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Assessing Concept Mastery in Physical Sciences: Implementing Formative Assessment Interventions for Teaching and Learning Electricity and Magnetism

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Abstract. This study examines the impact of formative assessment practices on concept mastery in Physical Sciences, with a particular focus on Electricity and Magnetism among Grade 10 learners. A quasi-experimental design was utilized, involving a purposive sample of 175 learners from five secondary schools in the uMkhanyakude district. Schools A–C constituted the experimental group, while schools D–E served as the control group. The intervention based on formative assessment practices was implemented in the experimental group. To assess concept mastery, a Physical Sciences test on Electricity and Magnetism was administered as both a pre-test and post-test for both groups. The findings revealed that the experimental group significantly outperformed the control group, highlighting the positive impact of formative assessment on learners' concept mastery. The study concludes that formative assessment is an effective strategy for enhancing concept mastery in Physical Sciences and recommends its integration into the teaching of Electricity and Magnetism. Additionally, it suggests further research to examine the long-term effects of formative assessment on learners' overall academic performance in the sciences.

Keywords: Concept Mastery, Formative Assessment, Physical Sciences, Assessment Interventions, Pedagogical Strategies

1. Introduction

The teaching of Physical Sciences, particularly topics such as Electricity and Magnetism, presents challenges for both teachers and learners due to the abstract nature of the concepts involved. Effective instruction in this area requires clear

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explanations, engaging demonstrations, and continuous assessment of learners' understanding. Formative assessment, conducted during the learning process rather than at its conclusion, plays a crucial role in evaluating and enhancing learners' mastery of concepts like Electricity and Magnetism (Lichtenberger et al., 2024). This approach enables teachers to identify misconceptions early, adapt teaching strategies, and provide real-time support for learners' progress (Elbasyouny, 2021).

In the context of Electricity and Magnetism, formative assessment techniques must accommodate the dynamic and complex nature of the subject. Learners often struggle with abstract concepts such as electric current and the behaviour of magnetic fields (Hernandez et al., 2022). Given that these concepts form the foundation of many scientific and technological fields, it is essential for teachers to implement diverse formative assessment strategies that promote both conceptual understanding and problem-solving skills. Techniques such as concept mapping, peer reviews, and interactive quizzes provide timely feedback, helping both learners and teachers gauge comprehension at different stages of learning (Akhmadkulovna, 2024).

Additionally, formative assessments can effectively address common misconceptions about Electricity and Magnetism. Research by Carpenter et al. (2022) indicates that learners often carry incorrect mental models from previous learning experiences, which can hinder their ability to grasp more complex physical phenomena. Strategies such as think-pair-share, real-time quizzes, and concept inventories help uncover these misconceptions, enabling targeted interventions and more effective teaching methods. Moreover, these assessments foster active engagement and reflection, both of which are essential for concept mastery (Elbasyouny, 2021).

2. Background to the study

The teaching and learning of Physical Sciences, particularly in the domains of Electricity and Magnetism, present unique challenges for both educators and students. These topics often introduce abstract concepts that are fundamental to understanding numerous scientific phenomena and technological applications. Despite their importance, students commonly struggle to grasp the intricate relationships and principles involved in these areas. As a result, misconceptions and gaps in understanding can hinder students' ability to make meaningful connections between theoretical knowledge and real-world applications (Radović et al., 2020).

In recent years, the educational landscape has seen a shift toward more dynamic and interactive approaches to teaching science. Central to these approaches is the incorporation of formative assessment interventions. Formative assessment, defined as assessments conducted during the learning process rather than at its conclusion, plays a crucial role in identifying students' strengths and weaknesses, providing feedback for improvement, and guiding instruction (Adarkwah, 2021). Unlike traditional summative assessments, formative assessments are intended to foster learning by continuously monitoring students' progress and responding to their individual learning needs (Ndlovu, 2025). This allows for timely intervention to correct misconceptions and reinforce key concepts, thereby promoting deeper understanding.

In the context of Electricity and Magnetism, formative assessments can be particularly valuable in addressing common challenges students face. These topics often require students to integrate abstract theoretical knowledge with practical problem-solving skills. Effective formative assessment strategies can guide students in refining their conceptual understanding, building confidence, and enhancing their ability to apply knowledge in diverse contexts (Putri et al., 2024). Previous research has highlighted the potential of formative assessment strategies in improving science education outcomes, particularly in STEM subjects (Atasoy & Kaya, 2022; Wafubwa, 2020). However, there remains a need for more focused studies that explore how these interventions can specifically support students' mastery of complex topics like Electricity and Magnetism. Additionally, while the value of formative assessment is widely acknowledged, there is limited research on how teachers can implement these strategies effectively in diverse classroom settings, particularly in resource-constrained environments (Schildkamp et al., 2020).

This study aims to fill this gap by exploring the impact of formative assessment interventions on students' concept mastery in Electricity and Magnetism. The focus will be on assessing how these interventions can enhance student engagement, conceptual understanding, and problem-solving abilities. By examining both the perspectives of students and teachers, the study seeks to contribute valuable insights into the practical applications of formative assessment in the teaching and learning of Physical Sciences. Ultimately, the goal of this research is to provide evidence-based recommendations for educators, policy makers, and curriculum developers on how to better support students in mastering key concepts in Electricity and Magnetism. Through this, the study seeks to contribute to the broader effort of improving science education and enhancing students' preparedness for future scientific and technological challenges.

