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Documentary content analysis of Grade 12 instructional resources on chemical equilibrium: Opportunities for curriculum enhancement

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ABSTRACT

This study examines the extent to which Grade 12 instructional resources on chemical equilibrium integrate mathematical and graphing skills within explanations and learning activities, with the aim of identifying opportunities for curriculum enhancement. A qualitative documentary content analysis was conducted on a purposive sample of South African Grade 12 instructional resources and curriculum guidelines. A conceptual framework drawing on representational competence and graph interpretation literature guided the analysis. The results reveal that most resources predominantly emphasise declarative knowledge of equilibrium terminology. However, they offer limited scaffolding for mathematical reasoning, particularly with rate–time graphs. Critical gaps were identified in tasks that require learners to interpret graphs, differentiate between rate-based and concentration-based representations, and apply mathematical skills essential for deep conceptual understanding of chemical equilibrium. These findings suggest that current instructional materials inadequately support learners' representational competence in chemical equilibrium. The study recommends that curriculum designers and teachers integrate richer graphing tasks, explicit mathematical reasoning prompts, and opportunities for learners to engage with multiple representational forms to bridge the identified gaps. This study contributes to scholarship by empirically mapping specific deficiencies in instructional resources at the interface of chemistry and mathematics education, and by offering an analytical framework for evaluating representational competence demands within curriculum materials.

Keywords: Chemical Equilibrium, Documentary Content Analysis, Instructional Resources, Graphing Skills, Mathematical Reasoning

INTRODUCTION

Chemical equilibrium is a cornerstone of senior secondary school chemistry, which requires learners to understand both conceptual and mathematical representations of dynamic systems. Learners must interpret graphs that depict changes in reaction rates and the species' concentrations over time, yet research has identified persistent misconceptions in this area. [1] These misconceptions include

[1] Wilbur Bergquist and Henry Heikkinen, "Student Ideas Regarding Chemical Equilibrium: What Written Test Answers Do Not Reveal," *Journal of Chemical Education* 67, no. 12 (1990): 1000; Louise Tyson, David F Treagust, and Robert B Bucat, "The Complexity of Teaching and Learning Chemical Equilibrium," *Journal of Chemical Education* 76, no. 4 (1999): 554.

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interpreting the point where forward and reverse rates intersect as reaction completion, and thus confusing equal reaction rates with equal concentrations.[2]

Although instructional resources such as textbooks and workbooks are central to learners' exposure to chemical equilibrium, there is limited research on how these resources support the development of mathematical and graphing skills required for meaningful interpretation. Previous studies have focused on student understanding or teacher practices, while content analyses of curricular materials remain sparse.[3]

Despite its curricular importance, chemical equilibrium is widely recognised as one of the most conceptually challenging topics in chemistry education. International research spanning several decades has consistently shown that learners experience persistent difficulties in understanding equilibrium concepts, regardless of educational system or cultural context.[4] These difficulties suggest that equilibrium learning challenges are not simply the result of learner deficiencies but may also be related to how the topic is represented and structured within instructional resources.

Within the South African context, the Curriculum and Assessment Policy Statement (CAPS) Physical Sciences curriculum identifies chemical equilibrium as a core Grade 12 topic and explicitly requires learners to interpret reaction rate–time and concentration–time graphs, explain equilibrium in terms of equal forward and reverse reaction rates, and apply this understanding to qualitative and quantitative problems.[5] These expectations align with international standards that emphasise conceptual understanding, representational competence, and scientific reasoning.

This paper addresses this gap by systematically analysing instructional resources to determine how they represent chemical equilibrium concepts mathematically and graphically. The extent to which these resources provide conceptual and procedural support for learners' development of representational competence was investigated.

The extent to which these resources provide conceptual and procedural support for learners' development of representational competence was investigated.

The following are the questions that guided this paper:

1. How do instructional resources depict chemical equilibrium concepts mathematically and graphically?
2. What opportunities do these resources offer for learners to practice mathematical and graphing skills?

This paper provides a structured content analysis of three core curriculum and assessment resources that inform the instructional delivery of chemical equilibrium in the Grade 12 Physical Sciences curriculum. These include the Annual Teaching Plan (ATP) for 2023 and 2024, the National Senior Certificate (NSC) Diagnostic Reports from 2022 to 2024, and the Department of Education's Content Manual titled Free State Chemistry Revision Guide. These documents are central to interpreting and implementing the curriculum and are therefore essential for exploring how opportunities to develop mathematical and graphing skills are presented to learners.

