

GRADE 11 PHYSICAL SCIENCES TEACHERS' EXPERIENCES OF USING PHET SIMULATIONS-ENHANCED INQUIRY-BASED TEACHING OF CHEMICAL CHANGE

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Abstract

This study investigated Grade 11 Physical Sciences teachers' experiences of using Physics Education Technology (PhET) simulation-enhanced inquiry-based teaching of the chemical change concept. The focus on chemical change was motivated by recurring evidence from South African national diagnostic reports, which consistently indicate that learners struggle to explain chemical processes at a sub-microscopic level. Despite the ongoing global advocacy of inquiry-based teaching practices for science classrooms, its implementation still remains a challenge. The study sought to explore how teachers utilise PhET simulations to facilitate inquiry-based teaching of chemical change and to identify the contextual factors influencing their implementation of PhET simulation to support inquiry teaching of chemical change. Following the interpretivist paradigm, a qualitative case study design was adopted to conduct this inquiry on four purposively selected Grade 11 Physical Sciences teachers from four secondary schools in the Johannesburg North Circuit, Gauteng. The purposive selection criteria included their experience in teaching chemical change and use of PhET simulations to support inquiry-based teaching. Data was collected through classroom observations and semi-structured interviews. Classroom observations were guided by the FIT:COM framework which focuses on the integration of technology, pedagogy, and learner interaction. The findings revealed that Physical Sciences teachers used PhET simulations primarily to support the visualisation of abstract aspects of chemical change, such as particle rearrangement during reactions, and to structure inquiry-based activities, including Predict–Observe–Explain. Findings from both classroom observations and semi-structured interviews further revealed that simulations supported the identification and addressing of learners' misconceptions, particularly the distinction between physical and chemical change. However, teachers' use of simulations often conformed to teacher-centred instructional approaches, which limited opportunities for learner-centred inquiry and independent exploration. Moreover, contextual factors such as limited technological resources, overcrowded classrooms, unreliable internet, and insufficient training led teachers to adopt teacher-centred approaches. Therefore, the study concludes that while PhET simulations have the potential to support the teaching of chemical change, their effectiveness depends on how they are pedagogically integrated to achieve meaningful conceptual understanding of chemical processes. It is recommended that professional development programmes focus on subject-specific strategies for using simulations in inquiry-based teaching and that schools adopt context-responsive innovations, such as shared-device use and offline simulations, to support implementation in resource-constrained environments.

Keywords: *Chemical change, inquiry-based learning, PhET simulations, technology-enhanced science teaching, teachers' lived experiences.*

1. Introduction

The teaching and learning of chemical change in Physical Sciences continues to present challenges in many South African classrooms. Chemical change is inherently abstract and requires learners to understand processes at a sub-microscopic level, which are not directly observable (Cooper & Stowe, 2018). Year after year diagnostic reports consistently highlights poor learner performance in chemistry-related topics, particularly those involving chemical change (Ramnarain & Penn, 2021). These persistent challenges suggest that traditional teaching approaches are not adequately supporting learners in developing meaningful conceptual understanding (Assem et al., 2023). In response to these challenges, the South African Physical Sciences Curriculum and Assessment Policy Statement (CAPS) Specific Aim 1 advocates for the use of inquiry-based teaching approaches, as it states that one of its aims is to make

learners aware of their environment and equip them with investigative skills relating to physical and chemical phenomena (Department of Basic Education, 2011).

The White Paper 7 on e-Education, a South African policy document posits that technology is essential because it allows teachers and learners to create new ways of gathering, sorting, selecting, and analysing information (Vandeyar, 2015). However, despite these policy expectations, the implementation of inquiry-based teaching supported by technology remains a challenge in many classrooms. A study conducted in a South African classroom show that teachers often struggle to integrate technology meaningfully into inquiry-based teaching due to contextual constraints such as limited resources, inadequate training, and curriculum pressures (Ramnarain, 2020). This study explores teachers' experiences of using PhET simulations to teach chemical change through inquiry-based approaches. Despite increasing emphasis on technology integration and inquiry-based teaching in policy and research, there is limited empirical evidence on how Physical Sciences teachers in South African classrooms implement PhET simulations within inquiry-based teaching, particularly when teaching abstract concepts such as chemical change. This gap underpins the need for the present study.