3. Literature Review

The review of literature in this study was structured as follows:

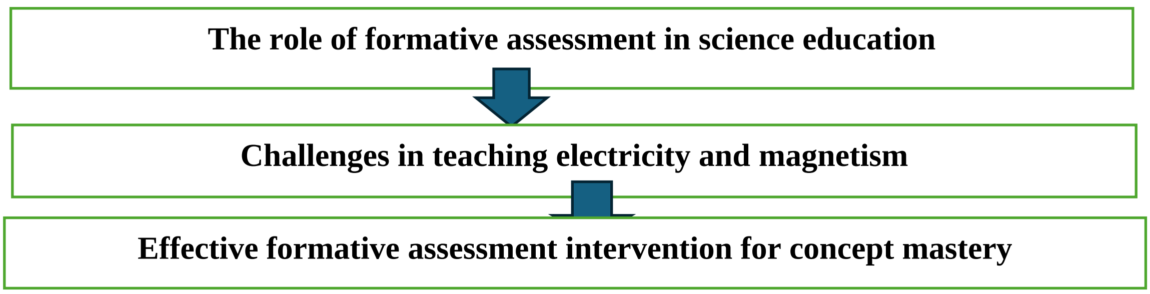

Figure 1: Literature review framework

3.1 The Role of Formative Assessment in Science Education

Formative assessment is crucial in the learning process, especially in the context of physical sciences, where learners often face challenges with abstract concepts, including electricity and magnetism. Leenknecht et al. (2021) argue that formative assessments, which occur during the learning process, provide valuable feedback to help teachers and learners adjust their strategies for better understanding. This continuous feedback loop enables teachers to identify learners' strengths and weaknesses in real-time, fostering an environment that supports mastery learning. In physical sciences, where understanding builds progressively, formative assessments are particularly beneficial for monitoring how well learners grasp foundational concepts, such as electricity and magnetism. Incorporating formative assessments into science teaching and learning allows teachers to adapt their teaching methods, clarify misconceptions, and provide targeted interventions. According to Kamran (2024), formative assessment supports the idea of "assessment for learning," wherein the goal is not simply to grade learners but to use assessment to guide instructional strategies and enhance learners' engagement with content. Teachers can ensure learners memorize facts and develop a deeper conceptual understanding of scientific principles by adopting formative assessment techniques in learning electricity and magnetism.

3.2 Challenges in Learning Electricity and Magnetism

Teaching electricity and magnetism presents unique challenges due to their abstract and often counterintuitive nature. Concept mastery in this domain requires learners to develop a deep understanding of electric fields, magnetic forces, and the interactions between charged particles, which are not directly observable. Assem et al. (2024) highlight that many learners struggle with visualizing these phenomena, leading to persistent misconceptions that hinder comprehension. For instance, distinguishing between static and dynamic electric fields or understanding the behaviour of magnetic fields in three-dimensional space poses significant cognitive challenges. Moreover, the strong mathematical foundation required to grasp concepts such as vector fields, electromotive force, and Maxwell's equations can create additional barriers for learners with limited mathematical proficiency.

Globally, research indicates that misconceptions in electricity and magnetism are widespread across different educational systems. Carpenter et al. (2022) note that learners often develop incorrect mental models from early exposure to simplistic analogies—such as comparing electric current to water flow in pipes—that persist despite formal instruction. These misconceptions are not limited to a specific region but have been observed in diverse educational contexts, from high-income countries with advanced laboratory resources to low-income settings where access to hands-on experimentation is limited. Addressing these challenges requires instructional approaches that emphasize conceptual understanding rather than rote memorization of equations and formulas.

In the country-specific context, challenges in teaching electricity and magnetism are further influenced by curriculum design, teaching methodologies, and resource availability. In many developing countries, limited access to laboratory equipment and digital simulations hinders experiential learning, making it difficult for students to test and refine their understanding through experimentation (Macayana & Mangarin, 2024). Additionally, teacher training programs may not adequately prepare educators to diagnose and address misconceptions effectively (Zhang et al., 2024). This gap underscores the need for innovative pedagogical strategies, such as inquiry-based learning and technology-enhanced instruction, to bridge the conceptual gaps in student understanding. To facilitate concept mastery, formative assessments play a crucial role in identifying and addressing misconceptions early in the learning process (Schildkamp et al., 2020). Structured interventions, including interactive simulations, problem-based learning, and guided discussions, can help learners confront and revise their misunderstandings (Wijnia et al., 2024). As educational research continues to explore effective strategies, integrating multimodal teaching resources and leveraging digital tools can enhance conceptual clarity and engagement in learning electricity and magnetism.

3.3 Effective Formative Assessment Intervention for Concept Mastery

A variety of formative assessment techniques have been identified as effective for teaching electricity and magnetism. Concept mapping, peer assessment, think-pair-share, and interactive quizzes are commonly used strategies in science education to gauge and enhance learners' learning. Concept mapping has been shown to help learners visually organize and connect ideas, which is particularly useful for abstract concepts like electric fields and magnetic induction (Mngomezulu, 2020). Through mapping out relationships between key concepts, learners are encouraged to think critically about how electricity and magnetism interrelate even with other subjects. Peer assessments, where learners review and provide feedback on each other's work, foster collaborative learning and help reinforce understanding through dialogue. In the context of physical sciences, this technique can allow learners to articulate their understanding and clarify any misunderstandings in a social context (Assem et al., 2023). Moreover, techniques such as interactive quizzes or formative multiple-choice tests offer immediate feedback, allowing teachers to gauge learners' understanding quickly and identify areas that need further explanation (Morris, 2021). When used in tandem, these techniques provide comprehensive insights into learners' progress and facilitate the timely adjustment of teaching strategies.

4. Theoretical Framework

This study adopted a Cognitive Load Theory (CLT) as a theoretical framework that underpins the study by providing insights into how to structure the learning and assessment of complex scientific concepts, such as electricity and magnetism, to maximize learners' learning. CLT posits that human cognitive capacity is limited, particularly in working memory, and if information is presented in a manner that overwhelms this limited capacity, learning can be hindered (Siregar, 2024). This theory is critical in designing effective formative assessment activities, as it emphasizes the need to carefully manage the amount and complexity of information presented to learners (Chew, et al., 2021). Teaching electricity and magnetism suggests that the topics should be broken down into smaller, more manageable parts, allowing learners to build their understanding gradually without feeling overloaded. The CLT is made up of intrinsic load, extraneous load, and germane load, as illustrated in the figure 2 below.