The documents are examined through three interconnected dimensions: representational competence, how learners are supported in working with symbolic, numerical, and visual representations; cognitive integration, the sequencing and linking of concepts to support cumulative

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[2] Malka, Gorodetsky and Esther Gussarsky, "Misconceptualization of the Chemical Equilibrium Concept as Revealed by Different Evaluation Methods," *European Journal of Science Education* 8, no. 4 (1986): 427–41; M. Prokša, J. Lavonen, and K. Juuti, "Supporting Students' Meaningful Understanding of Chemical Equilibrium through Formative Assessment and Representations," *Chemistry Education Research and Practice* 25, no. 1 (2024): 45–61.

[3] Ylva Hamnell-Pamment, "Making Sense of Chemical Equilibrium: Productive Teacher–Student Dialogues as a Balancing Act between Sensemaking and Managing Tension," *Chemistry Education Research and Practice* 25, no. 1 (2024): 171–92.

[4] Kirk W Voska and Henry W Heikkinen, "Identification and Analysis of Student Conceptions Used to Solve Chemical Equilibrium Problems," *Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching* 37, no. 2 (2000): 160–76.

[5] Department of Basic Education (DBE), *Curriculum and Assessment Policy Statements: English Home Language: Foundation Phase Grades R–3* (Pretoria: Government Printer, 2011).

learning; and the balance between procedural fluency and conceptual understanding.[6] Successful equilibrium learning requires coordination between symbolic rate–time graphs, concentration–time graphs, and conceptual explanations. The analysis goes beyond identifying whether particular content is included by critically evaluating the quality, clarity, and instructional coherence of the learning opportunities embedded in each resource.

The paper concludes with a comparative synthesis that integrates insights in the three documents. This synthesis identifies recurring patterns, areas of inconsistency, and possibilities for curriculum improvement that may better support the development of learners' mathematical reasoning and graphical interpretation skills within the topic of chemical equilibrium.

LITERATURE REVIEW

Analysis of the Annual Teaching Plan (ATP)

The 2023 and 2024 Annual Teaching Plan (ATP) for Grade 12 Physical Sciences allocates eight instructional hours over two consecutive weeks, identified as Week 7 and Week 8 of Term 2, for the teaching of chemical equilibrium. This sequence reflects an intended progression from the introduction of basic concepts to the development of quantitative problem-solving. However, when evaluated in relation to the exploration of how opportunities are provided for learners to acquire mathematical and graphing skills in this topic, several important limitations are observed.

During Week 7, the ATP introduces fundamental concepts such as open and closed systems, reversible reactions, and the dynamic nature of equilibrium. The learners are expected to identify the equilibrium factors that affect the position of equilibrium and apply Le Chatelier's Principle to predict the system's response to changes in conditions. A practical activity using cobalt chloride or nitrogen dioxide is recommended to demonstrate equilibrium visually. The plan also mentions interpreting concentration versus time graphs, referred to as simple graphs. However, there is no structured guidance on how to teach learners to interpret or construct more advanced graphical representations. This lack of progression in visual reasoning may restrict learners' ability to fully understand the dynamic nature of equilibrium or apply this understanding in examinations that frequently assess graphical interpretation.

In Week 8, the focus shifts to the quantitative aspects of chemical equilibrium. Learners are expected to write the expression for the equilibrium constant using balanced chemical equations, perform calculations using concentration data, and interpret the meaning of the Kc value. These learning outcomes are central to the mathematical dimension of the topic. Irrespective of their complexity, the ATP does not allocate time for the revision or reinforcement of fundamental mathematical concepts such as algebraic manipulation, ratio reasoning, or the use of exponents. This omission presents a significant challenge for learners who have not developed the foundational skills required to solve constant equilibrium problems.

The literature confirms the concern about time constraints. It is noted that the CAPS allocates limited time for Physical Sciences instruction. This prevents teachers from covering the curriculum efficiently and effectively.[7] This pressure often drives teachers to accelerate their pace, leaving little time for thorough instruction on the mathematical and graphical components of the subject. Learners have reported that this lack of focus on problem-solving and calculation during lessons contributes to their difficulties in examinations.[8] Furthermore, the complexity of equilibrium calculations, particularly those involving Kc, requires extended time and structured support. Learners benefit from opportunities to practise these calculations gradually and with guided reinforcement.[9] However, ATP does not offer flexibility to accommodate such instructional needs.

