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ASSESSING DEMOGRAPHIC DRIVERS AND TARGETED INTERVENTIONS FOR THE DEVELOPMENT OF CHEMISTRY PEDAGOGICAL CONTENT KNOWLEDGE

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ABSTRACT

This study investigated Pedagogical Content Knowledge (PCK) and instructional delivery among senior secondary school Chemistry educators in Northeast Nigeria. It examines how demographic factors affect teaching efficacy, and outlines tailored professional development strategies to overcome regional and resource-based limitations in science education. The research employs a descriptive survey design and mixed-methods approach to gather quantitative and qualitative data. A purposive and stratified random sampling technique targets 313 Chemistry teachers across urban and rural local government areas in Northeast Nigeria. Validated observation checklists, structured lesson plan analysis, and a modified PCK-efficacy questionnaire are used to gauge curriculum knowledge, teaching orientations, and instructional strategies. The Cronbach's alpha reliability coefficient of 0.873 was obtained which indicates a high level of internal consistency and reliability of the instrument. Demographic variance is evaluated using ANOVA and independent t-tests. Regression analysis is applied to determine how well PCK indicators predict teaching effectiveness. Statistical evaluations reveal that teachers' background variables, specifically gender, academic qualification, teaching experience, school location, and school type serve as non-significant predictors of their PCK and overall teaching effectiveness. Rather than inherent demographic traits or foundational degrees, these findings suggest that pedagogical competence and subject delivery are primarily shaped by continuous engagement with specific teaching methodologies and active learning models. To bridge gaps in chemistry education within the Northeast region the study recommended amongst others that; organizing routine practical workshops and inquiry-based laboratory simulations for chemistry teachers, resource provision in schools, and ensuring sustained Continuous Professional Development (CPD) programs.

Keywords: Demographic drivers (Gender, qualification, experience, school location & type), Targeted Interventions, Chemistry PCK, Northeast Nigeria

Introduction

Secondary school chemistry is a foundational STEM subject critical for scientific and technological advancement. However, it is often perceived by students as abstract and difficult. Teaching chemistry effectively requires more than just possessing a degree in the subject (Content Knowledge) or knowing general classroom management techniques (Pedagogical Knowledge). It demands Pedagogical Content Knowledge (PCK), which was initially conceptualized by Lee Shulman, is the unique intersection where a teacher's understanding of a specific

subject (e.g., chemistry) meets the art of teaching it. PCK is the specialized knowledge that integrates subject matter expertise with effective teaching strategies. PCK involves knowing how to represent and formulate the subject in ways that make it comprehensible to learners. This includes understanding common student misconceptions, using effective analogies, sequencing topics logically, and performing practical demonstrations mostly in chemistry lessons.

In chemistry, this involves a teacher's ability to simplify complex, abstract concepts (e.g., chemical bonding, thermodynamics, and molecular structures) using analogies, interactive demonstrations, and targeted representations/strategies to dismantle student misconceptions. Chemistry being a science subject, the learners, teachers and chemists have certain abilities such as science process skills or chemistry pedagogical skills that help them in the course of scientific investigation (Jack et al. 2025a). PCK is the specialized blend of content and pedagogy that allows a teacher to make complex subject matter understandable to students.

In the context of Northeast Nigeria (encompassing states like Borno, Adamawa, Yobe, Gombe, Bauchi, and Taraba), educational systems have grappled with infrastructural challenges, a lack of laboratory resources, and a shortage of qualified educators. Consequently, the reliance on traditional, teacher-centered "chalk-and-talk" methods rather than PCK-driven, student-centered instruction has contributed to a persistent decline in student performance and interest in chemistry. Also, with an educational landscape in this region that is highly complex, this framework (PCK-driven) is critical for transforming abstract scientific principles into comprehensible realities for diverse learners (Garba & Hassaini, 2024). Schools in this region face unique challenges, including disruptions from socio-religious conflicts and economic hardships that disproportionately affect female enrollment. Furthermore, there are stark disparities between well-resourced urban schools and underserved rural or public schools, which lack adequate laboratory facilities and teaching personnel. Consequently, teachers' capacity to deliver effective science instruction varies wildly based on their own demographic and institutional backgrounds.

