International Journal of Learning, Teaching and Educational Research
Vol. 24, No. 12, pp. 474-496, December 2025
https://doi.org/10.26803/ijlter.24.12.21
Received Jul 14, 2025; Revised Sept 8, 2025; Accepted Nov 11, 2025

Continuing Professional Development on Physical Sciences Educators' Content Knowledge and Curriculum Decision-Making in Electrochemical Reactions

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Abstract. Continuous professional teacher development (CPTD) programmes are widely recognised as essential for enhancing teachers' subject knowledge and refining their pedagogical practices, ultimately contributing to improved learner outcomes. However, there is limited focus on how these programmes influence teachers' content knowledge and pedagogical decisions when teaching electrochemical reactions in the South African education system. This study examined the influence of CPTD programmes on physical sciences educators' pedagogical content knowledge (PCK) and pedagogical decisions on electrochemical reactions. The study was framed within the PCK theoretical framework as a lens. This study used an interpretivist qualitative research approach, contextualised in one rural education district. Ten physical sciences educators were selected by employing a purposive sampling method. Data were gathered through semi-structured interviews and classroom observations. The data were analysed using thematic analysis. The findings show that educators' involvement in CPTD programmes significantly enhanced their pedagogical knowledge on electrochemical reactions, positively impacting their PCK in teaching these concepts. The study provides rtraining:tions for the Department of Education to intensify professional development programmes for physical science educators, ensuring minimal disruption to teaching while prioritising under-resourced schools and hands-on laboratory training; policymakers should enforce CPTD participation through the design of policy frameworks, and ensure continuous monitoring.

Keywords: Educator content knowledge; pedagogical knowledge; pedagogical content knowledge; professional teacher development programme; electrochemical reactions

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1. Introduction

In South Africa, physical sciences are widely regarded as gateway subject, offering learners opportunities for further education, specialised training, and access to a range of professional careers. The Department of Basic Education (DBE, 2011) envisions it as more than just an academic discipline; rather, it is a critical foundation for socio-economic development, civic engagement, and environmental awareness.

Recognising the challenges learners face, the DBE has structured the curriculum to provide broader career prospects. However, entry into these career trajectories is contingent upon learners attaining quality passes in the subject, a standard emphasised in the DBE policy document (DBE, 2011). Strong learner performance in physical sciences reflects their grasp of scientific concepts and indicates educators' Pedagogical Content Knowledge (PCK), a crucial factor in effective teaching and learning.

Despite this ambitious vision, recent National Senior Certificate (NSC) results paint a concerning picture of physical sciences performance in the Eastern Cape Province. The Eastern Cape Department of Education (ECDOE, 2023) conducted a comparative analysis of grade 12 physical sciences results from 2019 to 2022, revealing persistently low achievement levels. The data highlight a worrying trend, while a significant percentage struggle within the lower bands (30%). Among the various topics covered in physical sciences, electrochemical reactions emerge as one of the most challenging areas for learners.

The Chief Markers’ reports (2019–2023) further corroborate this, consistently showing poor learner performance in these topics, with scores fluctuating at concerningly low levels (ECDOE, 2023). Such persistent underperformance inevitably raises questions about the quality of teaching and, more specifically, the level of educators’ PCK in the subject. The DBE (2006) has long linked learner achievement to teacher competency, asserting that content knowledge and pedagogical skills gaps can significantly hinder effective instruction. Yeboah (2020) echoes this view, emphasising that educators’ PCK is a key determinant of teaching effectiveness in science education.

In addition, despite the fact that research has examined the efficacy of Continuous Professional Teacher Development (CPTD) in a variety of subject areas (Ahmad & Rochimah, 2022; Taran & Israel, 2023), there is a limited emphasis on the ways in which these programmes assist physical science teachers in navigating difficult topics. Specifically, the impact of CPTD programmes on the pedagogical decisions and content knowledge of teachers when teaching electrochemical reactions in the South African education system is not well explored.

If both policy documents and research studies converge on this perspective, then a critical issue must be acknowledged. The question is: *Are physical sciences educators in the Eastern Cape region adequately equipped to teach electrochemical reactions*?

Addressing this concern requires a closer look at CPTD programmes designed to enhance teachers' content knowledge and instructional strategies. The DBE and the Department of Higher Education and Training (DBE & DHET, 2011) advocate for professional development to improve classroom practice and, ultimately, learner performance. The researchers’ experiences in various roles (as educators, examiners, subject advisors, subject planners and teacher educators) have provided firsthand insights into the challenges educators face in teaching electrochemical reactions. School visits and teacher workshops have revealed recurring difficulties, with many educators struggling to grasp fundamental concepts, such as oxidation, reduction and the application of reduction potential tables, in identifying half-reactions.

Given this persistent challenge, this study examined the influence of CPTD workshops on educators' PCK in teaching electrochemical reactions over a five-year period (2019–2024). The study delved into how ongoing professional development initiatives have shaped educators’ understanding of the topic and influenced their instructional approaches over time. By exploring the evolution of their PCK on electrochemical reactions, the study provides evidence-based insights that could inform future teacher training programmes.

The following research questions guided the study:

1. In what ways does a continuing professional development programme influence the physical sciences educators' content knowledge of electrochemical reactions over time?
2. How does participation in the continuing professional development influence physical sciences educators' curriculum decision-making processes when teaching electrochemical reactions over time?