2. Literature review

Inquiry-Based Science Education (IBSE) is widely recognised as a key approach within reformed science education curricula, as it promotes active engagement, critical thinking, and the construction of scientific knowledge (Ronnebeck et al., 2016). Within this broader framework, inquiry-based teaching (IBT) refers to the ways in which teachers implement inquiry principles in classroom practice. IBT emphasises the role of the teacher in designing learning experiences that encourage learners to ask questions, investigate phenomena, and construct scientific explanations (Kazeni & Mkhwanazi, 2020; Greenwood et al., 2022). It aligns with the goals of the highly advocated reformed science education curriculum, which emphasises the development of scientific inquiry skills. In the context of Physical Sciences, studies have shown that teachers often struggle to implement IBT effectively, frequently resorting to teacher-centred approaches due to curriculum demands, limited access to technological resources, and lack of pedagogical support (Ramnarain et al., 2020). This highlights a gap between policy expectations and actual classroom practice, particularly in South African contexts. These contextual realities highlight that the challenges associated with integrating technology into inquiry-based teaching are not only pedagogical but also shaped by systemic and structural conditions within the South African education system.

Chemical change is one of the concepts that learners find particularly difficult to understand because it requires an understanding of processes that occur at a sub-microscopic level, which cannot be directly observed. This challenge is reflected in South African national diagnostic reports, which consistently indicate that learners struggle to explain chemical processes and to link observable phenomena with underlying particle interactions. Research indicates that these difficulties are often rooted in the way the concept is taught, where instruction tends to focus on symbolic and macroscopic representations without adequately linking them to sub-microscopic processes (Mamombe et al., 2020; Cooper & Stowe, 2018). As a result, learners often develop misconceptions, especially when distinguishing between physical and chemical changes and when explaining reactions in terms of particle interactions (Mamombe et al., 2020). PhET-enhanced inquiry-based teaching has the potential to address these misconceptions by providing interactive and visual representations of scientific phenomena (Wen et al., 2023). PhET simulations allow learners to manipulate variables and observe outcomes, making them particularly suitable for supporting inquiry-based learning. In the context of chemical change, these simulations can support the visualisation of abstract processes such as particle rearrangement during chemical reactions which are not directly observable in traditional classroom settings. When simulations are used within structured approaches such as Predict–Observe–Explain, they can support learners in developing an improved understanding of concepts by encouraging them to make predictions, observe outcomes, and explain their reasoning (Alfiyanti & Jatmiko, 2020; Makamu & Ramnarain, 2022).

3. Theoretical framework

Technological Pedagogical Content Knowledge (TPACK) was selected and deemed suitable for theoretically underpinning this inquiry. The TPACK (Mishra & Koehler, 2006) framework highlights the overlap between the PCK knowledge components of a teacher and the integration of technology to enhance pedagogical practices that will transform and promote enhanced conceptual understanding. The framework highlights the importance of teachers' ability to effectively combine these knowledge domains to enhance teaching and learning in meaningful ways. In the context of this study, content knowledge relates to the teaching of chemical change, a concept that requires learners to understand both observable phenomena

and sub-microscopic processes. Pedagogical knowledge is reflected in the use of inquiry-based teaching approaches, which promote learner engagement, questioning, and conceptual understanding. Technological knowledge focuses on the use of PhET simulations as tools to support the teaching and learning of abstract scientific concepts. The intersection of these knowledge domains is central to effective teaching. Teachers are required not only to understand the content, but also to apply appropriate pedagogical strategies while integrating technology in a way that enhances learning. The TPACK framework therefore provides a useful lens for examining how teachers use PhET simulations to support inquiry-based teaching of chemical change. In this study, the TPACK framework is used to analyse how teachers integrate PhET simulations into their teaching practices, as well as the challenges they experience in doing so. It also allows for an understanding of how contextual factors, such as access to resources and classroom conditions, influence the relationship between technology, pedagogy, and content in real classroom settings.