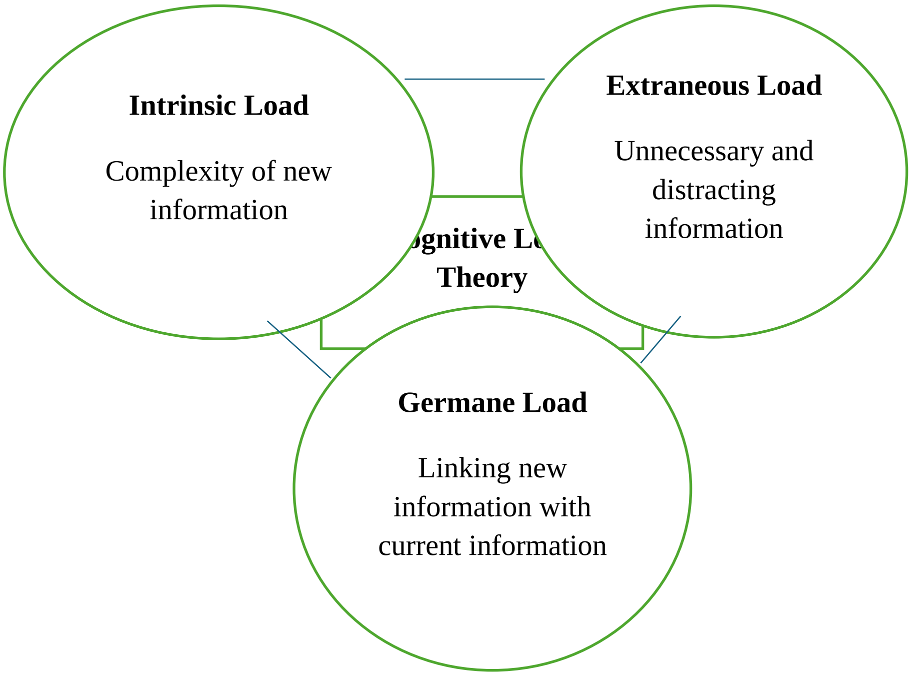

Figure 2: Cognitive Load Theory (Sweller, 1988)

This study aims to assess concept mastery in electricity and magnetism. Cognitive Load Theory (CLT) highlights the importance of managing different types of cognitive load—extraneous, intrinsic, and germane—to optimize learning. While reducing extraneous cognitive load is crucial to minimizing distractions and unnecessary complexity, it is equally important to consider the interplay between intrinsic and germane load. Intrinsic cognitive load arises from the inherent complexity of a subject. In electricity and magnetism, topics such as Ohm's Law or Faraday's Law involve mathematical relationships that require substantial cognitive effort to grasp. To manage this intrinsic load, teachers should scaffold instruction by breaking down complex concepts into smaller, digestible components. For example, before introducing electromagnetic induction, students should first develop a solid understanding of electric fields and currents. This ensures that their working memory is not overwhelmed when encountering more advanced topics.

Germane cognitive load, on the other hand, refers to the cognitive resources devoted to processing, understanding, and integrating new information into existing knowledge structures (Debue & van de Leemput, 2014). Teachers can enhance germane load by employing instructional strategies that encourage deeper engagement with the material (Haramain & Alih, 2021). For instance, formative assessments designed with problem-solving tasks, guided inquiry, and concept mapping can help students actively construct knowledge rather than passively receive information (Schildkamp et al., 2020). Dual coding—using diagrams alongside verbal explanations—also facilitates deeper processing by reinforcing conceptual understanding through multiple modalities (Barbieri, 2020).

Faber et al. (2024) emphasize the role of scaffolding in preventing cognitive overload while supporting conceptual mastery. Since electricity and magnetism concepts build upon one another, structuring learning experiences to incrementally increase complexity ensures that students develop a strong conceptual foundation. Formative assessments aligned with CLT principles should, therefore, not only eliminate unnecessary extraneous load but also optimize intrinsic and germane loads. This balanced approach enhances students' ability to process, retain, and apply complex concepts effectively (Siregar, 2024).

5. Research Problem

Concept mastery in Physical Sciences, particularly in topics such as Electricity and Magnetism, remains a persistent challenge for many learners. These topics involve abstract concepts, complex principles, and mathematical applications that often lead to misconceptions and gaps in understanding. Traditional instructional approaches, which primarily rely on summative assessments, may not adequately address these learning difficulties, as they focus on evaluating outcomes rather than guiding the learning process (Quamer et al., 2024). Formative assessment has been widely recognized as an effective strategy for enhancing learning by providing continuous feedback, identifying misconceptions early, and allowing for instructional adjustments (Yan, King & Haw, 2021). However, there is limited empirical research on the impact of formative assessment interventions specifically in the context of teaching Electricity and Magnetism (Schildkamp et al., 2020). The lack of structured implementation of formative assessment strategies in science classrooms further exacerbates learning difficulties, hindering learners' ability to develop a deep understanding of key concepts (Ayilimba, Tindan, & Dorsah, 2024). This study seeks to address this gap by investigating how formative assessment interventions influence concept mastery in Electricity and Magnetism among Grade 10 learners. By assessing the effectiveness of these interventions, the study aims to provide insights into best practices for integrating formative assessment into science instruction, ultimately improving teaching strategies and learner outcomes in Physical Sciences.

6. Purpose of the study

The purpose of this study is to explore the effectiveness of formative assessment interventions in enhancing concept mastery in Physical Sciences, with a particular emphasis on the topics of Electricity and Magnetism. These topics are notoriously difficult to teach due to their abstract nature, which often results in misconceptions and challenges in comprehension for learners. By incorporating formative assessment strategies into the teaching process, this study aims to assess their impact on learners' understanding of these complex concepts. The central research question guiding this study is: How do formative assessment interventions influence concept mastery in Electricity and Magnetism among Grade 10 learners? Through this investigation, the study seeks to identify best practices for integrating formative assessment techniques into science instruction and to determine the extent to which these interventions can improve students' grasp of the subject matter. Ultimately, the findings of this research will contribute valuable insights to the field of science education. By providing evidence-based recommendations for effective teaching practices, this study aims to enhance pedagogical approaches, promote a deeper conceptual understanding of Physical Sciences, and support the development of instructional strategies that address common learning challenges.

7. Methodology

7.1 Research Design

This study employed a quantitative approach and a pretest-posttest control group quasi-experimental design, selected to allow for manipulation of the independent variable (Gopalan et al., 2020). This design facilitates the creation of a hypothetical scenario or probable outcome in the absence of intervention, providing a baseline for estimating causal effects and understanding the impact of the intervention. It uses non-experimental variations in the primary independent variables of interest, simulating experimental conditions where specific individuals are randomly exposed to the intervention while others are not (Gopalan et al., 2020). The control group was taught using a conventional instructional strategy.