2. Literature review

2.1 Overview of physical sciences education in South Africa

Physical sciences is a subject specified in the curriculum in the Further Education and Training (FET) band, from grade 10 to grade 12, whose objective is to enhance learners' awareness about their environment, promote responsible interaction with it and equip them with investigative skills pertinent to physical and chemical phenomena (DBE, 2011).

It is a discipline that encompasses physics and chemistry, with six knowledge areas: Chemical Change, Matter and Materials, Chemical Systems, Waves, Electricity and Magnetism, Sound and Light, and Mechanics (DBE, 2011). Electrochemical reactions are addressed under the knowledge area of Chemical Change. They include concepts such as electrolytic and galvanic cells, the relationship of current and potential difference to reaction rate and equilibrium, standard electrode potentials, oxidation and reduction half-reactions, cell processes, oxidation numbers and the application of redox reactions (DBE, 2011).

The focus on electrochemical reactions within physical sciences education is both pertinent and significant as the concept often remains underrepresented in many science education programmes, posing substantial challenges for teachers.

Research indicates that electrochemical reactions can be particularly difficult for both teachers and learners to grasp due to their abstract nature and reliance on conceptual understanding of multiple scientific principles (Ali et al., 2022). Furthermore, there exists a notable research gap in the literature surrounding effective pedagogical strategies specific to teaching electrochemical reactions. Previous studies often overlook detailed methodologies that can improve PCK among science teachers (Neumann et al., 2019). Moreover, the lack of systematic professional development tailored to electrochemical reactions may hinder teachers' abilities to make informed decisions while teaching such critical concepts.

Nonetheless, other studies (e.g., Boateng & Mushayikwa, 2022; John, 2019), indicate that the poor performance of learners in physical sciences is due to outdated teaching methods used by educators and limited teacher content knowledge. A study by Selvaratnam (2011) reveals that many matric physical sciences educators lack problem-solving skills, which are critical for effective teaching and learning in this subject area. The need for targeted professional development programmes that enhance teachers' pedagogical skills and content knowledge is thus paramount.

2.2 Professional development programme for educators' pedagogical content knowledge

The professional development of teachers is the primary focus of this article. Teacher professional development (TPD) encompasses the learning process of educators, including the manner in which they acquire knowledge and the practical application of that knowledge to facilitate learning for learners (Avalos, 2011). In recent years, there has been a particular emphasis on TPD to assist teachers in making well-informed decisions and to prepare students better for real-world challenges (Valoyes-Chávez, 2018). Teachers can acquire knowledge by engaging in a variety of courses, reflecting on their own teaching and observing and reflecting on the teaching of others in collaboration with colleagues. Learning can take place in a variety of methods, both formally and informally. These include planned reflection meetings between teachers, or teachers learning from unplanned conversations with their colleagues.

One of the primary advantages of professional development is its potential to enhance educators' PCK and skills significantly. According to Dung et al. (2020), professional development plays a crucial role in improving educators' competencies. This assertion is echoed by Quayson (2022), who emphasises the importance of reflective practice and mentoring in fostering self-renewal among educators, thereby enhancing their teaching effectiveness. This aligns with the findings by Pozilova (2023) that indicate that CPTD has cultivated professional creativity among teachers, which is essential for effective teaching in topics such as electrochemical reactions.

However, despite these advantages, CPTD has notable challenges. One significant critique is that many CPTD programmes are often poorly designed and fail to meet the actual needs of educators. Studies have shown that "sit and get" CPTD approaches yield minimal impact on educators' competencies and teaching practices (Suhendri & Kawai, 2022). This highlights the need for more interactive and engaging CPTD formats that encourage educators' active participation and collaboration. Nonetheless, educators' pedagogical knowledge is a prerequisite for educators' professional growth. Stearns (2019) states that CPTD is important to educators' continuing improvement because educators learn new knowledge and skills that ultimately impact student learning. This shows that educators' pedagogical knowledge improves as educators gain new knowledge and improved pedagogy.

Kesson and Henderson (2010) argue that the aim of the CPTD programme is for educators to acquire deep content knowledge, set and achieve high academic standards, implement the curriculum in classrooms, learn new instructional methods, develop the capacity to differentiate instruction and create learning communities that foster discussion and reflection. Developing the capacity to differentiate instruction is an indication of a science educator's professional growth, which is a result of their improved pedagogical knowledge.

Neumann et al. (2019) indicate that an initial effort in describing teacher professional knowledge identified a range of teacher knowledge bases that include content knowledge and (general) pedagogical knowledge. They also added orientation to teaching science as one component of PCK that, in turn, shapes and is shaped by the other four components, namely, knowledge of science curricula, knowledge of students' understanding of science, knowledge of instructional strategies (pedagogical knowledge) and knowledge of assessment of science literacy. From this statement, the researchers learnt that CPTD may focus on teacher orientation to teaching science, which then, according to Neumann et al. (2019), will shape the pedagogical knowledge of the educators in teaching electrochemical reactions.

Moreover, in terms of CPTD specific to electrochemical reactions, the literature suggests that specialised training is essential for educators to effectively teach complex scientific concepts. For example, hands-on approaches and computational experiments are emphasised to deepen the understanding of concepts, such as electrochemical reactions, among teachers (Krushinski et al., 2024; Lin et al., 2024). This reflects an evolving understanding that CPTD must equip teachers with innovative pedagogical strategies that align with scientific inquiry to enhance overall effectiveness.