4. Methodology

This study adopted a qualitative case study design within an interpretivist paradigm to explore Grade 11 Physical Sciences teachers' utilisation and implementation of PhET simulation-enhanced inquiry-based teaching of chemical change. The study aimed to examine how teachers use PhET simulations to support inquiry-based teaching and to identify the contextual factors influencing the implementation of PhET simulation-enhanced inquiry-based teaching of chemical change. The qualitative case study design was considered appropriate as it allowed for an in-depth exploration of teachers' experiences within their real classroom contexts, where the use of PhET simulations and inquiry-based teaching practices are shaped by contextual realities. A purposive sampling was used to select four Grade 11 Physical Sciences teachers from four secondary schools in the Johannesburg North Circuit, Gauteng. The selection criteria included Physical Sciences teachers who were actively teaching chemical change and had prior exposure to PhET simulations. The selection of one teacher per school allowed for the exploration of experiences across different school contexts, including variations in resource availability and classroom conditions. Data was collected in two stages. Firstly, one lesson observation of approximately 45 minutes was conducted per teacher during the teaching of chemical change. Secondly, semi-structured interviews of about 20-30min were conducted with each teacher following the observation to gain more insight into their instructional choices and experiences. Classroom observations were guided by the FIT: COM instrument (Judson, 2006), which focuses on how technology is integrated with pedagogy and content, as well as the nature of learner engagement during instruction. Data was analysed thematically, with codes generated inductively from both observation and interview data, allowing patterns to emerge across data sources. The data analysis focused on how teachers used PhET simulations during inquiry-based teaching, the strategies they employed, and the challenges they encountered in their specific classroom contexts.

5. Presentation of findings

5.1. Use of PhET simulations to support understanding of chemical change

The findings revealed that teachers used PhET simulations primarily to support the teaching of abstract aspects of chemical change. During lesson observations, simulations were used to demonstrate processes such as particle rearrangement during chemical reactions, allowing learners to visualise changes that are not directly observable. This was evident in both classroom observations and interview data. Teachers indicated that simulations were particularly useful when explaining concepts that are difficult to visualise, such as particle rearrangement during chemical reactions and the distinction between physical and chemical change. During classroom observations, teachers frequently used simulations to demonstrate processes step-by-step, pausing at key moments to emphasise important concepts. This supported learners in linking macroscopic observations to sub-microscopic representations. Teachers further reported that simulations played a role in addressing misconceptions. For example, some learners initially believed that substances disappear during chemical reactions; however, through the use of simulations, they were able to understand that particles are rearranged rather than destroyed. This was also evident during observations where learners were able to describe reactions in terms of particle movement after interacting with the simulation. Teachers also used PhET simulations within structured inquiry-based approaches. In most observed lessons, simulations were integrated into Predict–Observe–Explain (POE) activities, where learners were required to predict the outcome of a reaction, observe the simulation, and explain their findings. This approach encouraged learner participation and created opportunities for addressing misconceptions related to chemical change.

5.2. Types of inquiry supported through simulation use

While PhET simulations were integrated into inquiry-based teaching, the nature of inquiry observed in the classroom was largely structured. Teachers incorporated simulations into activities such as Predict–Observe–Explain; however, these activities were often guided, with teachers directing learners toward specific outcomes. In most cases, learners were not given opportunities to independently manipulate the simulations or explore alternative explanations, which limited the extent of open inquiry. As a result, the use of simulations supported guided inquiry rather than learner-driven inquiry. This suggests that while simulations were aligned with inquiry-based teaching in principle, their classroom implementation reflected a more controlled pedagogical approach.

5.3. Extrinsic factors hindering the implementation of PhET-enhanced inquiry-based teaching

The findings further revealed several contextual challenges that influenced the use of PhET simulations in teaching chemical change. These included large class sizes, unreliable internet connectivity, and insufficient training on integrating simulations into inquiry-based teaching. These challenges were evident in both the observations and interviews, where teachers expressed frustration with technological limitations and the lack of professional development opportunities. Teachers reported that large class sizes made it difficult to manage inquiry-based activities effectively, as teachers had to balance learner engagement with classroom management. Unreliable internet connectivity also disrupted lessons, limiting the consistent use of online simulations. Furthermore, teachers indicated that they had not received sufficient training on how to integrate PhET simulations into inquiry-based teaching. As a result, simulations were often used for demonstration purposes rather than as tools for facilitating enhanced conceptual understanding. As a result, teachers often adopted teacher-centred approaches when using simulations, prioritising classroom control and content coverage over learner exploration. This limited the potential of simulations to fully support inquiry-based learning.