Chemistry education is fundamental to national development and technological advancement. However, in Northeast Nigeria, the effective teaching and understanding of chemistry remain constrained by several intersecting factors. In this region, the educational landscape is deeply marked by varying school types (e.g., public vs. private, single-sex vs. co-educational) and locations (urban vs. rural). Additionally, teaching workforces differ significantly, with teachers possessing varying academic qualifications (e.g., Bachelor of Education, Bachelor of Science with PGDE, or non-educational degrees) and different lengths of teaching experience. Given Northeast Nigeria's specific socio-cultural dynamics and post-crisis educational recovery, understanding how these

demographic variables affect the translation of chemical concepts into pedagogical practice is essential.

Demographic drivers such as gender, teacher qualifications, teaching experience, school location and school type significantly shape the delivery of Chemistry Pedagogical Content Knowledge (PCK) in Northeast Nigeria. These demographic factors could shape the delivery of chemistry PCK (Anthony et al. 2019; Asiyai, 2018). The teaching workforce in Northeast Nigeria is disproportionately male, particularly in the core physical sciences. On teachers' gender as a factor, the gender imbalance limits the availability of female role models for young girls in a region already grappling with cultural barriers to female education. Male students frequently exhibit higher self-efficacy and interest in chemistry. While some studies show no direct correlation between a teacher's gender and their students' academic achievement, female students consistently benefit from targeted encouragement to counter socialization processes that portray science as a "masculine" domain. Some studies such as Odumosu et al. (2018) indicated that gender has no significant effect after exposure to teachers' PCK; while that of Mapulanga and Chituta (2018) revealed that the learners have a positive perception of teachers' PCK although males have a higher positive perception that teachers meet their learning needs than females. These inconsistencies highlight the need for further research to explore the influence of gender on PCK among chemistry teachers.

On teachers' qualification, there is a stark divide between certified educators and unqualified or non-teaching-certified staff acting as chemistry instructors, particularly in rural and remote local government areas. Research indicates that PCK has the ability to transform complex chemical concepts into accessible, engaging lessons that is strongly tied to formal teacher qualifications. Unqualified teachers often resort to rote memorization methods, which exacerbates students' phobias for abstract chemistry concepts like qualitative analysis and stoichiometry.

On teaching experience as a factor, there still exists gaps in teachers with \(10\) to \(20\) years of experience disparities which generally demonstrate better classroom delivery, student engagement, and practical laboratory manipulation skills compared to novice teachers (less than \(10\) years). The Northeast faces a high attrition rate of seasoned science teachers due to regional insecurity. This results in a heavy reliance on early-career teachers who lack the pedagogical repertoire to manage large, under-resourced classrooms effectively. Mohammed et al. (2021) from Tanzania reported a significant difference in the levels of PCK based on teacher's experience

On school location as a factor, there still exists gaps in urban vs. rural disparities. Rural schools in states like Borno, Yobe, and Adamawa suffer from a severe scarcity of instructional materials and lack functional laboratory facilities. Students in these areas frequently have lower baseline exposure to hands-on practical activities. Diwa et al. (2023) attested that the location of a school has a significant effect on teaching

effectiveness and academic performance of the students.

On school type as a factor, there still exists gaps between public and private schools, or single-sex and coeducational schools. Private secondary schools (predominantly in state capitals) generally boast better-equipped laboratories and internet access. This infrastructural advantage allows private school educators to employ inquiry-based learning and PhET interactive simulations, which are largely unavailable in public institutions. Though, Konicwski (2021) demonstrated that school type is not a determining factor in the development of pedagogical content knowledge (PCK) among chemistry teachers; but there still exist gaps in the study area.

More so, to elevate Chemistry PCK and student performance in Northeast Nigeria, targeted interventions for PCK development is very paramount for the 21st century classroom. Targeted, context-sensitive interventions are also critical to overcome systemic educational disparities and improve student learning outcomes in the region. Professional development provides chemistry teachers opportunities for active learning and content knowledge. Effective professional development and has made knowledge base that has transformed and rebuild quality schools and requires tolerance and perseverance, that instructors or teachers need to comprehend this transformation process and assess the factors affecting it. Teachers' pedagogical content development and growth can be by way of long-term programmes. Professional development and in-service programmes as stated in Asiyai (2018) are intended to encourage the growth and development of teachers that may be employed for their development effective science instruction.

The integration of subject matter and teaching strategies is the cornerstone of effective science instruction. Pedagogical Content Knowledge (PCK) goes far beyond knowing the fundamental principles of chemistry; it encompasses an instructor's ability to utilize relevant analogies, targeted representations, and effective classroom management techniques to simplify difficult topics like stoichiometry, electrochemistry, and organic chemistry.

In Nigeria, the senior secondary school chemistry curriculum is designed to equip students with the foundational skills needed for careers in science, medicine, and engineering. However, successfully delivering this curriculum demands teachers who not only understand chemistry but also know how to teach it to diverse groups of learners.

