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Exploring the Role of Pedagogical Content Knowledge in Effective Chemistry Teaching

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Abstract
Effective teaching in chemistry requires not only mastery of content but also the ability to convey concepts in ways that enhance student understanding. This study explores the impact of Chemistry teachers' Pedagogical Content Knowledge (PCK) on their classroom practices. Using a mixed-method approach, data were collected from 80 secondary school chemistry teachers through structured questionnaires and classroom observations. The findings indicate a strong correlation between high levels of PCK and the use of innovative teaching strategies, conceptual explanations, and student-centered learning activities. Teachers with limited PCK often relied on rote teaching methods and lacked strategies to address student misconceptions. The study highlights the critical role of continuous professional development in strengthening PCK, thereby improving instructional effectiveness. Results underscore the importance of integrating content knowledge with pedagogical skills to foster meaningful learning experiences in chemistry classrooms.

Keywords: Pedagogical Content Knowledge (PCK), Chemistry teaching, Classroom practices, Teacher effectiveness, Secondary education

Introduction

Pedagogical content knowledge (PCK) has emerged as a pivotal framework in understanding the effectiveness of teaching practices, especially in specialized concern regions like chemistry. Seeing that its creation by way of Shulman (1986), PCK has been

extensively diagnosed as the amalgamation of issue-specific information and pedagogical competencies, enabling instructors to supply content in approaches that are understandable and significant to newcomers. Inside the context of chemistry, a subject characterised with the aid of summary principles, complicated theories, and microscopic methods, instructors' PCK plays a crucial function in facilitating college students' expertise, engagement, and achievement (Jammeh, Karegeya, & Ladage, 2024). The precise nature of chemistry as a technology discipline calls for teachers to own not most effective a deep knowledge of the content material however also the capability to convert this content material into teachable forms that deal with college students' prior knowledge, misconceptions, and numerous getting to know desires (Magnusson, Krajcik, & Borko, 1999). Therefore, the pleasant of teachers' PCK has an immediate impact on school room practices, shaping instructional strategies, scholar interactions, and usual getting to know outcomes. Chemistry coaching entails interaction between macroscopic view, submicroscopic images as well as symbolic words, which are often hard to affix and identify by college students (Taber, 2002; Gabel, 1999). Teachers who have high PCK are skilled bridges who go through those representational steps and apply effective teaching methods such as fashions, analogies, demonstrations, and hands on experiments to help children develop conceptual knowledge (Van Driel, Verloop, and De Vos, 1998).

As an example, the hardware simplicity of matter, equilibrium of chemical equations, or ciphering chemical responses requires instructors to rely on the fallacies of college scholars and find a way to address them, strategically with aptly crafted training and scaffold mastering tasks (type, 2009). In both advanced and developing conditions, the role of PCK in defining the learning demanding situations and failing to utilize proper pedagogical equipment has been significantly emphasized (Rollnick et al., 2008). It has been shown that powerful instructors combine such content material know-how and pedagogical techniques to develop meaningful gaining knowledge of studies to appeal to the cognitive and emotional needs of students (type and Chan, 2019). In illustration, a teacher with high stage of PCK is capable of applying real global examples, experiments and mastering problems based in problems in order to bring the abstract meaning into reality and familiarity (Loughran, Berry, and Mulhall, 2006). This ability is, particularly, needed in chemistry where students are

constantly fighting with subjects and chemical bonding, thermodynamics, and equilibrium due to their abstract and theoretical character (Nicoll, 2001).PCK permits instructors to simplify complex ideas without compromising scientific accuracy, thereby improving students' vital questioning and hassle-fixing capabilities. in spite of its importance, the development and utilization of PCK among chemistry instructors remain uneven, influenced with the aid of factors which includes teachers' educational backgrounds, professional training, coaching enjoy, and get admission to resources (Ouch, & Shimizu, 2024). Research have shown that beginner instructors frequently exhibit limited PCK due to inadequate publicity to concern-specific pedagogical tactics in the course of their pre-carrier training (Abell, 2008; Nilsson, 2008). Conversely, skilled instructors tend to expand richer PCK over time as they mirror on their teaching practices, interact in expert improvement, and adapt their practise based totally on college students' getting to know desires (Park & Oliver, 2008). However, the connection between PCK and classroom practices is not linear; it requires non-stop mirrored image, experimentation, and refinement to align academic strategies with evolving curricular standards and scholar expectancies (Gess-Newsome, 2015). Consequently, expertise the ways in which chemistry instructors' PCK affects their study room practices is important for informing instructor training programs, professional development initiatives, and curriculum reforms (Sarkar, et al., 2024).