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[6] Robert Kozma and Joel Russell, "Students Becoming Chemists: Developing Representational Competence," *Visualization in Science Education* 1 (2005): 121–46; Alex H Johnstone, "Why Is Science Difficult to Learn? Things Are Seldom What They Seem," *Journal of Computer Assisted Learning* 7, no. 2 (1991): 75–83.

[7] Zanoxolo Sibam, "An Investigation into Time Allocation in the Curriculum and Assessment Policy Statements (CAPS) for Grade 10 Physical Sciences," 2018.

[8] Wellington Itai Manzi et al., "Grade 12 Learners' Perceptions of Opportunities to Learn Imperfect Market Structures: Frances Baard District," *International Journal of Learning, Teaching and Educational Research* 20, no. 9 (2021): 255–71.

[9] Nur Syuhada Rusli et al., "E-Module Problem-Based Learning on Chemical Equilibria to Improve Students' Higher-Order Thinking Skills: An Analysis," *International Journal of Evaluation and Research in Education* 13, no. 1 (2024): 8822.

In addition, the integration of graphical and numerical reasoning is not evident. The treatment of graphing in Week 7 is not continued or expanded in Week 8, limiting the opportunity to link visual data interpretation with mathematical analysis. Such integration is essential for developing a holistic understanding of chemical equilibrium. Although the ATP lists resources such as Mind the Gap guides, online video content, and previous examination papers, it does not provide any guidance on how these materials should be used, sequenced, or adapted to support learners with different levels of understanding. Teachers are left to make these instructional decisions without structured support, which may contribute to unequal learning experiences across schools.

The ATP also places little emphasis on assessment. There is no mention of formal or informal classwork, practical tasks, or formative assessments to monitor learner understanding during these two weeks. The absence of feedback mechanisms and diagnostic tools reduces the potential to identify learner misconceptions or reinforce emerging skills, particularly in graphing and calculation tasks that require repeated practice.

The ATP outlines the key content areas of chemical equilibrium but provides limited instructional support for the development of essential mathematical and graphing skills. Restricted time allocation, lack of foundational skill reinforcement, weak integration of visual and numerical instruction, and minimal assessment provisions collectively reduce the potential for meaningful learning.

Analysis of NSC Diagnostic Reports (2022-2024)

The NSC Diagnostic Reports from 2022 to 2024 reveal consistent underperformance on the topic of chemical equilibrium, particularly in areas that require mathematical reasoning, graphical interpretation, and conceptual application. These diagnostic patterns align with research findings that confirm the complexity of the topic and its demanding nature within the Grade 12 Physical Sciences curriculum.

The reports show that many learners continue to struggle with the formulation and application of the equilibrium constant (Kc). Several learners substituted mole values into the Kc expression instead of using concentrations, including solids where they were not required, and presented incorrect or incomplete expressions. These difficulties reflect a limited understanding of the foundational principles that govern chemical equilibrium. As a result, chemical equilibrium requires not only definitional clarity but also a deep conceptual grasp that includes the ability to relate calculations to the dynamic behaviour of systems.[10] This need for integration between procedural and conceptual knowledge is often unmet in classroom instruction, as evidenced by the repeated learner errors observed in the three diagnostic cycles.

Chemical equilibrium demands a combination of mathematical proficiency and the ability to reason about the effects of external changes on system stability.[11] However, the learners showed limited ability to perform algebraic manipulations or interpret data tables correctly. The 2024 report highlighted that some learners defaulted to solving for Kc in questions that required different responses, such as determining the mass of a substance. This response pattern reflects a reliance on memorised procedures without the cognitive flexibility to interpret the actual demands of a task. These procedural tendencies suggest that learners may not engage in meaningful learning activities that foster understanding across a variety of problem types.

Interpreting the graphs was another consistent area of difficulty. Learners confused graph types, such as concentration versus time and rate versus time, and frequently failed to identify correct axes or curves. In essence, teachers experience difficulty in interpreting chemical equilibrium graphs.[12] This may result in a limited instructional emphasis on visual reasoning, leaving learners ill-equipped to respond to graphical tasks. In the diagnostic reports, learners often described “the graph” without

[10] Yannik Peperkorn, Jana-Kim Buschmann, and Stefanie Schwedler, “Comparing Drawing Tasks and Elaborate Single-Choice Questions in Simulation-Based Learning: How Do They Facilitate Students’ Conceptual Understanding on Chemical Equilibria?,” *Chemistry Education Research and Practice* 25, no. 4 (2024): 1030–51.