However, in many developing regions, there is often a significant gap in access to quality CPTD resources, as noted by the limited deployment of strategies that should facilitate teacher engagement and collaboration (Irwandi & Albert, 2018). Thus, while CPTD can enrich the PCK of science teachers, the extent of its success often depends on the context and availability of resources. In addition, rural infrastructure might limit opportunities for continuous learning and collaboration among science teachers. Research by Topuzov et al. (2021) outlines the challenges faced by rural schools in accessing effective CPTD tailored to science teachers in their unique contexts. As educators strive to make informed decisions on teaching electrochemical concepts, these challenges can directly impact their capability to impart sound knowledge effectively.

3. Theoretical Framework

3.1 Pedagogical Content Knowledge

Pedagogical Content Knowledge (PCK), initially conceptualised by Shulman (1986), represents the blend of subject matter knowledge and pedagogy necessary for effective teaching. PCK involves understanding how to structure and present content knowledge to be accessible and understandable to students, considering their prior knowledge, potential misconceptions and the instructional strategies best suited to the subject matter. PCK considers learners' prior knowledge, potential misconceptions, knowledge of student difficulties, content-specific representations and the instructional strategies best suited to the subject matter (Magnusson et al., 1999).

Dhurumraj and Ramaila (2024) infer that, for science educators to facilitate meaningful, effective conceptual development for science learners, they must be adequately grounded in content knowledge. CPTD programmes are viewed as key in enacting educators' CK, PK and PCK to improve educator efficacy in the classroom. As a theoretical framework, PCK is particularly suitable for studying the influence of CPTD on teachers' understanding of electrochemical reactions.

The researchers employed PCK as an ideal framework to assess educators' capacity to integrate macroscopic, microscopic, and symbolic representations as effective teaching strategies. This included the alignment of instruction with curriculum requirements, the comprehension of students' prior knowledge and challenges, their profound understanding of core concepts and their awareness of common learner misconceptions after the CPTD. Moreover, this study employed the PCK as a framework to guide the design of assessment tools to evaluate the effectiveness of the CPTD programme, providing a holistic view of teacher growth by observing shifts in their understanding, their application and their reflection on electrochemical content and pedagogy of teaching it (Gess-Newsome, 2015).

4. Methodology

4.1 Research approach

The study adopted a qualitative research design within the interpretivist paradigm, prioritising understanding human experiences from participants' perspectives. This approach enabled the researchers to capture the complexities of social phenomena by emphasising subjective meanings and contextual interpretations (Creswell & Poth, 2018). Consequently, the qualitative design was chosen to explore the participants lived experiences of engagement with CPTD programmes.

A case study research design was employed in this study (Yin, 2018). This design choice was justified by the need to delve deeply into physical sciences educators' specific educational practices and professional development experiences, which are influenced by contextual factors unique to a specific district in the Eastern Cape Province. By focusing on a single district, the researchers captured the nuances of educators' educational practices, their CPTD experiences, and educators' specific challenges in this context. This study employed a multiple case study design to examine each school as a distinct case. Since the study involved teachers from 10 schools, each school's unique context regarding teachers' practices were explored and compared. Multiple case studies offer a broader basis for analysing trends and concluding a single case study (Yin, 2018).

4.2 Sampling and sampling procedures

In this study, the targeted population was grade 12 physical science educators from O.R. Tambo Coastal Education District (ORTCED) who had participated in CPTD programmes for the previous five years. In our positions as subject advisors, we organised such workshops for teachers to bridge their content knowledge in challenging concepts in the subject. The ORTCED consists of 79 schools offering physical sciences. The population was chosen because the district is mainly rural and has many physical science schools that underperform in the physical sciences. Educators in this district have been attending organised workshops in the past and have been consistent in doing so as mandated by the district's subject advisor.

This study used purposive sampling to select the schools and educators (Patton, 2015). Since this study sought to understand the influence of CPTD on teachers' PCK in electrochemistry, selecting teachers who have undergone professional development in physical sciences was essential. Ten physical sciences educators were selected from one cluster of schools within this district.

4.3 Data collection instruments and their administration

The researchers employed interviews and classroom observations as the main instruments for data collection. The interview questions were organised into two main sections to align with the study's aims. Section A focused on gathering biographical information from the participants, capturing details relevant to their teaching backgrounds and demographics. Section B consisted of questions developed to address the study's two core research objectives.

This line of inquiry explored how teachers integrate new insights and methodologies gained from CPTD into their choices regarding content knowledge, curriculum design, content sequencing and instructional approaches in electrochemical reactions. A classroom lesson observation schedule was used to provide direct evidence of how teachers implement pedagogical strategies and curriculum decisions as they respond to student inquiries (Merriam & Tisdell, 2016).

Arrangements were made with the selected educators so that similar topics were covered during the lesson observation period. An observation schedule was developed, which comprised three sections. Section A requested the teacher's background characteristics. Section B explored the lesson plans of the teachers. The last section provided questions on the extent of teaching and learning electrochemical reactions facilitation after attending CPTD programmes.

One researcher established rapport with all the educators and scheduled times to conduct the interviews and the classroom observation. Each interview lasted approximately 35 to 40 minutes and was held privately at each teacher's school to ensure comfort and confidentiality. Follow-up questions were occasionally used to encourage elaboration on critical points, helping to clarify teachers' understanding of electrochemical reactions and the effectiveness of professional development sessions. All interviews were audio recorded, with the participants' consent, and later transcribed verbatim to ensure accuracy and reliability in data analysis.