School room practices, as a reflection of teachers' PCK, encompass various dimensions, consisting of lesson making plans, educational strategies, assessment methods, and classroom interactions. Teachers with nicely-advanced PCK are much more likely to design training which might be pupil-focused, inquiry-based totally, and aligned with the gaining knowledge of dreams of chemistry schooling (Cochran, DeRuiter, & King, 1993). They’re additionally adept at using formative and summative exams to diagnose students' know-how, provide feedback, and modify their coaching techniques therefore (Shulman, 1987). For example, in coaching stoichiometry, teachers with sturdy PCK may employ diagnostic tests to perceive college students' misconceptions approximately the mole concept and eventually layout sports that sell conceptual clarity through hands-on experimentation and visual representations (Arslan, 2019). Furthermore, such teachers foster interactive and inclusive classroom environments where

students are advocated to invite questions, have interaction in discussions, and increase scientific reasoning abilities (Lee, 2017). The impact of PCK on chemistry teachers' practices is further stimulated via the contextual and cultural factors inside instructional settings (Jain, Ling, & Jin, 2024). In useful resource-limited environments, instructors may face challenges along with constrained access to laboratory system, academic materials, and expert assist that may prevent the powerful software of PCK (Rollnick, Bennett, Rhemtula, Dharsey, & Ndlovu, 2008). Nevertheless, teachers with strong PCK often demonstrate resilience and creativity in overcoming such obstacles by way of the use of domestically available assets and designing alternative educational techniques (Mavhunga & Rollnick, 2013). As an instance, an instructor would possibly use household materials to simulate chemical experiments or rent storytelling and analogies to explain abstract ideas, thereby making learning extra available and attractive for college kids (Jin, 2019). Such adaptability underscores the dynamic nature of PCK and its important function in permitting instructors to navigate the complexities of classroom preparation (Bwalya, Rutegwa, & Mapulanga, 2024).

Empirical research have continually shown an effective correlation between instructors' PCK and student gaining knowledge of results in science education (Baumert et al., 2010; Lee & Luft, 2008). In chemistry, teachers who possess well-advanced PCK are much more likely to foster students' conceptual knowledge, medical literacy, and hobby in pursuing technological know-how-related careers (type, 2014). For example, a look at by using Mthembu and Ngema (2020) observed that scholars taught through teachers with high PCK established extra improvements in their knowledge of chemical equilibrium and reaction kinetics in comparison to those taught through teachers with confined PCK. further, Rollnick and Mavhunga (2016) stated that focused expert development packages focusing on PCK appreciably greater instructors' academic effectiveness and college students' instructional overall performance in chemistry. Those findings highlight the want for ongoing efforts to bolster instructors' PCK thru based training, mentorship, and collaborative gaining knowledge of opportunities (Chuene, & Singh, 2024). Since PCK plays a significant role in the school room practice of chemistry teachers, there is an urgent need to find out how teachers accumulate, expand, and monitor their PCK in many classrooms environments. This exploration may have useful information on

the stressful scenarios and opportunities involving coaching chemistry effectively, especially where resource and professional assistance is limited. In addition, it can guide development of training educator application that focuses on combination of content material knowledge and pedagogical skills so that the instructors can be better suited to handle the complexity of chemistry training (Van Driel and Berry, 2012). Through the enhancement of PCK of teachers, the schooling system is able to embellish the point of view of chemistry teaching and learning, and eventually lead to scientific literacy and academic success of college students (Hlaela, & Jita, 2024). The pedagogical content know-how of chemistry teachers is the key factor in the shaping of their practice in lecture rooms, which affects the methods of education, the interest of scholars, and the knowledge of influences. Instructors who have well-developed PCK are more equipped to meet the needs of teaching abstract and complicated chemistry standards, in which they design impactful learning environments that assist in the acquisition of the conceptual information and clinical judgment. However, PCK can be improved and used through a set of factors, including the professional history and the experience of coaches, as well as situational limitations (Buma, Sibanda, and Rollnick, 2024).Therefore, understanding the impact of PCK on chemistry teachers' practices is important for advancing teacher schooling, professional improvement, and curriculum reforms geared toward enhancing the pleasant of chemistry schooling. So, the purpose of this look at became to find out the relationship and impact of pedagogical content information of chemistry instructors on their classroom practices at secondary stage, and also check the difference among male & girl concerning pedagogical content material expertise of chemistry instructors and their school room practices at secondary stage.