7.2 Targeted Population and Sampling Procedure

This study focused on Grade 10 Physical Science learners from five secondary schools within the uMkhanyakude District. A total of 175 learners participated, divided into two groups: the experimental group, consisting of 118 learners, and the control group, which included 57 learners. These groups were from different schools, which introduces a potential source of bias in terms of school-based factors (e.g., school resources, teacher experience, or student demographics) that could influence the results. To address this, the authors justified the choice of different schools by ensuring that the schools were matched based on key characteristics such as socioeconomic status, previous academic performance, and availability of teaching resources. This matching was done to minimize the bias and ensure that the groups were as comparable as possible. Table 1 provides a detailed breakdown of the distribution of participants between the intervention and control groups across the five schools. For each school, the table shows the number of learners in the intervention group along with the percentage they represent of the total intervention group. It also displays the number of learners in the control group and their corresponding percentage of the total control group. For instance, in School A, 26 learners (22.0% of the intervention group) were assigned to the experimental group, while 18 learners (31.6% of the control group) were assigned to the control group. This structure is replicated for each of the five schools, offering a clear overview of the participant allocation. The table concludes with totals summarizing the number of learners in each group across all schools, along with their respective percentages.

Table 1: Number of learners by school and by group

	Intervention	Intervention	Control	Control	Total	Total
School	n	%	n	%	n	%
A	26	22.0%			26	14.9
B	40	33.9%			40	22.9
C	52	44.1%			52	29.8
D			18	31.6%	18	10.3
E			39	68.4%	39	22.9
Total	118	100.0%	57	100.0%	175	100.0

7.3 Formative Assessment Intervention Practices

This study seeks to examine the impact of implementing a formative assessment intervention on learners' concept mastery within the experimental group. To assess the influence of the intervention, it is essential to explore the specific formative assessment strategies employed in the experimental group and compare them with the conditions in the control group. The intervention was guided by the framework proposed by Ozan and Kincal (2018), with modifications made by the researchers to ensure its alignment with the context of the study. The intervention instructions were structured around the four key formative assessment strategies identified by Ozan and Kincal (2018), which include feedback, peer assessment, self-assessment, and questioning techniques. These strategies served as the foundation for the treatment protocols. By focusing on these strategies, the study aims to provide insights into how formative assessment can support and enhance concept mastery in Physical Sciences.

7.4 Experimental schools' teachers' training

Teachers in the experimental schools received comprehensive training on integrating formative assessment practices into their teaching as part of the intervention. This training emphasized the use of various formative assessment strategies, including concept mapping, peer assessment, think-pair-share activities, and interactive quizzes, to continuously monitor and support learners' progress. Teachers were guided on how to implement these assessment techniques effectively, such as providing regular feedback, conducting peer assessments, encouraging self-assessments, and using questioning strategies to actively engage learners and evaluate their understanding of key concepts. The goal was to create an interactive learning environment where assessments not only measured learners' current knowledge but also informed instructional adjustments, promoting deeper understanding. The ultimate aim was to help teachers develop reflective practices that would enhance learners' mastery of Electricity and Magnetism concepts throughout the learning process. In contrast, teachers in the control group were not exposed to these intervention practices and instead taught the concepts using their traditional instructional methods before and after the study.

7.4.1 Assessment Methods Used in the Intervention

In this intervention, four distinct methods of assessment were employed to gauge student understanding and engagement. These methods were carefully selected to align with the learning objectives and provide a comprehensive approach to assessing both individual and collaborative learning.

Concept Mapping
Students were tasked with creating concept maps as part of the assessment process. This activity allowed them to visually represent the relationships between key concepts introduced throughout the intervention. The purpose of the concept mapping was to assess students' understanding of how these concepts interconnect, helping to identify their grasp of both the individual concepts and the overarching themes. Students worked on these maps individually, with the results used to provide feedback on their comprehension and to highlight areas that required further exploration.

Peer Assessment
Peer assessment played a central role in the intervention, fostering collaborative learning and critical thinking. After completing their assignments, students were asked to review each other's work using a set of predefined criteria. This process enabled students to evaluate the quality of their peers' work, offering constructive feedback and reflecting on their own understanding. The peer assessment activities were structured to encourage dialogue and engagement, helping students refine their ideas and learn from each other.

Think-Pair-Share
The Think-Pair-Share strategy was used to facilitate formative assessment during group discussions. Students were presented with a question or topic and given time to reflect on it individually. They then paired up with a peer to discuss their thoughts, before sharing their insights with the entire class. This method not only encouraged critical thinking but also provided an opportunity for students to articulate their understanding in a supportive environment. The responses shared in the larger group were evaluated based on their depth and relevance to the topic at hand.

Interactive Quizzes
Interactive quizzes were implemented at the end of each lesson to assess students' comprehension and immediate retention of the material covered. The quizzes were designed with a variety of question types, including multiple-choice, true/false, and short-answer questions. These assessments provided immediate feedback to students, helping to identify areas of strength and areas needing improvement. The results of these quizzes were used to gauge individual understanding and inform any necessary adjustments in the delivery of the content.

Table 2: Actual practices took place during the integration of formative assessment intervention practices in both groups.

Lessons content: Electricity and Magnetism (3-weeks content)		
Action (Formative assessment intervention)	**Experimental Group**	**Control Group**
Explaining Learning Objectives	Clear explanation of learning objectives at the start, with ongoing reminders throughout the lesson.	No explanation; teachers relied on prior knowledge checks from students.
Effective Dialogue and Inquiry	Heterogeneous cooperative groups; high-order thinking questions encouraged dialogue.	Students chose non-heterogeneous groups; the questions did not address all cognitive levels.
Feedback to Move Learners Forward	Feedback is provided in comments, not scores; there are ample opportunities for learners to engage with feedback.	Scores dominate feedback; there are limited opportunities for learners to engage with feedback due to time constraints.
Self and Peer Assessment	Consistent integration of self and peer assessments with clear instructions and discussions.	Unintentional integration of self and peer assessments.