In the Northeast geopolitical zone, the educational landscape has faced significant disruptions. Despite these challenges, the demand for STEM education remains vital. Effective teaching in this region requires educators to be culturally responsive, highly adaptable, and resourceful. While various studies on PCK have been conducted in other parts of Nigeria, the specific socio-educational realities and unique resource constraints of Northeast states (such as Adamawa, Borno, Taraba and Yobe) necessitate a highly localized evaluation of

demographic drivers (Gender, qualification, experience, school location & type), and targeted interventions, for development of Chemistry PCK in Northeast Nigeria to help improve students' learning outcomes.

Statement of the Problem

Despite the critical role of chemistry in scientific innovation, students in Northeast Nigeria persistently record low academic achievement and lack interest in the subject. This issue is exacerbated by systemic challenges: an acute shortage of qualified science educators, socio-cultural barriers to learning, and disparities in instructional resources between urban centers and rural or crisis-affected communities.

Currently, there is a lack of empirical data regarding how specific demographic drivers such as whether a teacher is based in an urban public school versus a rural private school, or whether they possess years of experience versus a fresh degree impacts the development of their Chemistry PCK. Without a clear mapping of these demographics, existing teaching methodologies remain highly generalized, failing to address the specific needs of diverse classrooms and leading to continued underachievement among students.

Purpose of the Study

This study investigates the demographic variables (gender, academic qualification, teaching experience, school location, and school type) that influence chemistry Pedagogical Content Knowledge (PCK) among educators in Northeast Nigeria. It aims to identify knowledge gaps to design tailored professional interventions that improve instructional quality and student comprehension in the region.

Specifically, the study seeks to:

i. Investigate if teachers' PCK differs based on gender, educational qualification, years of teaching experience, school location, and school type; and
ii. Formulate targeted, localized professional interventions and capacity-building frameworks to help chemistry educators overcome identified pedagogical challenges.

Ultimately, the findings aim to provide actionable insights for curriculum planners, the Federal Ministry of Education, and state ministries of education in Northeast Nigeria to design targeted capacity-building, in-service training, and professional development programs for teachers

Research Questions

1. Does chemistry teachers' PCK differ based on gender, educational qualification, years of teaching experience, school location and school type?
2. What are the targeted, localized professional interventions and capacity-building frameworks to help chemistry educators overcome identified pedagogical challenges?

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Methodology

The research employs a descriptive survey design and mixed-methods approach to gather quantitative and qualitative data. A purposive and stratified random sampling technique targets 313 Chemistry teachers across urban and rural local government areas in Northeast Nigeria during the 2024/2025 academic session. This study used a correlational research design to collect both qualitative and quantitative data from respondents.

Population of 313 chemistry teachers in secondary schools located in Adamawa and Taraba States in Northeast Nigeria during the 2024/2025 academic session was used for the study. Adamawa State has 605 secondary schools with 257 chemistry teachers (173 males & 84 females); while Taraba State has 338 secondary schools across its Educational Zones with 56 chemistry teachers (42 males & 14 females) according to the Adamawa and Taraba States Ministry of Education (2024). The entire population as sample size for the study hence, sampling technique was not necessary for the study. The total population of Chemistry teachers in both Adamawa and Taraba states is 313. Three hundred and thirteen questionnaires were printed and distributed to the sample states. Adamawa has 257 Chemistry Teachers while Taraba has only 56 Chemistry teachers. The entire population was used as Sample size for the study hence, sampling technique was not necessary for the study. The total population of Chemistry teachers in both Adamawa and Taraba states is 313. Three hundred and thirteen questionnaires were printed and distributed to the sample states. Adamawa has 257 Chemistry Teachers while Taraba has only 56 Chemistry teachers.

Validated observation checklists, structured lesson plan analysis, and a modified PCK-efficacy questionnaire are used to gauge curriculum knowledge, teaching orientations, and instructional strategies. The Cronbach's alpha reliability coefficient of 0.873 was obtained which indicates a high level of internal consistency and reliability of the instrument.

The descriptive statistics of mean and standard deviation as well as Spearman's correlation coefficients were used to answer the research questions, and multiple regression analysis was used to test the study's hypotheses at a .05 significance level. The data processing was based on the correlation analysis in accordance with the objectives and research questions/hypotheses of the study. Demographic variance is evaluated using ANOVA and independent t-tests. Regression analysis is applied to determine how well PCK indicators predict teaching effectiveness.