Methodology

A quantitative survey research design was employed in this study, with positivism as the philosophical paradigm underpinning the quantitative research. The population consisted of all secondary schools in the Punjab province. There are a total of 8,786 schools, with 7,951 chemistry teachers, including 3,704 male and 4,247 female teachers (School Information System, 2024). A simple random sampling technique was utilized to select a sample from the population. A total of 460 schools were randomly chosen, followed by the selection of 477 chemistry teachers, comprising

212 male and 265 female teachers, also selected randomly. The study's instrument was a self-developed five-point Likert scale questionnaire. The validity of the questionnaire was established through expert opinions, while reliability was ensured via pilot testing. The Cronbach's Alpha values for the pedagogical content knowledge of chemistry teachers and classroom practices were 0.821 and 0.830, respectively, indicating adequacy for further analysis. Inferential statistics, including regression analysis, Pearson correlation, and independent sample t-test, were used to analyze the data through SPSS.

Data Analysis

Table 1: Effect of pedagogical content knowledge of chemistry teachers on their classroom practices at secondary level

Model Summary[b]				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.122[a]	.015	.013	.35084
a. Predictors: (Constant), Pedagogical Content Knowledge				
b. Dependent Variable: Classroom Practice				

The above table illustrates the effect of pedagogical content knowledge of chemistry teachers on their classroom practices at secondary level. The R-square 0.015 and standard error value 0.35 shows that the variability observed in the independent variable (pedagogical content knowledge) has a significant effect on dependent variable (classroom practice) is explained by the regression model.

Table 2: Effect of pedagogical content knowledge of chemistry teachers on their classroom practices at secondary level

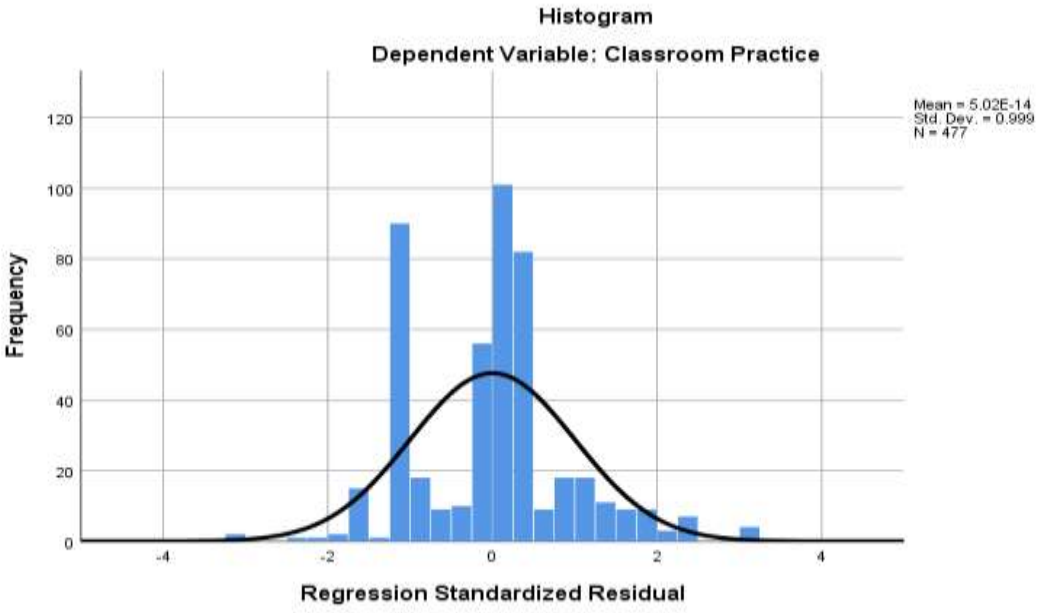
ANOVA[a]						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.885	1	.885	7.190	.008[b]
	Residual	58.467	475	.123		
	Total	59.352	476			
a. Dependent Variable: Classroom Practice						
b. Predictors: (Constant), Pedagogical Content Knowledge						