Classroom observations were also conducted to examine the practical application of teachers' PCK in electrochemical reactions after attending a CPTD programme. Each teacher was observed during a scheduled lesson on the topic, allowing the researcher to document the instructional practices and curriculum decisions to gauge whether professional development influenced their PCK. A structured observation protocol was used, focusing on elements such as lesson structure, mastery of the content, questioning techniques and strategies for addressing student misconceptions in electrochemistry. Field notes were taken during each observation to capture non-verbal cues and contextual information relevant to classroom dynamics.

In the interviews, data saturation occurred after the interview with the seventh participant, when participants repeated ideas from earlier respondents, and no new categories or patterns emerged about how CPTD programmes influence content knowledge and pedagogical decisions. The researchers identified this redundancy through iterative data collection and preliminary analysis (Creswell & Poth, 2018).

4.4 Data analysis processes

Thematic analysis was employed to analyse the data to ensure a systematic and trustworthy approach to interpreting research findings (Braun & Clarke, 2006). A hybrid thematic analysis approach was implemented in this study, which integrated both predetermined (a priori) and emerging (inductive) themes. The research objectives and existing literature on pedagogical practices in teaching electrochemical reactions and CPTD were used to derive predetermined themes. The analysis was guided by a structured framework that ensured alignment with the research questions, which provided themes that included content knowledge development, pedagogical decision-making and the impact of CPTD programmes (Braun & Clarke, 2006).

Simultaneously, the analysis maintained an openness to emerging themes, which were explicitly identified from the experiences of participants during interviews and classroom observations. As a result of this inductive component, the study identified unexpected insights, such as the unique challenges that teachers encountered when integrating CPTD knowledge into classroom practice and the collaborative strategies that were developed among teachers. The credibility and authenticity of the findings were strengthened by the integration of both predetermined and emergent themes, which was achieved by maintaining a balance between the research objectives and the accurate representation of the lived experiences of the participants (Nowell et al., 2017). This integrated methodology guaranteed that the investigation satisfied its objectives while simultaneously acknowledging the intricate, context-specific circumstances of physical sciences educators in the South African educational system. Following this, codes were grouped into broader themes that encapsulated key aspects of CPTD's influence on teachers' PCK. The themes were then reviewed against the original data to ensure consistency and accuracy in representing teachers' experiences. Finally, each theme was clearly defined and named, with supporting narrative examples.

4.5 Trustworthiness

In this study, the semi-structured interviews were validated through careful design and piloting. The interview guide was aligned with the research objectives and literature on CPTD, and electrochemical reactions, ensuring that questions were relevant and meaningful. A pilot interview was conducted to refine the clarity and sequencing of questions. The same interview guide was used for all participants, and an audit trail of the data collection and analysis process was maintained (Merriam & Tisdell, 2016). The classroom observation schedule was also subjected to validation procedures. It was designed to capture both content knowledge application and pedagogical decision-making during lessons on electrochemical reactions. Subject experts reviewed the instrument to ensure content relevance and alignment with the study objectives.

To further strengthen the trustworthiness of the research findings, the researchers engaged in prolonged engagement with educators that allowed for in-depth observations of their PCK development. Semi-structured interviews and follow-up discussions refined insights, minimised bias and strengthened the study's credibility. Member checking was also conducted, where participants verified the accuracy of findings, ensuring that their perspectives were captured correctly. In addition, all research phases were documented, and data analysis underwent peer review.

Moreover, the researchers employed interviews and observation data sources that were triangulated to strengthen the reliability of the findings. Haq et al. (2023) support this approach, asserting that triangulating data collection methods enhances the dependability of research outcomes. These combined strategies ensured that the findings were trustworthy and reflected educators' experiences. Confirmability was accomplished by maintaining a transparent audit trail and triangulating observational data with interviews. The lived realities of educators' classroom practices were captured to guarantee authenticity, reflecting the complexity of their pedagogical decisions without distortion.

4.6 Ethical considerations

The data collection process is a sensitive step in a study as it involves individuals and credible institutions, which demand that a researcher shows empathy and upholds ethical considerations. This assertion is supported by Taherdoost (2021) who opines that ethical considerations should be noted during data collection processes to ensure confidentiality of data and participants, safety of participants (as there may be risks involved) and the reputations of the organisations concerned. These include the institution under which the researcher is registered and the institution from which the data would be collected.

For the purposes of this research, ethical clearance was sought and received from the institution's ethics committee (FEDFREC 11-04-24-01). The researchers then requested permission from the Eastern Cape Department of Education to conduct the study in the sampled schools of the selected district, which was granted. The researcher then wrote to the schools' authorities and participants requesting their consent to participate in the study. The consent form clarified that their identities and the data collected would be kept confidential and would only be used for the purposes of the study.

5. Findings

5.1 Participants' biographic information

The biographic information of the participants is contained in Table 1 below.

Table 1: Biographic information of participants

School Code	Teacher Code	Gender	Age	Experience	Qualification
ORTCSA	CHEMEA	M	40	10	BSc, PGCE
ORTCSB	CHEMEB	F	54	27	BSc, HDE, BEd (FET Sciences)
ORTCSC	CHEMEC	M	58	17	BSc (Hons), PGCE
ORTCSD	CHEMED	M	41	18	BSc, PGCE, BEd Hons
ORTCSE	CHEMEE	F	32	8	BEd (NS)
ORTCSF	CHEMEF	M	49	21	BSc (Ed), BEd (Hons)
ORTCSG	CHEMEG	M	43	18	MEd (Science Education)
ORTCSH	CHEMEH	F	39	12	BEd (NS)
ORTCSI	CHEMEI	F	38	18	NDEd
ORTCSJ	CHEMEJ	F	42	13	NTDTEC, BTech.