Results

The data collected for the study are presented in tables and analyzed using mean and standard deviation, as well as Spearman's correlation coefficients to answer the research questions, with multiple regression analysis used to test the study's hypotheses at a .05 significance level.

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Answering Research Question One

Does chemistry teachers' PCK differ based on gender, educational qualification, years of teaching experience, school location and school type?

Table 1a

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.074[a]	.005	-.001	.18005

a. Predictors: (Constant), teacher gender, teaching experience, teacher qualification, school location, school type

Table 1b

ANOVA[a]

Model	Sum of Squares	Df	Mean Square	F	Sig.
Regression	.052	5	.010	.324	.899[b]
Residual	9.563	295	.032		
Total	7.464	300			

a. Dependent variable: teaching effectiveness
b. Predictors:(Constant), teacher gender, teaching experience, teacher qualification, school location, school type

Table 1c: Coefficients[a]

Model	Unstandardised Coefficients	Standardised Coefficients	T	Sig.	Collinearity Statistics	
	B	Beta			Tolerance	VIF
(Constant)	3.590		90.447	.000		
Gender	-.023	-.060	-1.005	.316	.953	1.050
Teacher qualification	-.011	-.046	-.525	.600	.444	2.250
Teaching experience	.007	.050	.584	.560	.465	2.152
School location	-.004	-.011	-.173	.863	.829	1.207
School type	-.006	-.010	-.162	.872	.894	1.119

a. Dependent Variable: teaching effectiveness

A multiple linear regression analysis was conducted to investigate the extent to which teacher gender, qualification level, teaching experience, school location, and school type influence the teaching effectiveness of chemistry teachers in secondary schools across Adamawa and Taraba States. The aim was to determine whether these background

and contextual variables could significantly predict variations in teaching effectiveness. The results presented in the model summary (Table 1a) indicate a very weak predictive relationship. The multiple correlation coefficient (R) was 0.074, while the coefficient of determination (R^2) was only 0.005. This means that the combined predictors accounted for just 0.5% of the variance in teaching effectiveness. Moreover, the adjusted R^2 value was slightly negative (-0.001), suggesting that the model does not generalise well to other samples and may even perform worse than a model with no predictors. The relatively high standard error of the estimate (0.18005) further underscores the model's poor fit.

The ANOVA results shown in Table 1b support this conclusion. The regression model was not statistically significant, as indicated by an F-value of 0.324 and a corresponding p-value of 0.899. These findings suggest that the model, which includes all five predictors, does not explain a statistically meaningful portion of the variation in teaching effectiveness. In practical terms, the inclusion of these variables does not offer a better explanation than random variation. Further examination of the coefficients table (Table 1c) confirms that none of the individual predictors had a statistically significant effect on teaching effectiveness. Gender ($p = 0.316$), teacher qualification ($p = 0.600$), teaching experience ($p = 0.560$), school location ($p = 0.863$), and school type ($p = 0.872$) all yielded p-values well above the conventional threshold of 0.05, indicating that their individual contributions to the model were not significant. While the direction of the relationships varied slightly—some positive, others negative—none of these associations were strong enough to draw reliable inferences.

It is worth noting that multicollinearity was not a concern in this model. The tolerance values and variance inflation factors (VIFs) for all predictors were within acceptable limits, confirming the independence of the variables in the regression. In conclusion, the analysis reveals that the background characteristics examined in this study, namely, teacher gender, qualification level, teaching experience, school location, and school type, do not significantly predict the teaching effectiveness of chemistry teachers in the context of Adamawa and Taraba States. This suggests that other factors, possibly related to instructional quality, pedagogical strategies, institutional support, or teacher motivation, may play a more central role in determining effectiveness. Future studies should therefore consider a broader range of variables, including those related to classroom practices and teacher professional development, to gain a deeper understanding of what drives effective teaching in science education.

Answering Research question two

What are the targeted, localized professional interventions and capacity-building frameworks to help chemistry educators overcome pedagogical challenges?