[11] Melisa Damayanti Lubis and Ayi Darmana, “The Effect of Teaching Materials for Chemical Equilibrium Based on Spiritual Values on Student Learning Outcomes in the Guided Inquiry Learning Model,” *Jurnal Teknologi Pendidikan: Jurnal Penelitian Dan Pengembangan Pembelajaran* 9, no. 2 (2024): 247–55.

[12] Stacey Greengold, “Experienced High School Chemistry Teachers’ Conceptions of Chemical Equilibrium in Terms of Rates of Reaction” (State University of New York at Stony Brook, 2019).

specifying particular trends or variables, indicating a lack of representational competence. This skill, which involves moving easily between visual and symbolic forms, is essential in mastering equilibrium concepts, but appeared to be underdeveloped.

Many learners were observed to perceive chemical equilibrium as one of the most challenging topics in Physical Sciences.[13] This perception is largely attributed to its abstract nature and the intensive mathematical reasoning it demands. Learners' inability to interpret graphs or apply Le Chatelier's Principle to specific situations, even when they recalled the definition of the principle, illustrates this challenge. In several instances, learners correctly quoted the principle but could not use it to explain the effect of temperature or pressure changes on equilibrium. This failure to transfer theoretical knowledge to real problem settings indicates shallow understanding and insufficient opportunities for reasoning practice.

Another issue observed in the diagnostic reports was the frequent use of algorithmic methods or pre-constructed tables. Learners attempted to apply fixed templates even when the data or question format did not warrant such strategies. In 2024, some learners used tables that did not match the question well yet were awarded partial marks for procedural effort. These instances suggest that learners are trained to memorise processes rather than being guided to develop adaptive thinking. Thus, achieving mastery of chemical equilibrium requires participation in well-planned learning tasks that promote understanding of how changes in conditions influence system balance.[14] In particular, learners often lack the autonomy needed for self-directed learning on this topic. They advocate for instructional resources that integrate chemistry content with broader social and scientific issues to encourage critical thinking and learner independence.[15] The diagnostic findings reinforce this view, as many learners could not apply concepts in unfamiliar settings or interpret questions that required analytical reasoning. Instead, learners demonstrated a tendency to recall isolated facts without linking them to the broader chemical context. This pattern implies that classroom experiences may be dominated by rehearsal rather than inquiry-based learning.

From the Opportunities to Learn (OTL) perspective, the persistent learner challenges documented in the NSC Diagnostic Reports suggest limited exposure to structured learning experiences. Although the Annual Teaching Plan and Department of Basic Education materials outline the required concepts and skills, the reports reflect that learners are not receiving sufficient structured opportunities to practise and internalise these concepts. There appears to be limited emphasis on tasks that promote graph construction, mathematical reasoning, and the transfer of learning to new contexts. In addition, the lack of frequent assessment of these skills may reduce the feedback available to teachers and learners, further hindering instructional adjustments.

The NSC Diagnostic Reports provide strong evidence that chemical equilibrium remains a topic of significant difficulty due to its abstract content, symbolic complexity, and requirement for integrated reasoning. These challenges are compounded by instructional practices that prioritise procedural accuracy over conceptual depth. The literature confirms that teachers and learners require stronger support systems, including targeted professional development, socio-scientific contexts, and learner-centred materials that promote meaningful engagement with equilibrium concepts. Addressing these issues is essential for creating equitable and effective learning opportunities in Physical Sciences.

Analysis of the DoE Content Manual (2024)

The Free State Chemistry Revision Guide, developed by the provincial Department of Education, serves as a curriculum-aligned instructional resource intended to support Grade 12 learners in revising key concepts and preparing for the National Senior Certificate (NSC) examinations. Its content is largely drawn from previous NSC examination papers, with a strong emphasis on standardised responses and

[13] Nur Fitriyana et al., "In-Service High School Chemistry Teachers' View towards Chemistry: Is It a Difficult Subject?," in *AIP Conference Proceedings*, vol. 2556 (AIP Publishing LLC, 2023), 040016.

[14] M.S Sari, R Rusman, and L Hanum, "The Implementation of the Problem-Based Learning (PBL) Model on the Topic of Factors Affecting Chemical Equilibrium," *Journal Ilmiah Mahasiswa Pendidikan Kimia*, 2024, 9–2.