7.5 Instrument and Data Collection

In this study, learners' mastery of the presented concepts was assessed by evaluating their understanding through a set of 25 multiple-choice questions. These questions included 21 individual items, one of which contained five sub-questions, and were administered in both the Pre-test and Post-test sessions (Grade 10 Physical Science Test on Electricity and Magnetism) (Appendices 1 & 2). Prior to data collection, the research instrument (the test) underwent validation and reliability checks. Subject advisors and senior Physical Science teachers served as moderators to ensure the test's quality. The validation process focused on assessing the test's content and face validity. The test's reliability was measured using both KR-20 and KR-21, and reliability coefficients were found to be satisfactory. These values met the established standards for a reliable and valid instrument (Taherdoost, 2016). The same test was administered consistently to all Grade 10 Physical Science learners as a class test before and after the interventions involving formative assessment strategies.

8. Findings

The pre- and post-test results revealed that learners who participated in the intervention showed significant improvement in their mastery of electricity and magnetism concepts. This improvement was evident from the marked increase in their scores from the pre-test to the post-test. The intervention group, which was exposed to formative assessment practices, demonstrated a deeper understanding of the material, as reflected in their higher post-test scores compared to their pretest performance. This positive change was consistent across various statistical measures, including the median, mean, and standard deviation.

Statistical analysis showed that the mean score of the intervention group in the post-test was notably higher than in the pretest, indicating the positive impact of the intervention on learners' understanding. The median score also showed an upward shift, further confirming the overall improvement in the group's mastery of the concepts. Additionally, the standard deviation was smaller in the post-test, suggesting a more consistent performance among the learners after the intervention. This reduction in variability indicates that the formative assessment practices helped enhance overall understanding and promote more uniform comprehension across the group.

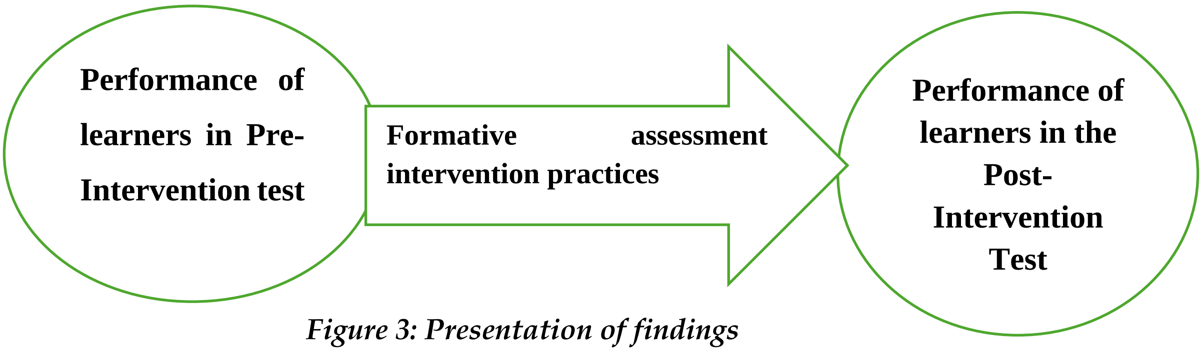

Figure 3: Presentation of findings

8.1 Pre-intervention findings

Table 3 below presents the summary statistics for the pre-intervention scores from both the experimental and control groups. The pre-test was administered during the ongoing teaching of Electricity and Magnetism, a topic covered over three weeks with a total of eleven hours in Grade 10. It is assumed that the learners had similar characteristics prior to the intervention. The table summarizes the dataset, offering insights into the central tendency, variability, and range of the scores. The mean represents the average score, while the median is the middle value when the data is ordered in ascending order. The mode indicates the most frequently occurring score, and the standard deviation reflects the extent of dispersion around the mean. The minimum and maximum values show the range within the dataset, providing additional context to the scores.

Table 3: Learner performance on Pre-Test (N=175)

Mean	Median	Mode	Std. Deviation	Minimum	Maximum
23.50	24.00	18	8.214	4	48

The pre-test, designed to assess learners' basic understanding of electricity and magnetism, was scored out of a total of 50 marks. As shown in the table above, the lowest score obtained was 4, which corresponded to answering 2 questions correctly, while the highest score recorded was 48, indicating that 24 out of 25 questions were answered correctly. The passing score for the test was set at 25/50, representing 50% of the total possible marks. The mean score for the pre-test was 23.50, or 47% of the total possible marks, while the median score was 24.00, or

48%. These results suggest that a significant portion of learners demonstrated a basic understanding of the topic of electricity and magnetism. However, it is important to note that a substantial percentage of learners (53%) scored below both the mean and median scores of 47% and 48%, respectively, and therefore failed the pre-test. This indicates that many learners had an inadequate grasp of the concepts related to electricity and magnetism. While the overall mean and median reflect a general level of competency, they also highlight that a considerable number of learners lacked sufficient understanding of the material covered in the pre-test.

8.2 Performance of control and experimental groups on post-intervention test

Table 4 below presents the summary statistics for the test scores of both the control and experimental groups.

Table 4: Post-intervention test scores for experimental and control groups

Group	n	Mean	Median	Std. Deviation	Minimum	Maximum
Experimental	118	40.32	40.00	5.06	26	50
Control	57	20.60	20.00	7.79	8	40

An independent samples t-test was conducted to compare the average post-intervention test scores between the experimental and control groups. The results revealed a significant difference in the mean scores of the two groups ($t = 17.419$, $df = 79.594$, $p = 0.000$). This indicates that, on average, the experimental group performed significantly better than the control group, as evidenced by their higher mean scores. Additionally, the experimental group showed less variability in their scores compared to the control group, suggesting more consistent performance among the learners.

These findings suggest that the formative assessment intervention had a positive and significant impact on the experimental group. The higher mean scores and reduced variability in the experimental group imply that the intervention enhanced learners' understanding of electricity and magnetism, leading to improved overall performance. Furthermore, the consistent results within the experimental group suggest that the formative assessment practices helped promote a more uniform level of mastery among the learners. In contrast, the control group did not exhibit similar improvements, highlighting the effectiveness of the formative assessment intervention. The diagram below visually summarizes the pre- and post-intervention test scores for both groups.