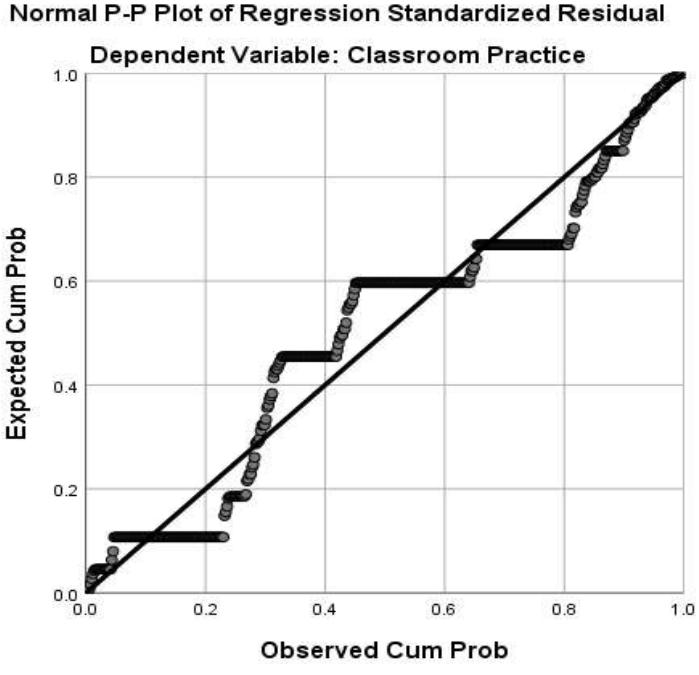
The above table illustrates the value of Mean square 0.123, F-value 7.190 and p-value 0.008 which shows that significant effect and

pedagogical content knowledge of chemistry teachers reliably predict teachers' classroom practices at secondary level.

Table 3 Effect of pedagogical content knowledge of chemistry teachers on their classroom practices at secondary level

Coefficients[a]					
	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	3.395	.191	.122	17.761	.000
Pedagogical Content Knowledge	.117	.043		2.681	.008
a. Dependent Variable: Classroom Practice					





The above table illustrates the effect of pedagogical content knowledge of chemistry teachers on their classroom practices at secondary level. The B-value 0.122, t-value 2.68 and p-value 0.008 shows that there was highly significant effect of pedagogical

content knowledge of chemistry teachers on their classroom practices at secondary level.

Table 4 ***Relationship between pedagogical content knowledge of chemistry teachers and their classroom practices at secondary level***

Correlations			
		Pedagogical Content Knowledge	Classroom Practice
Pedagogical Content Knowledge	Pearson Correlation	1	.122**
	Sig. (2-tailed)		.008
	Sum of Squares and Cross-products	65.194	7.596
	Covariance	.137	.016
	N	477	477
Classroom Practice	Pearson Correlation	.122**	1
	Sig. (2-tailed)	.008	
	Sum of Squares and Cross-products	7.596	59.352
	Covariance	.016	.125
	N	477	477
**. Correlation is significant at the 0.01 level (2-tailed).			

The above table illustrates the relationship between pedagogical content knowledge of chemistry teachers and their classroom practices at secondary level. The Pearson value 0.122 shows that there weak positive significant relationship between pedagogical content knowledge of chemistry teachers and their classroom practices at secondary level.