Ten educators, five females and five males, consented to participate in the study. Their ages ranged from 32 to 58 years of age, with an average age of 43 years. While the collected information was not a prerequisite to participation in the study, it provided insight into the experiences of the participants in the field under study, their age and experience. This also indicated how long they had been exposed to the field of education, their experience in handling the subject and whether they were appropriately qualified. Their qualifications ranged from a teaching diploma to a master's degree in education. Their responses to interview questions resulted in the generation of the themes discussed below.

5.2 Data presentation
The data collected from interviews, classroom observations and field notes were categorised into two main themes as follows:
a. Educators' PCK growth on electrochemical reactions; and
b. Educators' curriculum decision-making evolution.

Theme 1: Educators' PCK growth on electrochemical reactions
Educators' responses were collated and structured into sub-themes that included:
(a) Teacher experience with CPTD;
(b) Incremental and sustained growth in content knowledge; and
(c) Growth in pedagogical approaches.

Sub-theme 1: Teacher experience with CPTD
Educators were asked to describe their experiences with CPTD and how these experiences influenced their confidence in teaching electrochemical reactions. Many educators highlighted a particular CPTD workshop where they conducted experiments as the most impactful. Given the inadequate resources in their schools, they expressed that their experience of hands-on experimentation, as a teaching approach, was transformative. They found that conducting experiments deepened their understanding of concepts and enhanced their excitement and engagement while recording observations.

Moreover, some educators noted that CPTD introduced them to PhET Interactive Simulations, which provided valuable experience in visualising the movement of electrons in an electrochemical cell’s external circuit.

Reflecting on their experiences, two participants shared the following insights:

> *“The CPTD programme that stood out for me was one where numerous experiments and demonstrations on electrochemical reactions were conducted. The programme emphasised the importance of hands-on experiments with learners, making it easier for me to replicate these demonstrations in my classroom. Allowing students to observe oxidation and reduction processes in real time significantly enhanced their understanding.”* (CHEMEG)

Another participant indicated:

> *“The most impactful CPTD programme for me was the one that focused on unpacking content and conducting experiments. Before attending the workshop, we struggled with experiments, not just due to limited resources but also because of our lack of exposure to practical applications. Engaging in hands-on experimentation was an eye-opening experience that improved my teaching approach and enhanced my ability to assess students' scientific practical skills.”* (CHEMEI)

This feedback highlights the vital role of hands-on experimentation in strengthening educators’ confidence and pedagogical effectiveness in teaching electrochemical reactions.

Almost all the educators appreciated the CPTD programmes that were organised to conduct experiments. Participants voiced their appreciation for clearly understanding, among others, the functions of a salt bridge, the deposition of copper during the reduction process and noting the blue colour of a copper sulphate solution fading due to the formation of copper from copper (ii) ions. This implies that practical experiments facilitate learning better than verbal understanding.

Given the lived experiences shared by participants CHEMEG and CHEMEI, participant CHEMEB added:

> *"After attending a series of CPTD programmes, I became more confident in handling the topic. It became easy for me to introduce electrochemical reactions to my learners as I now understand the chemical processes that take place during electrochemical reactions. I can now relate electric current and potential difference under electric circuits and Chemical Equilibrium to the topic of electrochemical reactions."* (CHEMEB)

Improved educator confidence levels make educators empathic to their learners. Although participant CHEMEA reported improved confidence levels in defining and explaining concepts, their classroom observation showed that less time was spent allowing learners to demonstrate their understanding of the difference between oxidising and reducing agents.

Sub-theme 2: Incremental and sustained growth in content knowledge

When educators were asked about the impact of CPTD on their content knowledge of electrochemical reactions, they highlighted that engaging with fellow educators and facilitators enhanced their understanding of the subject. Some educators reported that the CPTD programmes addressed their prior misconceptions and knowledge gaps. Their responses also indicated that ongoing participation in CPTD consistently provided opportunities to acquire new content knowledge. In addition, most educators linked their improved content knowledge to developing innovative teaching strategies. Two educators specifically shared how their content knowledge had evolved:

> *"Attending CPTD has significantly enhanced my content knowledge. There were several topics I previously felt uncertain about, but through CPTD, I gained a much clearer understanding of many of them. My improved grasp of electrochemistry concepts is now reflected in the way I teach. Since I am more confident in my understanding, I can effectively set up experiments on galvanic and electrolytic cells to demonstrate various chemical processes."* (CHEMEF)

The following participant demonstrated the impact of CPTD, stating:

> *"Now, I teach with more confidence because many of the grey areas and content gaps I had were addressed during CPTD. I can now handle more complex questions at a higher grade. No resource material or textbook can fully prepare you for that, but engaging with other educators during CPTD has allowed me to grow my content knowledge to the point where I'm confident in teaching with a solid understanding. This has made*

> *topics like electrochemical reactions much easier to teach. Even concepts that were overlooked during my teacher training were covered in the CPTD programmes."* (CHEMEI)

These responses suggest that attending CPTD over time facilitates gradual growth in content knowledge. This growth becomes sustainable as educators apply the knowledge in their teaching and continue to engage with more experienced colleagues. When new knowledge is shared with others, it solidifies in the educator's cognitive domain. This finding was also observed during the classroom observation. Most of the participants demonstrated growth in content mastery in their explanations and used different strategies to enhance learner understanding.

