4). Regarding interview question 3, preservice teachers frequently mentioned keywords such as "repeated revisions," "learning from each other," "reflection," "mentoring feedback and guidance," and "capitalizing on strengths and addressing weaknesses." In response to interview question 4, preservice teachers often mentioned keywords like "common progress," "professional learning community," "mutual achievements," "collective brainstorming," "working side by side," and "collaborative teamwork." From this, it is evident that within the course, preservice teacher groups have formed a professional learning community. Within this community, they have transformed the individual "I" into the collective "we." Through continuous collaborative design, mutual reflection, joint problem-solving, and collaborative revisions, they have facilitated the development of collective PCK within the community. Collaborative group work in designing teaching has provided preservice teachers with a platform for dialogue and mutual assistance and has stimulated their subjective initiative. After actively absorbing collective PCK from the community, they gradually internalize it as their personal PCK, resulting in mutual achievements and collective progress.

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Discussion

This study developed a high-quality pre-service chemistry teacher PCK questionnaire using the SEM and Magnusson et al.'s (1999) five-element model of teacher PCK. The study also implemented the LBCD teaching model to support the development of pre-service chemistry teacher PCK.

Regarding research question 1, many previous studies have explored methods for assessing PCK. For example, Schubatzky et al. (2023) investigated the development of digital media teaching content knowledge in physics teacher education through workshop-based approaches, while Kutluca (2021) designed and conducted interviews to determine the PCK levels of elementary school teachers. However, these studies mostly used qualitative assessment methods and lacked effective quantitative assessment tools (Schiering et al., 2023). Currently, Magnusson's five-element PCK model is the most widely applied (Leijen et al., 2022). Based on this model, the researchers designed a 20-item PCK scale for pre-service chemistry teachers. To validate the reliability and validity of this measurement tool, the researchers calculated Cronbach's α reliability coefficient and conducted EFA and CFA. By calculating Cronbach's α reliability coefficient, researchers can assess the internal consistency of the scale (Bland et al., 1997). In addition, EFA and CFA can verify the distribution of the five components of PCK and confirm whether the scale's structure aligns with expectations (Orçan, 2018). Through these validation steps, this study developed a quantitative assessment tool for pre-service chemistry teacher PCK, enabling a comprehensive understanding and analysis of PCK development. It also provides an effective measurement tool for future teacher training.

For research question 2, developing chemistry teacher PCK, this study employed a quasi-experimental research method and designed and implemented the LBCD teaching curriculum model. This model aimed to engage pre-service chemistry teachers in collaborative learning experiences within a supportive practice community to enhance their understanding of subject matter content, teaching strategies, and instructional design (Stammes et al., 2020; Weinberg et al., 2021). The curriculum design consisted of five phases: collaborative design analysis, collaborative design guidance, collaborative design construction, collaborative design refinement, and collaborative design reflection. These five phases formed a continuous cycle of "collaborative design-reflection-revised collaborative design-revised reflection" to develop collective PCK among the pre-service teacher cohort and promote individual PCK development (Chai et al., 2020). Through carefully designed pre- and post-assessments using questionnaires, it was found that the LBCD curriculum significantly affected various dimensions of pre-service chemistry teacher PCK. The improvement levels ranked from highest to lowest were KoL, KoA, KoC, KoS, and CTO.

Through an in-depth analysis of the reasons for the significant improvements in KoL and KoA, it was found that the current emphasis on knowledge and skill transmission and paper-and-pencil testing as the primary means of evaluating student development in secondary school chemistry education due to academic pressures limits pre-service chemistry teachers' understanding of student learning. Their understanding is primarily based on their learning experiences, literature, and textbooks, with limited consideration of higher-dimensional aspects such as chemical literacy and fundamental concepts (Ye et al., 2021). However, after participating in the intervention curriculum, pre-service teachers realized the need to comprehensively understand student learning from various dimensions, such as knowledge, skills, methodological abilities, and conceptual understanding, based on curriculum standards, textbooks, and empirical papers (Vojíř & Rusek, 2022). They began consciously designing assessment goals from different dimensions and selecting or developing assessment tools (Tomasevic et al., 2021). This shift enabled them to analyze students' knowledge levels and learning difficulties more accurately and provide targeted support and guidance (Navy et al., 2021). The intervention curriculum may have provided theoretical and practical knowledge of multidimensional assessment, helping pre-service teachers better understand and apply assessment methods. They may have learned how to design challenging and inspiring tasks based on the requirements of subject literacy to assess students' understanding of fundamental concepts, mastery of experimental skills, and ability to solve chemical problems (Babinčáková et al., 2020).

Additionally, the intervention curriculum may have provided specific data analysis tools and techniques to help pre-service teachers better utilize student assessment data, identify student learning needs, and develop personalized teaching plans (Boesdorfer et al., 2022). On the other hand, teaching beliefs require time and accumulated practice to learn and understand, and CTO, as an essential dimension in the PCK model, often undergoes slow changes over time (Hashweh, 2005; Jay, 2023). Compared to other PCK dimensions, the development of a CTO may require longer-term interventions and continuous support (Ekiz-Kiran & Boz, 2020).

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Conclusions and Implications

Through designing the Chemistry PCK questionnaire and implementing the LBCD curriculum for preservice chemistry teachers, this study yielded three main conclusions: (1) The designed chemistry PCK questionnaire exhibited high quality, indicating its effectiveness in measuring PCK. (2) Implementing the LBCD curriculum model resulted in a statistically significant positive impact on developing PCK components among preservice chemistry teachers. However, it was observed that the growth across these components was uneven. The improvement levels across different dimensions of PCK varied, with the highest improvement seen in KoL, followed by KoA, KoC, KoS, and finally, CTO. Based on these findings, several recommendations can be made for chemistry PCK assessment and teacher education. The findings of this study highlight the effectiveness of the designed chemistry PCK questionnaire in measuring PCK. Researchers and educators can employ this questionnaire to gain valuable insights into the pedagogical content knowledge of chemistry teachers and inform targeted professional development programs. Besides, in chemistry teacher education, the LBCD curriculum model developed in this study demonstrates innovative design and practicality in implementation, showing effectiveness in practice. It serves as a valuable reference for higher education of chemistry teachers. For instance, based on the success of the LBCD model, peer assistance, mentoring programs, and the establishment of professional learning communities for teachers can be considered.

This study also has limitations. Regarding PCK assessment, future research could consider applying the questionnaire designed in this study to different groups of chemistry teachers. This would allow for quantitative exploration of PCK component levels among different groups and further exploration of the relationship between chemistry teacher PCK and factors such as subject knowledge, teaching experience, and teacher beliefs. It also provides an opportunity to validate the reliability and validity of the questionnaire further. Second, the questionnaire developed in this study focused on assessing PCK in the domain of chemistry but needed more specificity in terms of subject matter. Subsequent research could enhance the thematic specificity of questionnaire development by designing PCK questionnaires tailored to specific chemistry topics. Besides, the LBCD curriculum model significantly impacted the development of PCK components among preservice chemistry teachers. However, the uneven growth observed across these components suggests the need for further exploration and refinement of the curriculum model. Educators and curriculum designers should consider tailoring the model to address preservice chemistry teachers' specific needs and challenges, ensuring a more balanced development of PCK components. Lastly, this study lacked a control group due to the limitations of time and resources. Future research should employ controlled experiments or comparative studies to determine the differences in PCK development between the LBCD curriculum intervention group and a blank control group.

Declaration of Interest

The authors declare no competing interest.

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