[15] Lestari Anggriani, Radjawali Usman Rery, and Jimmi Copriady, "Development of a Socio-Scientific Issues-Based Module on Chemical Equilibrium to Enhance Students' Critical Thinking and Learning Autonomy," *Al-Ishlah: Jurnal Pendidikan* 16, no. 4 (2024): 5014–28.

procedural clarity. Although this approach helps learners become familiar with the examination formats, it provides limited opportunities to foster a deeper conceptual understanding, particularly concerning mathematical reasoning and graph interpretation.

An Indonesian study highlights that the absence of real-world contextualisation and multiple representations in the available resources makes numerous learners experience difficulty with chemical equilibrium.[16] The manual introduces chemical equilibrium using a static flow diagram that outlines the necessary conditions for equilibrium to be established. This includes concepts such as reversibility, a closed system, and the influence of concentration, temperature, and pressure. The diagram provides a useful summary for examination revision purposes.[17] However, the resource does not extend to tasks that require learners to interact with, construct, or compare visual representations of equilibrium conditions. Although graphs are presented, learners are not guided to interpret them through progressive steps or are required to construct their own. These omissions limit the development of representational competence, which is essential for conceptual understanding.

A significant focus of the manual is the structured explanation of Le Chatelier's Principle through a four-step process. Learners are required to identify the disturbance, state the system's response, predict the direction of the shift, and describe the resulting concentration change. This structure supports learners in answering standard examination questions, but it remains isolated from visual and numerical reasoning. Learners are not expected to apply this explanatory model to graphical data or quantitative scenarios. Consequently, instructional resources that do not encourage critical or analytical thinking often result in passive learning, where learners memorise procedures without understanding underlying principles. In this case, learners are not assisted in drawing links between verbal explanations and graphical or symbolic representations, thereby limiting the integration of knowledge.[18] In the section on the equilibrium constant (Kc), the manual demonstrates procedural clarity by guiding learners through formulating expressions from balanced equations and avoiding common misconceptions, such as the inclusion of solids and liquids. A structured six-row table, similar to the Reaction, Initial, Change, Equilibrium (RICE) method, is used to facilitate step-by-step calculations involving mole ratios, initial amounts, changes in concentration, and equilibrium values. This approach benefits learners who are already confident in mathematical reasoning. However, the manual does not offer revision or support for foundational mathematical skills, such as algebraic manipulation or mole conversions, which are crucial for successful calculation. Therefore, the central role of teaching materials in equipping learners with essential skills is emphasised.[19] Resources that assume prior competence without providing scaffolding place learners who need targeted mathematical support at risk. Additionally, the guide does not explain the conceptual implications of Kc values or illustrate how these values relate to equilibrium position or graphical representations. The absence of such integration limits learners' ability to reason across different forms of representation.

The manual presents concentration-time graphs to illustrate the effect of changes in variables such as concentration, temperature, and pressure. These graphs are accompanied by labels that indicate the nature of the change, such as an increase in temperature. However, the manual does not provide tasks that require learners to interpret these graphs independently or explain their features using chemical reasoning. Learners are not guided through reading axes, identifying key points, or making inferences based on trends. This represents a gap, particularly in light of curriculum expectations which specify that learners should be able to interpret experimental data and graphs on reaction rates using principles such as collision theory. Researchers argue that effective teaching materials should promote active engagement, adapt to learners' needs, and maintain suitable academic standards.[20] Learners are not

[16] Yuli Rahmawati et al., "Students' Conceptual Understanding in Chemistry Learning Using PhET Interactive Simulations," *Journal of Technology and Science Education* 12, no. 2 (2022): 303–26.

[17] Nani Mariliaty And T Suhery, "Optimization Of Basic Chemistry Learning: Validation Of Stem-Based Problem-Based Learning Materials For Chemical Equilibrium," *Asian Journal Collaboration Of Social Environmental And Education (Ajcsee)* 2, No. 1 (2024).

[18] Reza Suci Rahmadani and Achmad Lutfi, "Inquiry-Flipped Classroom E-Worksheet to Train Critical Thinking Skills on Chemical Equilibrium Learning," *Jurnal Pijar MIPA* 19, no. 4 (2024): 564–71.

[19] Putri Nadia Rizal, Mawardi Mawardi, and Okta Suryani, "Development of Teaching Materials to Support Learning of the Merdeka Curriculum on Chemical Equilibrium," *Edunesia: Jurnal Ilmiah Pendidikan* 5, no. 3 (2024): 1352–70.

[20] E Wang et al., "Teachers' Perceptions of What Makes Instructional Materials Engaging, Appropriatel y Challenging, and Usable," *RAND Corporation*, 2021.

adequately supported in developing the competencies required for high-stakes assessments when structured tasks that link visual, symbolic, and verbal reasoning are absent.