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Table 2: Strategies for enhanced development of chemistry teachers' PCK

S/N	Items on Content Knowledge	N	Mean	Std. Deviation	Remark
1	Intensive in-service training for less experienced chemistry teachers on a regular basis	301	3.4917	.53923	Strongly Agree
2	In-built training workshops in chemistry within schools on a termly basis	301	3.6412	.48045	Strongly Agree
3	Building professional development programmes in selected chemistry topics in school activities	301	3.4817	.50711	Strongly Agree
4	Linking teachers' professional development to students' learning	301	3.6213	.48588	Strongly Agree
5	Mentoring of less experienced chemistry teachers by head teachers	301	3.5316	.51300	Strongly Agree
6	STAN focusing conferences for chemistry teachers on difficult topics	301	3.3887	.48827	Agree
7	Sponsoring teachers on a field trip to other schools to watch expert teachers teach difficult topics	301	3.8272	.37867	Strongly Agree
8	Empowering chemistry teachers through summer workshop attendance in other countries	301	3.7076	.47705	Strongly Agree
9	Private involvement in organising chemistry education programmes for chemistry teachers	301	3.4817	.50050	Strongly Agree
10	Provision of current chemistry journals in school libraries	301	3.4518	.53713	Strongly Agree
11	Publishers of chemistry textbooks should concentrate on difficult topics in the subject	301	3.7010	.45858	Strongly Agree
12	Provision of current chemistry textbooks in school libraries	301	3.3422	.47523	Agree
13	Regular classroom practice	301	3.7010	.46580	Strongly Agree
14	Provision of visual game materials to enhance the teaching of chemistry	301	3.7076	.47001	Strongly Agree

Table 2 presents data on the strategies perceived to enhance the pedagogical content knowledge (PCK) and teaching effectiveness of secondary school chemistry teachers in Adamawa and Taraba States. The table summarises responses from 301 participants who rated 14 different strategies using a Likert scale. The mean scores for all strategies are above 3.0, indicating general agreement among respondents that each strategy is effective. Among the strategies, sponsoring teachers on field trips to observe expert teachers teaching difficult chemistry topics received the highest mean score

(3.8272), suggesting it is considered the most impactful. This is followed closely by the provision of visual game materials (3.7076), participation in summer workshops abroad (3.7076), publishers concentrating on difficult topics in textbooks (3.7010), and regular classroom practice (3.7010). These strategies emphasize experiential learning, resource enhancement, and focused support on complex chemistry content.

Moderately rated strategies, with mean scores ranging between 3.50 and 3.69, include in-built termly workshops within schools (3.6412), linking teacher professional development to student learning (3.6213), mentoring of less experienced teachers by head teachers (3.5316), and intensive in-service training (3.4917). Other strategies in this category include private sector involvement in professional development, development programs focused on selected chemistry topics, and the provision of current chemistry journals. These strategies represent systemic and institutional support mechanisms that reinforce teacher capacity building.

Strategies with relatively lower ratings, although still scoring above 3.0, include organising STAN conferences on challenging topics (3.3887) and providing current chemistry textbooks (3.3422). While still seen as beneficial, these were viewed as slightly less effective compared to more interactive or experiential strategies. In terms of variability, responses to sponsoring field trips showed the least divergence (standard deviation of 0.37867), suggesting strong consensus on its importance. Conversely, in-service training had the highest variability (standard deviation of 0.53923), indicating a more diverse range of views on its effectiveness. In response to research question twelve, the findings suggest that the most effective strategies involve active, hands-on learning experiences, resource provision, and continuous, targeted professional development. These include field-based learning opportunities, integration of visual teaching aids, participation in international workshops, and alignment of teaching materials with challenging curriculum content. Institutional support, including mentoring, in-school training workshops, and linking teacher development to student outcomes, also plays a critical role in fostering effective teaching practices.

Overall, a combination of experiential, collaborative, and resource-oriented strategies is considered key to enhancing chemistry teachers' effectiveness and deepening their pedagogical content knowledge in these regions.

Discussion of Findings

The key findings are:

1. Teacher gender, qualification level, teaching experience, school location, and school type do not significantly predict teaching effectiveness.
2. The most effective strategies for enhancing chemistry teachers' pedagogical content knowledge and teaching effectiveness include hands-on learning experiences, resource provision,

and continuous, targeted professional development.

The key findings are discussed as follows:

Findings on Non-Significant Predictors of Teaching Effectiveness (Teacher gender, qualification level, teaching experience, school location, and school type):

The finding that teacher gender, qualification level, teaching experience, school location, and school type do not significantly predict teaching effectiveness is a notable one. This suggests that these variables may not be as crucial in determining teaching effectiveness as other factors, such as pedagogical knowledge and skills. This implies that teachers' ability to design and deliver effective instruction, manage classroom dynamics, and assess student learning is more closely tied to their pedagogical expertise rather than their demographic characteristics or school context. The findings of this study align with previous research that highlights the importance of pedagogical knowledge and skills in teaching effectiveness. Ultimately, the study strives to empower educators through tailored professional development, ensuring equitable and high-quality chemistry education across the Northeast region regardless of a school's geographic location or demographic makeup. To this finding: non-significant predators (teacher gender, qualification, experience, school location, and school type) of PCK and teaching effectiveness

Finding that teacher demographics and school contexts are "non-significant predictors" of Pedagogical Content Knowledge (PCK) and teaching effectiveness implies that these surface-level attributes do not automatically dictate a teacher's classroom competence or instructional quality.