5.4. Summary of key findings

Table 1. Summary of Key Findings on the Use of PhET Simulations.

Theme	Evidence from data	Link to chemical change
Visualisation of abstract concepts	Simulations used to demonstrate particle rearrangement during reactions	Helped learners understand sub-microscopic processes
Use of inquiry strategies	Integration of Predict–Observe–Explain (POE) activities	Supported explanation of chemical vs physical changes
Teacher-directed use	Simulations controlled by teacher and projected to class	Limited learner manipulation of variables
Addressing misconceptions	Classroom discussions revealed confusion between physical and chemical changes	Simulations used to clarify conceptual misunderstandings
Learner engagement	Increased participation during simulation-based lessons	Simulations used to clarify conceptual misunderstandings

6. Discussion

6.1. PhET simulations and conceptual understanding of chemical change

The findings of this study indicate that the use of PhET simulations supported teachers in explaining abstract aspects of chemical change. In this study, simulations were particularly effective in supporting the visualisation of sub-microscopic processes, such as particle rearrangement during chemical reactions. This aligns with existing literature, which suggests that digital simulations can make invisible scientific processes more accessible to learners. Simulations function as cognitive tools that support conceptual understanding by linking macroscopic observations with sub-microscopic representations. Furthermore, the findings showed that simulations assisted in addressing learners' misconceptions, particularly the belief that substances disappear during chemical reactions, by illustrating the rearrangement of particles.

Through the visualisation of sub-microscopic processes, teachers were able to demonstrate particle interactions during chemical reactions, which learners are unable to observe directly. This was evident during lesson observations where learners engaged with explanations of chemical processes at a particle level. The use of structured inquiry approaches, particularly Predict–Observe–Explain, further supported conceptual understanding by encouraging learners to actively engage with the content and reflect on their thinking. This aligns with the principles of inquiry-based learning, which emphasise learner participation

and knowledge construction (Kazeni & Mkhwanazi, 2020; Greenwood et al., 2022). However, the findings also suggest that the effectiveness of simulations is dependent on how they are integrated into teaching. While simulations have the potential to support inquiry-based learning, their use in a teacher-directed approach, in which learners follow prescribed steps rather than exploring independently, limits opportunities for learner exploration and inquiry.

6.2. The influence of context on technology integration

Although PhET simulations were used within an inquiry-based framework, the findings reveal a tension between the intended learner-centred nature of inquiry-based teaching and the teacher-directed manner in which simulations were implemented. In this study, simulations were often used in a structured and guided manner, limiting opportunities for learners to engage in independent exploration and knowledge construction. This suggests that the presence of technology alone does not automatically result in learner-centred pedagogy. This finding is concurring with research indicating that teachers often revert to teacher-centred practices due to contextual pressures. Factors such as time constraints, large class sizes, and curriculum demands influenced how teachers mediated the use of simulations. As a result, the use of simulations tended to support guided inquiry rather than open inquiry, which may limit the development of higher-order thinking skills associated with inquiry-based learning.

The challenges identified in this study reflect broader issues related to technology integration in South African classrooms. Limited access to resources, large class sizes, and unreliable internet connectivity have been widely reported as barriers to effective implementation (Ramorola, 2013). In this study, these factors directly influenced how PhET simulations were used, often resulting in a shift from learner-centred inquiry to teacher-directed instruction. These findings highlight the importance of considering context when integrating technology into teaching and further reinforces the gap between policy expectations, such as those outlined in White Paper 7 on e-Education, and the realities of classroom practice. While policy documents such as CAPS promote the use of inquiry-based approaches, the realities of classroom environments may constrain their implementation. This suggests the need for context-responsive innovations that consider the conditions under which teachers work.

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