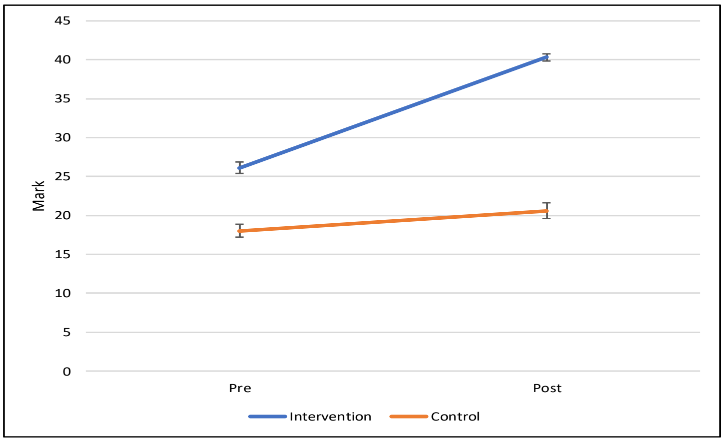

Figure 4: Pre- and post-marks for intervention and control groups

9. Discussion

The findings of this study reveal that the implementation of formative assessment interventions significantly enhances concept mastery in Electricity and Magnetism among Grade 10 learners. The quasi-experimental design, which compared an experimental group exposed to formative assessment strategies with a control group receiving conventional instruction, demonstrated notable differences in learners' conceptual understanding. The post-test results showed that learners in the experimental group outperformed those in the control group, reinforcing the effectiveness of formative assessment as a pedagogical strategy. The formative assessment practices adopted in this study, including concept mapping, peer review, and interactive quizzes, contributed to improved engagement and understanding of abstract scientific concepts. These strategies enabled learners to actively reflect on their learning, identify misconceptions, and apply corrective measures in real time. The results align with previous research (Leenknecht et al., 2021; Kamran, 2024), which highlights formative assessment as a critical tool for reinforcing learning and promoting conceptual comprehension in science education.

One of the key findings was the effectiveness of formative assessment in uncovering and addressing misconceptions related to Electricity and Magnetism. Learners in the experimental group demonstrated a significant reduction in misconceptions compared to those in the control group. The analysis of learners' responses revealed common misunderstandings, such as the belief that electric current flows similarly to water through pipes and confusion between static and dynamic electric fields. Formative assessment techniques such as think-pair-share and real-time quizzes allowed teachers to diagnose and address these misconceptions effectively. By providing immediate feedback and corrective explanations, learners had opportunities to refine their understanding and replace incorrect mental models with scientifically accurate concepts. These findings corroborate the arguments made by Carpenter et al. (2022), who emphasized that formative assessment plays a crucial role in reshaping learners' conceptual frameworks in science education. The application of Cognitive Load Theory (CLT) in designing formative assessment interventions proved instrumental in enhancing learning efficiency. The findings indicated that breaking down complex concepts into manageable units, reducing extraneous cognitive load, and scaffolding learning progression contributed to better knowledge retention and application.

For instance, the stepwise introduction of key principles—starting with basic electrical concepts before progressing to advanced topics such as electromagnetic induction—helped learners manage cognitive load effectively. The reduction in unnecessary complexity, coupled with guided problem-solving exercises, enabled learners to develop a coherent and structured understanding of Electricity and Magnetism. These findings support Siregar (2024) and Chew et al. (2021), who emphasize the importance of cognitive load management in optimizing educational interventions. Another significant finding was the positive influence of formative assessment on learner engagement and motivation. Learners in the experimental group exhibited higher levels of participation and enthusiasm towards learning Electricity and Magnetism. Interactive assessment methods, such as peer discussions and quizzes, fostered a more collaborative and dynamic learning environment. Observational data and learner feedback indicated that formative assessment practices encouraged active participation, self-reflection, and a deeper appreciation for science learning. The study echoes findings from Assem et al. (2023), which suggest that formative assessments enhance learner motivation by promoting a sense of ownership and responsibility for learning progress.

10. Interpretations of the findings in relation the Cognitive Load Theory

The results from the t-test strongly align with the principles of Cognitive Load Theory (CLT), which emphasizes the importance of optimizing the cognitive load placed on working memory during learning. The findings suggest that the formative assessment intervention in the experimental group effectively supported cognitive load management, leading to improved learning outcomes. The experimental group demonstrated a higher mean score and less variability in their post-test scores, indicating that the formative assessment intervention successfully reduced unnecessary cognitive load. According to CLT, learners' working memory has a limited capacity, and excessive cognitive load can hinder learning (Paas & van Merriënboer, 2020). By incorporating formative assessments, the experimental group received timely feedback and opportunities to process information incrementally, preventing cognitive overload. This structured approach likely facilitated better consolidation of knowledge, allowing learners to deepen their understanding of electricity and magnetism without overwhelming their cognitive resources.

The lower variability in the experimental group's post-test scores further supports the idea that formative assessments contribute to more consistent learning outcomes. CLT suggests that reducing extraneous cognitive load enables learners to focus more effectively on the content, leading to a more uniform mastery of concepts (Gkintoni et al., 2025). In this case, the intervention likely helped learners break down complex material in a manageable way, providing clear guidance and reducing the cognitive strain typically associated with learning challenging topics. As a result, learners exhibited more consistent performance, reinforcing the benefits of formative assessments in promoting steady progress. CLT also emphasizes the importance of scaffolding and targeted support, which help learners gradually build expertise (Yildiz & Celik, 2020). The experimental group's improved performance can be attributed to the formative assessment practices, which provided learners with opportunities for deliberate practice and corrective feedback. These strategies likely helped learners reduce their cognitive load over time by allowing them to build knowledge incrementally. With each cycle of feedback and practice, learners were able to make more efficient use of their cognitive resources, leading to better overall performance in the post-test compared to the control group.

The significant difference between the experimental and control groups underscores the effectiveness of formative assessments in managing cognitive load. By offering frequent feedback, formative assessments allow learners to process smaller, more manageable chunks of information at a time, reducing the need to process large amounts of unstructured data all at once. This minimizes extraneous cognitive load and enhances the retention of key concepts. The findings indicate that formative assessments enabled learners to focus on essential aspects of the content, promoting deeper understanding and more effective learning. The findings of this study are consistent with the principles of Cognitive Load Theory. The formative assessment intervention helped learners optimize their cognitive load, enhancing their ability to process information effectively. The higher mean scores and lower variability observed in the experimental group suggest that the intervention was successful in supporting efficient learning, allowing learners to manage their cognitive resources more effectively and achieve better learning outcomes. Overall, the study reinforces the value of formative assessments in aligning with cognitive load principles to improve student performance and mastery of complex concepts.