The guide's reliance on past NSC questions supports examination preparation and procedural accuracy. Learners benefit from exposure to the structure of typical questions and explanation templates. However, this retrospective focus limits the development of transferable skills. Opportunities to practise novel or open-ended tasks are absent, and activities that involve constructing or critically analysing graphs are not included. This is particularly concerning given the increasing emphasis in national assessments on data interpretation and higher-order reasoning.

The Free State Province Chemistry Revision Guide offers structured support for examination revision but does not adequately address the need for conceptual integration, representational competence, and learner engagement with mathematical and graphical elements of chemical equilibrium. The findings of the literature support this observation, highlighting the need for materials that encourage active participation, foster analytical thinking, and integrate multiple forms of representation in alignment with curriculum expectations.

THEORETICAL FRAMEWORK

The analysis draws on the Opportunities to Learn framework, which focuses on the availability, structure, and quality of learning experiences provided to learners.[21] It is further grounded in Ausubel's Theory of Meaningful Learning, which emphasises that new learning is most effective when it builds on relevant prior knowledge through conceptually coherent instruction.[22] Collectively, these theoretical perspectives offer a comprehensive foundation for evaluating the extent to which instructional resources facilitate learners' engagement with key mathematical concepts such as algebraic manipulation and equilibrium constant calculations, along with the interpretation of graphical representations such as concentration versus time graphs and the visual application of Le Chatelier's Principle.

METHODOLOGY

Research Design

This study adopted a qualitative documentary content analysis research design to examine how chemical equilibrium is represented in instructional resources and to identify the opportunities these resources provide for developing mathematical and graphing skills. An analysis of the documentary content of instructional resources related to chemical equilibrium was conducted. Documentary analysis involves systematic examination of text and graphic content to identify patterns and underlying messages.[23]

The choice of this design is aligned with the aims of the study, which focus on the intended curriculum as embodied in instructional materials rather than on enacted classroom practices or learner outcomes. This approach is particularly appropriate for investigating chemical equilibrium, where persistent learner misconceptions have been documented internationally despite extensive curriculum reforms, suggesting a need to examine how learning opportunities are structured within instructional resources.

Sample Selection

The study was situated within the South African Grade 12 Physical Sciences curriculum, as prescribed by the Curriculum and Assessment Policy Statement (CAPS) (DBE, 2011). CAPS explicitly requires that learners interpret reaction rate–time and concentration–time graphs, explain equilibrium in terms of equal forward and reverse reaction rates, and apply mathematical reasoning to chemical systems.
The purposive sample included:

- the Annual Teaching Plan (ATP for 2023 and 2024),
- the National Senior Certificate (NSC) Diagnostic Reports from 2022 to 2024, and

[21] David P Ausubel and Donald Fitzgerald, "Chapter V: Meaningful Learning and Retention: Intrapersonal Cognitive Variables," *Review of Educational Research* 31, no. 5 (1961): 500–510.
[22] Bernadette N Chabongora and Loyiso C Jita, "Opportunities to Learn (OTL) Grade-10 Algebra in Three South African Catholic Secondary Schools," *Journal of Educational Studies* 12, no. 1 (2013): 172–88.
[23] Ausubel and Fitzgerald, "Chapter V: Meaningful Learning and Retention: Intrapersonal Cognitive Variables."

- the Department of Education's Content Manual titled Free State Chemistry Revision Guide (2024).

These materials were selected for their widespread use and official alignment with the South African Curriculum and Assessment Policy Statement (CAPS) national curriculum guidelines.

Unit of Analysis

The primary unit of analysis was the instructional segment related to chemical equilibrium. This included:

- Content focus
- Focus on graphing skills
- Support for Mathematical Skills
- Instructional time and depth
- Nature of Learning Opportunities
- Support for Le Chatelier's Principle
- Assessment and feedback mechanisms
- Instructional support

Analysing multiple elements within each instructional segment allowed for a comprehensive examination of how representations, explanations, and tasks were integrated within the resources.

Ethical considerations

This paper forms part of a bigger study where Ethical approval was obtained from relevant authorities prior to data collection, and permission was granted by the provincial Department of Education. However, for the purpose of this paper, the analysis of publicly available instructional materials was involved and did not involve human participants. As such, formal ethical clearance was not required. Nevertheless, the study observed ethical research principles by accurately representing the content of instructional resources, avoiding evaluative judgements about authors or publishers and acknowledging the contextual nature of the findings.