Sub-theme 3: Growing in pedagogical approaches

During the interviews, participants were asked to share their experiences regarding the influence of CPTD on their pedagogical content knowledge. Most participants indicated that their confidence in teaching had significantly improved as a result of attending CPTD sessions. They shared that these experiences helped them to gain new approaches and strategies to enhance student learning. Two participants described their experiences as follows:

> *"Workshops are really helpful. I gained valuable insights from educators who marked chemistry papers. They pointed out areas where learners struggled and shared effective teaching strategies. They demonstrated how to teach learners to write oxidation and reduction half-reactions. Thanks to the CPTD experience, I can now identify areas where learners may face difficulties in learning."* (CHEMEF)

The positive impact of workshops on teaching approaches was further emphasised by another participant, who explained:

> *"Attending CPTD workshops greatly improved my teaching methods. Before, I had gaps in conducting experiments. Sometimes, I had the necessary lab equipment but could not carry out experiments. After attending these workshops, I now know how to conduct these experiments as demonstrations in my lessons. I also had the content knowledge but struggled to deliver it effectively. After attending these workshops over time, I learned how to teach the content in a way my learners understand, and their performance in electrochemical reactions has improved during assessments."* (CHEMEJ)

These quotations indicated that the knowledge and skills gained from the CPTD programmes enhanced their teaching practices.

Theme 2: Educators' curriculum decision-making evolution

Educators from various schools attend CPTD programmes for a variety of reasons. Some participate to share and learn from best practices with other educators from different contexts, while others are motivated by a desire for professional growth. Professional growth, in this context, refers to an improvement in decision-making abilities, which positively influences an educator's judgment on what actions to take and when to take them. To explore the impact of CPTD on their curriculum-related decision-making processes, participants were asked a series of questions. Their responses were grouped into four key sub-themes based on commonalities and differences, as follows:

(a) Physical sciences educators' prioritisation of curriculum goals (or the pressure to conform to education policy);
(b) Physical sciences educators' pedagogical decision-making;
(c) Balancing curriculum flexibility and rigour; and
(d) Alignment of professional growth with assessment practices.

Sub-theme 1: Physical sciences educators' prioritisation of curriculum goals
Educators require a clear understanding of the curriculum goals, especially in the physical sciences. They must fully comprehend the objectives they aim to achieve through the implementation of the physical sciences curriculum. When asked how they prioritise curriculum goals, participants emphasised their adherence to the Curriculum and Assessment Policy Statement (CAPS), which serves as the policy foundation for the National Curriculum Statement (NCS). Many noted that CAPS provides an organised structure, with content arranged and paced to ensure conceptual progression from one grade to the next.

In addition, some participants mentioned other important documents, such as the Examination Guidelines (EG), Annual Teaching Plans (ATPs), and Chief Markers' reports. These resources, they said, are crucial in guiding curriculum delivery. Participants acknowledged that these documents contain specific curriculum goals. They believe that using them during lesson preparation helps them focus on achieving those goals while maintaining a sequence that ensures effective learning. Two participants shared their personal experiences:

> *"My image as a teacher has improved drastically, and I am always motivated to go to class because I now know exactly what to teach. I used to leave some concepts out when teaching, but now my lesson preparation has improved. I can prioritise concepts to enhance learning and ensure that I cover all the objectives of the curriculum. My aims and objectives are always with me when I prepare for my lessons."* (CHEMEH)
>
> *" The programme facilitated my realisation that I cannot simply expedite the curriculum in order to complete the syllabus. I now prioritise the fundamental concepts that learners typically encounter, such as oxidation and reduction processes, before transitioning to the more abstract aspects, such as electrode potentials. My initial emphasis is on conceptual understanding, which I then connect to practical experiments, as the training emphasised the importance of learners recognising the relevance of their studies. Therefore, my primary objective is to establish a robust foundation in the fundamentals, even if it necessitates dedicating additional time to this area."* (CHEMED)

These responses suggest that educators have a solid understanding of the curriculum they deliver. The goals of the curriculum are best achieved when educators are comfortable with the content and develop the skills to present it in various ways to enhance learning. Educators can effectively prioritise objectives and improve educational outcomes by consulting and utilising the various documents that outline the curriculum and its goals.

Sub-theme 2: Pedagogical decision-making of physical sciences educators
Educators regularly face situations that require professional judgment and sound decision-making to improve their teaching practices and benefit their learners. When asked about their pedagogical decision-making process and how CPTD influences these decisions, participants shared that they often encounter situations throughout the academic year where they must make choices to enhance curriculum delivery.

To implement differentiated teaching approaches, many participants highlighted the importance of understanding their learners' needs. They mentioned conducting diagnostic assessments to identify content gaps and learning losses, and an asset audit to determine available teaching aids. Based on these analyses, educators tailor their lesson plans accordingly. Most participants noted that students' varying learning abilities and challenges often compel them to develop strategies that cater to these diversities.