11. Implications for meaning teaching and learning

The findings from this study offer important insights for enhancing teaching and learning in the context of Physical Sciences education. The study highlights the role of formative assessments in fostering a deeper understanding of complex scientific concepts, such as electricity and magnetism. The significant improvement in the experimental group's mean scores and consistency in performance suggests that when strategically implemented, formative assessments can effectively enhance students' mastery of challenging topics. Through ongoing feedback, formative assessments allow learners to identify gaps in their understanding, address misconceptions, and reinforce their knowledge (Ndlovu, 2025). This underscores that formative assessments should not be seen as isolated tools, but rather as continuous learning processes integrated throughout instruction. Teachers can leverage these insights to better support students in achieving a deeper, more comprehensive understanding of content.
The reduced variability in the experimental group's scores highlights how formative assessment interventions can help standardize learning outcomes. This consistency in performance suggests that the intervention created a more structured and supportive learning environment, enabling all learners to engage with the material in ways that promoted conceptual clarity. Teachers can use

formative assessment strategies to ensure that learners, regardless of their initial ability levels, can achieve a consistent level of mastery over time (Schildkamp et al., 2020). This promotes equity in learning by ensuring that each learner's progress is tracked and supported according to their individual needs.

The alignment of the study's findings with Cognitive Load Theory (CLT) further reinforces the importance of optimizing cognitive resources in the classroom. By reducing extraneous cognitive load, formative assessments offer timely, targeted feedback that helps prevent cognitive overload, allowing learners to focus their cognitive resources on mastering core concepts like electricity and magnetism. Instructors can use formative assessments to structure learning tasks that are appropriately challenging without overwhelming students, which can enhance learners' retention and understanding of scientific principles (Schildkamp et al., 2020). The study also emphasizes the value of scaffolding in the learning process. Formative assessments help teachers identify where students struggle and provide the necessary support to guide them toward mastery (Ndlovu, 2025). This tailored approach ensures that no student is left behind and can progress at a pace suited to their individual needs. Personalized feedback enables students to build on their strengths and address weaknesses, leading to a balanced learning experience (Obilor, 2019). Teachers can use formative assessments to modify instructional strategies, adjust pacing, and provide resources that address specific challenges faced by students, promoting meaningful learning experiences that cater to diverse needs (Ndlovu, 2025).

Another important implication of the study is the potential for formative assessments to foster collaborative learning environments. By incorporating peer assessments and group discussions as part of formative feedback, students can engage in deeper learning through social interaction (Adarkwah, 2021). Collaborative learning allows students to exchange ideas, explain concepts to one another, and collectively solve problems (Taggart & Wheeler, 2023). This peer-based approach not only distributes cognitive load but also enhances understanding of difficult topics like electricity and magnetism. Teachers can design formative assessment tasks that encourage peer collaboration, benefiting both individual learners and the overall classroom culture (Hansen, 2020). Finally, the study suggests that formative assessments can help develop self-regulation skills among learners. By encouraging students to reflect on their performance, set learning goals, and adjust strategies, formative assessments contribute to the growth of independent, self-directed learners (Vishwakarma & Tyagi, 2023). This reflective practice empowers students to take ownership of their learning journey, which is vital for long-term success in complex subjects such as Physical Sciences. Teachers can guide students in using formative assessments to reflect on their progress, identify areas for improvement, and develop strategies for continued growth (Ndlovu, 2025).

Incorporating formative assessments into the teaching and learning of Physical Sciences, particularly for complex topics like electricity and magnetism, can significantly enhance learners' understanding and mastery. By providing timely feedback, reducing cognitive load, promoting consistent learning outcomes, and fostering collaborative learning, formative assessments can create more meaningful and effective educational experiences (Adarkwah, 2021). The implications of this study suggest that teachers should integrate formative assessment practices throughout the learning process to maximize student engagement, improve academic performance, and develop critical thinking skills. This approach will not only enhance content mastery but also cultivate reflective, self-regulated learners equipped to navigate challenges in higher education and beyond.

12. Limitations

The study had a small sample size, limiting the generalizability of the results to a broader population. The participants were from a specific educational setting and demographic, which restricts applicability to different age groups, educational levels, or socio-economic backgrounds. The interventions were focused on Electricity and Magnetism, meaning the findings may not be applicable to other areas of the Physical Sciences. The context-specific nature of the intervention limits its broader application in other subjects or teaching contexts. Variations in teaching experience, instructional styles, and students' prior knowledge or attitudes toward the subject could have influenced the results, making it difficult to apply a universal approach to formative assessments.

The study was conducted over a fixed period, which prevented an assessment of the long-term effects of formative assessments on concept mastery. Longer studies would be needed to explore sustained learning outcomes. The tools used to measure student understanding may not have captured the full complexity of the Electricity and Magnetism concepts. Traditional formative assessment methods, such as quizzes, may not account for all forms of learning, such as hands-on activities or collaborative work. Factors like the classroom environment, resource availability, and students' socio-emotional well-being were not controlled, which may have influenced the outcomes. The role of technology in formative assessments was also not explored. In summary, while the study offers valuable insights, its limitations suggest the need for further research with larger, more diverse samples, extended timeframes, and varied assessment tools to better understand how formative assessments can enhance concept mastery in Physical Sciences across different educational settings.

13. Recommendations

To enhance the effectiveness of formative assessments, it is essential for teachers to integrate these assessments more frequently throughout the learning process. By offering continuous feedback, teachers can help learners identify and address any gaps in their understanding before they become barriers to further learning. The use of a variety of assessment methods ensures that learners remain engaged and that the assessments are inclusive of different learning styles. This approach fosters an environment where all students can actively participate and demonstrate their understanding in a way that best suits them. Clear scaffolding and support are also critical components of effective formative assessment. Breaking down complex concepts into manageable chunks can help students make sense of difficult material, reducing cognitive overload and facilitating deeper learning. Moreover, teachers should continuously monitor learners' progress through formative assessments and adjust their teaching strategies based on the data collected. This adaptive approach ensures that instruction is personalized, catering to individual learners' needs and allowing for more targeted interventions when necessary. In addition to these strategies, promoting collaborative learning activities can further enhance the learning process. Through peer interactions, students can distribute cognitive load, allowing them to share ideas, clarify misunderstandings, and build on each other's strengths. This collaborative approach not only supports individual learning but also fosters a sense of community within the classroom, where learners can develop a deeper understanding through shared experiences.