Table 5 Difference between male & female regarding pedagogical content knowledge of chemistry teachers and their classroom practices at secondary level

Variables		Levene's Test for Equality of Variances		t-test for Equality of Means				
	Gender	**F**	**Sig.**	**t**	**df**	**Sig. (2-tailed)**	**Mean**	**S.D.**
Pedagogical Content Knowledge	Male	10.794	.001	-8.821	475	.000	4.2333	.34807
	Female			-8.803	458.536	.000	4.5116	.33941
Classroom Practice	Male	62.920	.000	3.655	475	.000	3.9694	.30534

	Female			3.721	473.413	.000	3.8523	.38150

The above table illustrates the difference between male & female regarding pedagogical content knowledge of chemistry teachers and their classroom practices at secondary level. The male teachers' pedagogical content knowledge (M=4.233; SD=0.34) while female teachers' (M=4.51; SD=0.34), t-value 8.821, and p-value 0.000 shows highly significant difference among the groups. While on the other hand, the male teachers' classroom practices (M=3.96; SD=0.30), while female teachers' (M=3.85; SD=0.38), t-value 3.65, p-value 0.000 also shows highly significant difference among the groups. The results shows that there was highly significant difference between male & female teachers regarding pedagogical content knowledge of chemistry teachers and their classroom practices at secondary level.

Discussion

The pedagogical content material understanding (PCK) of chemistry teachers extensively affects their school room practices on the secondary level through enabling them to convert complicated, abstract content into understandable paperwork. Instructors with sturdy PCK hire strategies inclusive of models, analogies, experiments, and actual-life examples to address pupil misconceptions and facilitate conceptual know-how (Type, 2009). Powerful PCK permits instructors to bridge the macroscopic, submicroscopic, and symbolic representations of chemistry, enhancing college students' engagement and critical questioning abilities (Taber, 2002; Gabel, 1999). Conversely, inadequate PCK can lead to fragmented education, restricting college students' hold close of difficult topics like chemical bonding or stoichiometry (Rollnick et al., 2008).

There is a considerable dating between the pedagogical content information (PCK) of chemistry teachers and their study room practices at the secondary degree. Teachers with well-developed PCK effectively combine content knowledge and pedagogical techniques to create significant and engaging gaining knowledge of reports, improving college students' conceptual knowledge and problem-solving skills (Nkundabakura, et al., 2024). Research suggests that strong PCK allows teachers to pick out and deal with students' misconceptions via focused educational methods, consisting of inquiry-primarily based gaining knowledge of and actual-world programs (Van Driel, Verloop, & De Vos, 1998; Loughran, Berry, & Mulhall, 2006). This courting highlights that

teachers with strong PCK can drastically beautify classroom interactions, educational great, and scholar results, especially in subjects as abstract and complicated as chemistry (Mazibe, 2024).

Differences among male and female chemistry teachers regarding pedagogical content expertise (PCK) and their lecture room practices at the secondary level were found in diverse studies. Research shows that male and lady instructors may also rent unique teaching techniques and lecture room interactions because of variations in pedagogical approaches, verbal exchange patterns, and perceptions of pupil needs (kind, 2009; Park & Oliver, 2008). As an instance, woman instructors are often found to recognition greater on scholar-centered techniques and fostering collaborative mastering environments, even as male instructors may lean towards content material-centered and lecture-primarily based strategies (Van Driel & Berry, 2012). Those differences, however, tend to be context-specific and based on factors that cover revel in, training, and gain access to resources (Flores-Castro, Campos-Nava, Ramirez-Diaz, and Moreno-Ramos, 2024). As usual, every male and female teacher with a solid PCK depicts potent school room practices that embellish learning outcomes of students at their disposal given satisfactory professional development chances.

Conclusion

Finally, the pedagogical content knowledge (PCK) is very important in determining the way a secondary level teacher of chemistry should teach; it has direct implications on the understanding and academic achievement of students. Well developed abstract concepts can be taught to students successfully through teachers who have good PCK understanding how to effectively adapt abstract concepts with hands-on instructional plans to counter the misconceptions and bring conceptual clarity to students using models, experiments and real-life illustrations. The strong correlation between PCK and classroom practices shows its relevance in improving the quality of instruction, student interest and learning. Gender difference on PCK and pedagogical approaches imply that male and female teachers might have different pedagogical strategies but both teachers can be effective in teaching given good teaching training and professional development chances. Such results highlight the importance of constantly improving PCK by creating specific teacher education modules, mentoring, and reflections. Through this, education systems will be in a position of equipping teachers with the strength to overcome the instructional challenges and enhance the

quality of chemistry education. Finally, good PCK by teachers is not only beneficial to teaching effectiveness, but also scientific literacy of students as they are ready to become future academically and professionally active people.

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