PRESENTATION OF FINDINGS AND DISCUSSION

Documentary evidence from NSC diagnostic reports

Analysis of the NSC Diagnostic Reports from 2022 to 2024 provided corroborative qualitative evidence of persistent learner difficulties in chemical equilibrium. The reports documented consistent underperformance in tasks that required mathematical reasoning, graphical interpretation, and conceptual application. Learners frequently constructed incorrect Kc expressions, substituted mole values for concentrations and incorrectly included solids. These errors reflect limited conceptual understanding rather than isolated calculation mistakes. The reports also showed that learners struggled with algebraic manipulation and interpretation of tabulated data. In several instances, learners defaulted to calculating Kc in questions that required alternative responses, indicating reliance on memorised procedures.

Graph interpretation was a recurring difficulty. Learners confused graph types, misidentified axes, and described graphs vaguely without reference to specific variables or trends. These response patterns indicate underdeveloped representational competence and limited opportunities to practise visual reasoning. The reports also revealed the frequent use of fixed tables and algorithmic approaches, even when inappropriate. Learners often reproduced memorised procedures without adapting them to task demands. Although some procedural effort was awarded partial credit, conceptual understanding remained weak.

From an Opportunities to Learn perspective, the diagnostic reports indicate limited exposure to structured learning experiences that support reasoning, representation, and conceptual transfer. Although curriculum documents specify required content and skills, the reports suggest that learners do not have enough opportunities to practise and integrate mathematical and graphical reasoning in chemical equilibrium.

A Comparative Synthesis of the ATP, Diagnostic Reports, and DBE Content Manual

To explore the opportunities available for learners to develop mathematical and graphing skills in the topic of Chemical Equilibrium in Grade 12 Physical Sciences, a comparative synthesis was undertaken. Using the Opportunities to Learn (OTL) framework and Ausubel's Theory of Meaningful Learning, this synthesis draws on the findings from the analysis of three core instructional documents: the 2023/2024 Annual Teaching Plan (ATP), NSC Diagnostic Reports (2022–2024), and the DBE Content Manual (2024). The documents collectively contribute to shaping the instructional context and learning experiences of learners, but their capacity to promote the targeted skills is uneven.

In all three documents, a common strength is the inclusion of essential content on chemical equilibrium, such as the conceptual foundations of reversible reactions, closed systems, Le Chatelier's Principle, and the equilibrium constant (Kc). However, when considering the integrated development of mathematical and graphing competencies, several critical gaps emerge. The ATP presents a structured timeline to teach equilibrium and includes references to graph interpretation and Kc calculations; however, it does not provide progressive support for these skills. The emphasis is on content delivery rather than the development of representational fluency, which limits learners' ability to interpret or apply graphical and mathematical reasoning to novel problems.

The Diagnostic Reports confirm this limitation by highlighting repeated learner difficulties with Kc calculations and graph interpretation over three examination cycles. Learners consistently misapply formulas, neglect conversion steps, and fail to align theoretical explanations with graphical features. These issues are symptomatic of a learning environment where procedural memorisation is prioritised over conceptual integration. Furthermore, the reports show that learners struggle to apply Le Chatelier's Principle in graphical contexts, suggesting inadequate exposure to tasks that require them to reason across multiple representations.

The DBE Content Manual offers the most extensive support for procedural tasks, especially in Kc calculations, and includes illustrative graphs aligned with examination requirements. However, it does not provide guided interpretation activities, structured visual reasoning, or integrated tasks linking calculations with graphical data. Its predominant use of past paper questions further contributes to a retrospective and examination-focused approach, rather than fostering transferable or exploratory skills. The absence of open-ended, graph-based, or interpretive exercises restricts the development of flexible problem-solving abilities.

The comparative analysis reveals that although the documents address curriculum content, they fall short in supporting the development of learners' mathematical and graphing skills in a holistic and integrated manner. This shortfall undermines the realisation of meaningful learning, as proposed by Ausubel, and limits equitable learning opportunities, as highlighted in the OTL framework. To enhance the instructional environment, curriculum planning and resource development must prioritise the inclusion of structured, interpretive, and integrative tasks that build representational competence alongside procedural fluency.

Table 1 presents a comparative synthesis of key aspects relevant to the objective of this study, serving to critically consolidate the findings of the three documents.