Many participants also shared that they regularly organise extra tuition sessions for learners, driven by the specific needs and challenges learners face. Furthermore, the CPTD programmes have emphasised the value of using experiments as a teaching tool, with some educators conducting experiments as demonstrations, where learners record their observations.
One educator, CHEMEA, shared her experience:

> *"During CPTD programmes, the department advises us to separate learners based on their performance and teach them in a way that helps them improve. By sharing good practices, we learn new ways of teaching challenging concepts, which helps learners understand better. The only challenge comes when learners misinterpret this approach and think they are being grouped together because they are 'stupid,' not realising it's because we want to offer them special attention to focus on their learning issues."*

CHEMEE, another educator, echoed this sentiment, reflecting on his professional growth in decision-making:

> *"Students are different, and they learn in different ways. As a teacher, you must use various approaches to teach these diverse learners. It was not easy for me to choose the right teaching approach, but after attending CPTD programmes, things have improved. Experienced educators share their effective practices for teaching students who struggle to understand, and now I know how to make things easier for my learners."*

The participants' responses reveal that educators understand the importance of making informed decisions that will help them become more effective facilitators of learning. Pedagogical decision-making involves a thorough analysis of each situation, followed by the implementation of appropriate strategies to address students' learning challenges. Effective teaching approaches are chosen based on a deep understanding of the factors hindering the learning process, and these interventions can mitigate such difficulties.

Sub-theme 3: Balancing curriculum flexibility and rigour
Participants understood how to balance curriculum flexibility and rigour when responding to questions that sought to establish if they could balance the two variables without compromising the educational outcomes.

When participants were asked what influences their choice of teaching strategies, they responded that the type of learners in the class plays a significant role in deciding which approach to use. Most participants emphasised that, although they must adhere to the ATPs, which are time-bound and specify the content to be taught, they still need to accommodate individual students' diverse learning abilities and styles. According to the participants, the ATP dictates the topics and concepts to be taught in a specific week of the academic year. The Examination Guidelines identify which concepts within each topic are examinable, while the Chief Markers' report highlights common errors made by students and misconceptions about the content.

Two participants shared the following insights:

> *"The ATP guides me to determine which topic should be taught at a specific time. In preparing my lessons, I ensure they accommodate diverse learning styles in my class. I also consult the Chief Markers' report, which informs my teaching approach by revealing misconceptions held by both learners and educators regarding the concepts."* (CHEMEB)

CHEMEA agreed, stating:

> *"In physical sciences, we cannot teach any concept we like. Guidelines, such as the ATP, tell us what and when to teach. Also, the Chief Markers' report identifies the challenging aspects of topics for learners. This information helps me improve my lesson preparation, ensuring that most learners can understand."*

This suggests that educators use ATPs to determine when specific concepts should be taught. The Chief Markers' report helps educators to identify learning challenges students face, allowing them to tailor their lesson plans and delivery to accommodate the varying abilities of their learners.

Sub-theme 4: Alignment of professional growth with assessment practices
Assessment is a fundamental aspect of teaching and learning. As educators progress in their professional development, they are expected to refine their methods for facilitating learning. Their growth is incomplete unless it is aligned with the development of assessment practices. When participants were asked about their decision-making process regarding the emphasis placed on teaching certain concepts over others, they indicated that their decisions are influenced by the CAPS and ATPs, which allocate time for content delivery, and the Examination Guidelines, which provide the weightings of topics in the final

examination. Some participants noted that topics with higher marks in the examination are given more attention and time in teaching. Also, some participants highlighted that concepts that have previously posed challenges for learners, as indicated by poor performance in past final examinations, are given extra focus.

Two participants shared the following:

> *"Attending workshops helped me understand the impact of topic weightings in terms of their contribution to the overall exam paper. For example, Organic Chemistry accounts for 50 marks out of 150, which is approximately 33.3% of the total paper. This is why I devote more time to teaching Organic Chemistry, ensuring that learners fully understand it to achieve a good pass."* (CHEMEF)

Another participant added:

> *"Examination questions are classified into low-order and high-order based on their cognitive demand. High-order questions require more emphasis and call for more effective teaching strategies. By analysing past exam papers, I can see that some topics carry more marks, and these require more time for teaching. I always advise my learners to allocate more time to topics with more marks."* (CHEMEJ)

This implies that educators must continue to grow professionally by acquiring the knowledge and skills necessary to improve their teaching practices. Their teaching methods must align with assessment practices to help learners acquire the knowledge, skills, and competencies required for success. Effective alignment ensures that assessments and teaching strategies work together to promote meaningful learning outcomes. It was also found that the teachers experienced limitations in resources for use in science teaching and they improvised as much as they could in their classroom practices.

6. Discussion

This study explored the influence of CPTD programmes on physical sciences educators' PCK in teaching electrochemical reactions in the O.R. Tambo Education District. The discussion of these findings is grounded within the PCK framework, ensuring alignment with the study's conceptual foundation. In addition, relevant literature is referenced to substantiate the findings and enhance their credibility.

One of the prominent findings of this study is that educators who participated in CPTD programmes experienced considerable growth in both their content knowledge and their pedagogical approaches to teaching electrochemical reactions. Many educators indicated that the training clarified the concepts, empowering them to teach with greater confidence.

Furthermore, many educators expressed the desire to improve their practical skills in conducting experiments. This finding aligns with Doyle et al. (2020), who found that CPTD programmes significantly enhance educators' subject matter knowledge. Similarly, Fischer et al. (2012) and Nixon et al. (2017) argue that CPTD strengthens science educators' content knowledge, which benefits their teaching practices. This finding aligns with the assertion by Dhurumraj and Ramaila (2024) that, for science educators to effectively facilitate meaningful conceptual development by science learners, they must be adequately grounded in content knowledge. CPTD programmes are viewed as key in enacting educators' CK, PK and PCK to improve educator efficacy in the classroom.