A breakdown of why these variables consistently yield statistically insignificant effects in educational research reveals several key patterns:

One gender, the research consistently shows that male and female teachers are equally capable of developing strong PCK and delivering effective instruction. The finding that gender does not have a significant influence on chemistry teachers' pedagogical content knowledge (PCK) in secondary schools in Adamawa and Taraba States in Northeast Nigeria is consistent with previous research that has found no significant differences in teaching effectiveness between male and female teachers. This finding suggests that both male and female chemistry teachers possess similar levels of PCK, which is essential for teaching chemistry effectively. The reason being that both genders are exposed to the same teacher-training curricula, pedagogical workshops, and professional development programs. A teacher's ability to simplify complex concepts and manage a classroom is rooted in their cognitive and professional skills, not their biological sex. This implies that teacher education programs and professional development initiatives should focus on developing the pedagogical knowledge and skills of all teachers, regardless of gender.

The findings on teachers' PCK and teaching effectiveness based on gender supports Mira et al. (2018) in Lampung province in the profile comparison, revealed information instruments for pck were very high (97.4%) for female science teachers. Saka and Onanuga (2019) in Ogun State revealed no significant gender difference in teacher effectiveness of the selected STEM subjects' teachers. Odumosu et al. (2018) in Lagos State indicated that gender has no significant effect on students' achievement in algebra after exposure to teachers' content and pedagogic knowledge. However, the present study's findings contradict those of Mpiti (2025), Saka and Onanusy (2019), and Mira et al. (2018), which reported significant differences in PCK between male and female chemistry teachers. Also, the studies by Williza and Joji (2022) in Central Philippines showed that the female doctorate degree elementary teachers with longer teaching experience perform better; and Mapulanga and Chituta (2018) revealed that the learners have a positive perception of teachers' PCK although males have a higher positive perception that teachers meet their learning needs than females.

Finding on teachers' qualification, formal qualifications (such as holding a bachelor's vs. a master's degree) show non-significant relationships with practical PCK and actual teaching effectiveness. The reason being while academic degrees prove a teacher has mastered subject-specific Content Knowledge (CK), they do not automatically translate into Pedagogical Content Knowledge. PCK is the specific skill of turning subject matter into relevant, accessible learning experiences by utilizing analogies, anticipating misconceptions, and designing appropriate evaluations. Practical, ongoing professional development, not just the level of a university degree builds this specific skill. Though, Anthony et al. (2019) in Magelang City, Indonesia concluded that teacher academic qualifications significantly affect a teacher's overall TPACK and its seven specific components. And, teachers with higher educational degrees (such as Master's or PhDs) demonstrated significantly higher TPACK competency compared to Bachelor's degree holders.

Finding on teachers' experience, years of teaching often have a non-significant or weak impact on PCK. The reason being that teaching quality is less about how many years an educator has been in the system and more about how those years were spent. A teacher who does not engage in continuous self-reflection, peer mentoring, or active professional development can easily plateau. Conversely, a highly reflective junior teacher can develop strong PCK relatively quickly. Though, the findings based on influence of teachers' experience do not significantly predict teaching effectiveness, Sewell (2023) opined that the teacher as an expert should be able to research on practice in teaching, psychological aspects of learning, instructional design models and strategies, and classroom management skills. This deep understanding and professionalism will help ensure that teachers can effectively teach their subjects to create successful learning experiences. However, the study by

Mohammed et al. (2021) from Tanzania reported a significant difference in the levels of PCK based on teacher's experience. Also, Anthony et al. (2019) in Magelang City, Indonesia concluded that teaching experience significantly affect a teacher's overall TPACK and its seven specific components. And, the amount of time spent teaching directly impacts a teacher's ability to seamlessly integrate technology with subject content and pedagogy.

On finding based on school location, whether a school is located in an urban or rural setting often produces non-significant differences in teacher PCK and effectiveness. The reason being while location strongly influences the availability of physical resources or socio-economic demographics, the inherent cognitive and instructional skills teachers use to mediate lessons remain localized to the individual educator. Furthermore, standardized teacher-preparation programs and nationwide curriculum mandates often homogenize the pedagogical methods taught to educators, regardless of where they are ultimately deployed to teach.