Table 1: Comparative Content Analysis of Instructional Documents on Chemical Equilibrium

Aspect	Annual Teaching Plan (ATP) (2023/2024)	NSC Diagnostic Reports (2022–2024)	DoE Content Manual (Free State Chemistry Revision Guide: 2024)
Content Focus	Covers key concepts including equilibrium, Le Chatelier's Principle, and Kc.	Emphasises learner errors and challenges in applying concepts.	Based on past NSC papers, it reinforces exam-related content.
Focus on Graphing Skills	It mentions "interpretation of simple graphs" briefly in Week 7 but lacks	Graph interpretation is repeatedly flagged as a major difficulty. Learners misread axes, ignore time	Includes static graphs, focused on interpretation, but lacks step-by-step

	depth, progression, and structure.	intervals, and struggle with equilibrium shifts.	guidance or integration with other data.
Support for Mathematical Skills	Covers Kc calculations in Week 8. No revision of ratios, algebra, or exponents. No support for foundational math skills.	Highlights frequent errors in writing Kc expressions, using incorrect units, and applying formulas. Learners confuse moles and concentration.	Provides procedural structure and worked examples. Assumes learners are mathematically proficient. No remediation or scaffolding included.
Instructional Time and Depth	8 hours over 2 weeks (Term 2, Weeks 7 & 8). Prioritises coverage over depth. No diagnostic or remedial support embedded.	Suggests that time constraints result in superficial learning. Learners often memorise rather than understand.	Designed for revision, not teaching. Encourages repetition of known items, not conceptual development.
Nature of Learning Opportunities	Learning is fragmented. Graphing, calculations, and conceptual reasoning are taught in isolation.	Learners do not integrate mathematical and graphical representations. Performance is procedural, not conceptual.	Emphasises exam rehearsal. Does not promote exploration or cognitive flexibility.
Support for Le Chatelier's Principle	Covered conceptually but not linked to data interpretation or graphical analysis.	Learners state the principle but cannot apply it in problem-solving contexts.	Provides an explanation structure but lacks application exercises, especially with visual or numerical data.
Assessment and Feedback Mechanisms	No formative assessment embedded. Homework was assigned but not clearly linked to skill development.	Reveals repeated misconceptions over the years. The lack of real-time feedback contributes to poor learning outcomes.	No diagnostic or formative tasks included. Emphasis on correct answers without attention to the learning process.
Instructional Support	Minimal instructional support; relies on teacher discretion.	Indicates gaps in conceptual understanding and transfer skills.	Procedural focus with minimal integrative reasoning or representational development.

All three documents demonstrate alignment with the curriculum's content requirements for chemical equilibrium; however, they collectively offer limited opportunities for learners to develop integrated mathematical and graphing skills. The ATP does not provide sufficient instructional sequencing; the Diagnostic Reports highlight performance gaps linked to weak reasoning abilities; and the DBE Content Manual, although procedurally detailed, lacks the emphasis on representational competence and flexible application. These findings highlight the necessity for deliberate curriculum enhancement that fosters learners' meaningful engagement with both symbolic and visual dimensions of chemical equilibrium, thereby supporting the central aim of this study.

RECOMMENDATIONS

Supplementary activities that require learners to explain graph behaviour using particle-level reasoning and mathematical relationships are recommended. Therefore, curriculum developers and instructional materials developers should be encouraged to integrate tasks that explicitly require learners to interpret graph features in terms of reaction rates, gradients, and dynamic balance.

CONCLUSION

The content analysis of the Annual Teaching Plan (ATP), the National Senior Certificate (NSC) Diagnostic Reports, and the Department of Basic Education (DBE) Content Manual confirmed that these documents addressed the core content requirements but offered limited guidance to support integrated and conceptual instruction. ATP did not allocate specific time to develop graphing skills. The NSC Diagnostic Reports highlighted recurring errors in learner responses but did not provide pedagogical strategies to address these difficulties. The DBE Content Manual emphasised procedural practice and repetition, with little focus on promoting conceptual depth or visual reasoning.

The findings point to significant gaps in the delivery and experience of the curriculum in actual classroom settings. Learners are often exposed to isolated content segments without the necessary foundational support or opportunities to make meaningful connections. Instructional approaches tend to prioritise factual recall and examination practice, limiting the development of key mathematical and representational skills. In conclusion, the current instructional environment presents constraints to meaningful engagement with the mathematical and graphical aspects of chemical equilibrium. These constraints reflect broader systemic and pedagogical misalignments that impact learners' ability to develop a coherent and functional understanding of the topic.

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