Another significant finding pertains to the influence of CPTD on educators' curriculum decision-making. Participants noted that their involvement in CPTD influenced how they prioritised curriculum goals and structured their teaching. Through CPTD, educators developed a better balance between curriculum flexibility and rigour, and they aligned assessment practices more effectively with instructional strategies. A key revelation was that CPTD encouraged educators to conduct situational analyses, allowing them to identify student misconceptions and adjust their teaching approaches accordingly.

This finding resonates with the work of Ogegbo et al. (2019) and John (2019), who highlight that CPTD improves educators' teaching competencies, professional knowledge and classroom practices. Sadler et al. (2013) also stress the importance of educators' awareness of student misconceptions as a key component of PCK. In this study, educators identified persistent student difficulties in understanding oxidation states and responded by reinforcing foundational concepts. Furthermore, educators found that using real-world analogies helped students grasp these concepts more effectively.

The findings also emphasise the importance of differentiated teaching strategies, particularly experiments, in improving student understanding of electrochemical reactions. Educators recognised the value of hands-on learning in addressing diverse learning abilities and alleviating learning difficulties. This finding aligns with Burke et al. (2020) who assert that PCK encompasses both content mastery and the ability to employ various instructional techniques. Educators in this study reported that their improved PCK enabled them to create more engaging and adaptable learning experiences for their students, ensuring that their teaching was responsive to the varied needs of their learners.

The study’s findings also reinforce the principles of PCK theory, as Shulman (1986) proposed, which underscores the integration of content knowledge and pedagogical strategies to represent and adapt subject matter effectively for diverse learners. Participants affirmed that CPTD programmes enhanced their understanding of the subject content and the instructional methods necessary for effective teaching. This suggests that teaching practice is not static but is a dynamic and evolving process that requires ongoing professional development. As educators continue to engage in CPTD programmes, they are likely to encounter new pedagogical strategies, conceptual insights, and opportunities for professional growth.

A key implication of these findings is the interconnectedness between improved content knowledge, effective teaching strategies, and enhanced student learning experiences. Educators noted that, as their understanding of electrochemical reactions improved, so did their ability to adapt their teaching methods to meet the needs of their learners, even though they experienced challenges in the utilisation of resources. This observation is consistent with Jacob et al. (2020) who contend that inadequate Subject Matter Knowledge (SMK) among educators often leads to student misconceptions and learning difficulties. Nixon et al. (2017) further assert that CPTD programmes strengthen science educators' content knowledge. Borko et al. (2010) argue that, to offer more powerful learning opportunities for students, researchers must provide more robust learning opportunities for educators.

7. Conclusion and recommendations

In conclusion, this study highlights the long-term influence of CPTD programmes on physical science educators' content knowledge and curriculum decision-making when teaching electrochemical reactions. The findings underscore the importance of ongoing professional development in enhancing educators' content knowledge. Through active participation in CPTD programmes, educators were able to deepen their understanding of complex concepts, engage in meaningful group discussions, and gain hands-on experience in conducting experiments. These opportunities were instrumental in boosting their confidence and improving their teaching abilities.

The significant improvement in educators' content knowledge and the acquisition of new pedagogical skills enabled them to manipulate the content and present it in multiple ways to meet students' needs more effectively. This improvement enhanced their teaching confidence and facilitated their ability to deliver the curriculum with greater clarity and depth. This study affirms that CPTD programmes improve physical sciences education.

Furthermore, the study reveals that CPTD programmes are critical in enhancing educators' curriculum decision-making. Educators reported that participation in these programmes improved their ability to decide what content to teach, how to teach it, and how to integrate related content areas with electrochemical reactions. This growth in decision-making capacity is consistent with earlier findings that emphasise the importance of professionalism in teaching, including effective decision-making, professional competence, and sound teaching methods.

The study reinforces the notion that CPTD programmes are crucial for the professional growth of physical sciences educators. By continuously enhancing their content knowledge and pedagogical strategies, these programmes equip educators with the tools they need to improve their teaching effectiveness, ultimately leading to a more robust learning experience for students. Based on the findings of this study, several recommendations are proposed to enhance the professional development of physical sciences educators and improve teaching outcomes in the Eastern Cape Province.

First and foremost, the ECDOE should enhance the frequency of CPTD programmes for physical sciences educators while minimising disruptions to teaching schedules. These programmes should be targeted, topic-specific and differentiated, incorporating practical workshops with hands-on experiments to improve educators' practical teaching skills. Special attention should be given to educators in under-resourced schools by providing them with the necessary skills in laboratory management and experimental teaching techniques.

Secondly, school managers should encourage educators to participate in these programmes and apply the acquired knowledge in their teaching practices. Furthermore, schools must allocate adequate budgets to procure necessary laboratory equipment and create structured opportunities for students to engage in experiments. This will foster greater interest in physical sciences and potentially improve student performance. Thirdly, educators should actively participate in their professional development by continuously engaging in CPTD programmes to enhance their PCK.

Fourthly, policymakers should implement policies that mandate educator participation in these programmes and hold them accountable for applying new skills in the classroom. These policies should support and reinforce the role of structured monitoring to ensure effective outcomes of the CPTD programmes.
Finally, further research is recommended to explore the potential integration of digital tools into physical sciences teaching and to assess the long-term impact of departmental support on sustaining educators' PCK development in diverse school settings. This would provide valuable insights into the effectiveness of different professional development approaches in enhancing teaching practices and improving student learning outcomes in physical sciences.

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