Though the findings based on influence of school location do not significantly predict teaching effectiveness, however, Diwa et al. (2023) attested that the location of a school has a significant effect on teaching effectiveness and academic performance of the students. Since teaching effectiveness could have effect on both teachers, and students' proficiency, environmental factors such as school location (rural or urban) could also have effect or impact on the proficiency or academic achievement of students.

On finding based on school type show differences in school type (e.g. single & coeducational) generally yield non-significant differences in pedagogical competence. The reason being that PCK is an individualized cognitive construct; hence an effective teacher who deeply understands how to represent ideas and address learners' interests can successfully adapt their PCK to the specific culture and student profile of any school.

The study by Konicwski (2021) also demonstrated that school type is not a determining factor in the development of pedagogical content knowledge (PCK) among chemistry teachers. This suggests that teachers' PCK is more closely related to their individual knowledge, skills, and experiences rather than the type of school in which they teach. This finding has implications for teacher education and professional development. Rather than focusing on demographic characteristics or school context, teacher education programs and professional development initiatives should prioritize the development of pedagogical knowledge and skills. By doing so, teachers can develop the expertise needed to teach chemistry effectively and promote student learning outcomes.

In summary, because PCK is a dynamic, practical knowledge base built through active classroom interaction, continuous professional development, and reflective practice, formal demographic and environmental classifications fail to capture

the real drivers of effective teaching. To learn more about how teachers build this essential bridge between subject matter and student learning. When demographic and background characteristics—such as gender, qualifications, experience, school location, and school type—are non-significant predictors of PCK and teaching effectiveness, it means that high-quality teaching is universal. Success in the classroom depends on innate pedagogical competence rather than institutional or demographic pedigree.

Finding on targeted interventions for the development of chemistry teachers PCK

Finding based on targeted interventions (such as hands-on experiences, resource provision, and continuous targeted professional development) for the development of chemistry teachers PCK in northeast Nigerian. The finding indicates that targeted interventions (hands-on experiences, resource provision, continuous professional development) are essential for developing chemistry teachers' PCK in Northeast Nigeria, they point to a critical need to bridge the gap between abstract chemical theories and practical, locally relevant classroom delivery. The findings based on effective strategies for enhancing chemistry teachers' pedagogical content knowledge and teaching effectiveness include hands-on learning experiences, resource provision, and continuous, targeted professional development.

The findings suggest that teachers value these strategies and believe they can improve their teaching effectiveness. Specifically, teachers recognize the importance of experiential learning opportunities in enhancing their PCK and teaching skills. This finding implies that chemistry teachers who possess a deep understanding of how to teach chemistry effectively are better equipped to promote student learning and achievement. The study's findings are consistent with previous research that emphasizes the significance of pedagogical knowledge in teaching. Studies by Mohammed et al. (2021), Aydin and Turhan (2023), and Morris (2024) have demonstrated a strong positive relationship between pedagogical knowledge and teaching effectiveness among chemistry teachers. These studies highlight the critical role of pedagogical knowledge in promoting student learning and achievement, and underscore the importance of providing teachers with ongoing support and continuous professional development opportunities which could be improved through digital mentoring (Jack et al., 2025b) on science teachers' continuous professional to advance teachers' education for 21st-century classrooms.

Educational Implications

School administrators and education boards must shift focus away from traditional teacher demographics or where a teacher was educated/hired. Recruitment and promotion should prioritize demonstrated pedagogical competence and subject mastery over surface-level traits. Because years of experience and formal qualifications do not solely dictate teaching effectiveness, training

programs should be universally accessible and ongoing for all educators, rather than assuming senior teachers require less support. Policy and funding models should ensure that regardless of school type or school location, resources for developing PCK are distributed equitably, as effective teaching is highly achievable anywhere.

More so, teachers need direct support to translate the standardized national chemistry curriculum into localized, understandable lessons. Without hands-on practical, teaching abstract concepts (like organic chemistry or stoichiometry) remains disconnected from students' realities. A teacher's pedagogical skill directly predicts student learning outcomes. Equipping teachers with PCK transitions classrooms from rote memorization to meaningful, critical thinking. The need for "resource provision" implies that regional disparities in laboratory equipment and instructional materials significantly hinder effective pedagogy, making improvisational skills and local material usage vital.

Implications on PCK and Teaching Effectiveness:

The findings of this study have significant implications for stakeholders in education, including teachers, school administrators, and policymakers. The study underscores the critical role of pedagogical knowledge and skills in teaching effectiveness, emphasizing the need for teachers to receive support and training to develop their pedagogical expertise. By investing in teacher professional development programs that focus on enhancing pedagogical knowledge and skills, educational institutions can promote teaching effectiveness and ultimately improve student learning outcomes. The study's findings suggest that professional development programs should prioritize providing teachers with hands-on learning experiences and resources to enhance their teaching effectiveness. This could include workshops, field trips, and peer mentoring opportunities that allow teachers to develop their pedagogical skills and share best practices with colleagues.

The study provides valuable insights into the teaching effectiveness of chemistry teachers in secondary schools in Adamawa and Taraba States. The findings highlight the importance of pedagogical knowledge and skills in teaching effectiveness and suggest that teachers should be supported in developing their pedagogical skills. By doing so, teachers can create engaging and inclusive learning environments that promote student motivation, participation, and academic achievement. The study identifies several strategies that can enhance the pedagogical content knowledge and teaching effectiveness of chemistry teachers. These strategies include hands-on learning experiences, resource provision, and continuous professional development. By adopting these strategies, teachers can develop their pedagogical expertise and improve their teaching effectiveness, ultimately leading to better student learning outcomes. The findings of this study are

consistent with previous research that emphasizes the significance of pedagogical knowledge in teaching effectiveness. Studies by Mohammed et al. (2021), Turhan (2024), and Morris (2024) have demonstrated a strong positive relationship between pedagogical knowledge and teaching effectiveness among chemistry teachers. These studies highlight the critical role of pedagogical knowledge in enhancing student learning outcomes and underscore the need for teachers to receive ongoing support and training to develop their pedagogical expertise.

Implications for Teacher Education and Professional Development:

The study has profound implications for teacher education and professional development, underscoring the critical role of pedagogical knowledge and skills in teaching effectiveness. The study emphasizes the need for teachers to receive support and training to develop their pedagogical expertise, enabling them to plan, deliver, and adapt instruction to meet the diverse needs of learners.

The study's findings suggest that teacher education programs should prioritize providing teachers with the knowledge and skills necessary to create engaging and inclusive learning environments that promote student motivation, participation, and academic achievement. By focusing on the development of pedagogical knowledge and skills, teacher education programs can equip teachers with the expertise needed to teach chemistry effectively and promote student learning outcomes.

Conclusion

Teaching effectiveness and Pedagogical Content Knowledge (PCK) are not bound by demographics or institutional context. A teacher's ability to effectively deliver content and engage students relies on individual classroom competence and mastery of teaching strategies, rendering variables like gender, years of experience, or school location irrelevant to their ultimate success.

Also, targeted interventions for chemistry PCK in Northeast Nigeria are critical due to localized educational disruptions. Possessing subject knowledge alone is insufficient; teachers require specialized training on how to teach difficult concepts effectively. Chemistry is inherently an experimental science. The lack of hands-on experience and laboratory access fundamentally cripples the development of robust chemistry PCK in the region. Though isolated, one-time workshops are inadequate, but continuous, targeted professional development (CPD) is required for sustained, long-term pedagogical improvement.

Recommendations

Recommendations on demographics or institutional context of chemistry teachers PCK are:

i. Educational systems should implement usage of standardized, competency-based assessments and classroom observations to measure and guide teacher effectiveness, rather than relying on credentials or

years of service as benchmarks for quality.

ii. Targeted, continuous Professional Development PD should be designed based on individual teacher needs and learning gaps, rather than generalized assumptions that more experienced or highly qualified teachers have already mastered all aspects of PCK.

iii. Policymakers and local education districts should ensure that all schools, regardless of their location, are equipped with the same foundational infrastructure and instructional resources to support effective teaching.

Recommendations on targeted interventions for the development of chemistry teachers PCK:

i. State Ministries of Education and relevant boards should prioritize targeted funding for equipping school laboratories and distributing updated, culturally-responsive teaching guides. Subject-specific professional development programs should be organize focused on the use of low-cost, locally sourced materials and improvisational techniques to overcome the lack of standard laboratory equipment.

ii. Chemistry educators should shift teaching strategies away from traditional "chalk-and-talk" (lecture methods) by mandating and training teachers in inquiry-based, problem-solving, and hands-on pedagogies.

iii. Continuous peer-learning or Communities of Practice (CoPs) should be established at the local level. This ensures that pedagogical skills, formative assessment strategies, and inclusive teaching practices are continuously shared among educators.

iv.

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