14. Recommendations for Further Research

Long-term Impact of Frequent Formative Assessments: Future research could investigate how the frequent use of formative assessments influences students' academic achievement over time. Specifically, examining the long-term effects on students' ability to retain and apply knowledge in various contexts could provide valuable insights into the sustained benefits of formative assessments.

Role of Digital Tools and Technologies: Exploring how digital tools and technologies can support formative assessments is another promising avenue for research. This includes examining how these tools enhance feedback delivery and create personalized learning pathways, making the assessment process more efficient and tailored to each student's needs.

Effectiveness of Collaborative Learning Activities: Further studies could explore the role of collaborative learning in reducing cognitive overload during formative assessments. Research could focus on how group activities, peer discussions, and collaborative problem-solving contribute to improved learner outcomes and help students manage the cognitive demands of the learning process.

Diverse Assessment Methods: Investigating the strategic integration of various assessment methods—such as peer assessments, self-assessments, quizzes, or reflections—could reveal how these tools address diverse student needs. Research could focus on how these methods contribute to deeper learning and support different types of learners throughout the educational process.

Professional Development for Teachers: Assessing the professional development needs of teachers is crucial for ensuring effective formative assessment practices. Research could explore how teachers can be better equipped with the knowledge, skills, and tools to effectively use formative assessments in a way that promotes individualized learning, ultimately leading to more impactful assessment practices.

By exploring these areas, educators and researchers can further refine and optimize formative assessment practices, ensuring that they support diverse learners and improve academic outcomes in meaningful ways.

15. Conclusion

This study demonstrates the positive impact of formative assessment interventions on learners' understanding of electricity and magnetism. The results of the independent samples t-test revealed that the experimental group, which received the intervention, achieved significantly higher mean test scores compared to the control group. Moreover, the reduced variability in the experimental group's performance suggests that the intervention fostered more consistent learning outcomes, ensuring a standardized level of mastery across the learners. These findings directly answer the research question, highlighting that formative assessments not only enhance academic performance but also promote more reliable improvements in learners' achievements. This is in alignment with the introduction, which anticipated that formative assessments would have a positive impact on learning outcomes and supports the central theme of the study—the value of formative assessments in fostering more effective learning experiences. Cognitive Load Theory provides a theoretical explanation for these outcomes, as the intervention helped optimize cognitive resources by reducing extraneous cognitive load. By providing timely feedback and structured learning opportunities, the formative assessments allowed learners to focus on mastering key concepts without becoming overwhelmed. Consequently, the intervention facilitated more effective processing of complex material, leading to improved learning results. Overall, this study underscores the importance of formative assessments in promoting deeper understanding and consistent performance, reinforcing the central argument that effective learning strategies, supported by Cognitive Load Theory, can significantly enhance students' mastery of content.

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Appendix 1

GRADE 10 PHYSICAL SCIENCES

TEST

ELECTRICITY AND MAGNETISM

MARKS: 50

TIME: 1 HOUR

INSTRUCTION AND INFORMATION

1. This question paper consists of twenty-one (21) multiple-choice questions
2. Each question is allocated 2 marks
3. Write only the correct letter next to the question number
4. Number correctly according to the numbering system used in this question paper
5. You may use a non-programmable calculator
6. You may use appropriate mathematical instruments
7. Write neatly and legibly

QUESTIONS (1-21)

Four options are provided to answer the following questions. Each question has only ONE correct answer. Write down only the letter (A-D/ or F) next to the question number (1-21) in the answer book, for example 1. C

1. A glass rod is POSITIVELY charged by rubbing it with a silk cloth. Which one of the following statements is TRUE?
(2)
A. Electrons are transferred from the glass rod to the silk cloth.
B. Electrons are transferred from silk cloth to the glass rod.
C. Protons are transferred from the glass rod to the silk cloth.
D. Protons are transferred from silk cloth to glass rod.

2. Which of the following terms best describes the ability of a metal to change shape on hammering
(2)
A. Brittle
B. Density
C. Ductile
D. Malleable

3. The process when solid change directly into the gaseous phase is called…
(2)
A. Condensation
B. Sublimation
C. Freezing
D. Combustion

4. The energy released when an electron is added to an atom or molecule is called…
(2)
A. Electron affinity
B. Electronegativity
C. Ionisation energy
D. 1 ionisation energy

5. The bond between two nitrogen atoms in the N_2 molecule is known as a/an
(2)
A. Ionic bond
B. Dative covalent bond
C. Metallic bond
D. Covalent bond

6. The N ‘’ion is known as the … ion
(2)
A. Nitrite
B. Nitride
C. Nitrate
D. Nitrogen

7. Use the following substances to answer the questions that follow.

A	Iron
B	Copper
C	Sulphur
D	Silicon
E	Air
F	Ammonium Sulphate

7.1. Identify the ELEMENT that has a dull surface and cannot conduct electricity (2)

7.2. Identify substances that are brittle (2)

7.3. Which element has magnetic properties (2)

7.4. Identify the metalloid that is used in computers (2)

7.5. Identify the mixture in the table (2)

8. Which ONE of the following regarding thermal conductivity and electrical conductivity in most metals is TRUE? (2)

	THERMAL CONDUCTIVITY	ELECTRICAL CONDUCTIVITY
A	Good	Bad
B	Good	Good
C	Bad	Good
D	Bad	Bad

9. A permanent magnet is placed close to a bar of soft iron

Permanent Magnet Soft iron bar

After so 

the soft iron 

(2)

A. The pole of the magnetic are reversed
B. PQ does not become magnetic
C. P becomes the North Pole
D. P becomes the South Pole

10. What do magnets do? (2)

A. Attract all types of objects
B. Attract plastic objects
C. Attract wooden objects
D. Attract iron objects

11. What is found at the centre of an atom? (2)

A. Electrons
B. The nucleus
C. Ions
D. The orbital shell

12. In electricity, a current is (2)

A. A flow of electrons
B. The price we pay for electricity
C. A flow of atoms
D. A device engineers use to measure electricity

13. The north pole of one magnet attracts (2)

A. The north pole of another magnet
B. The south pole of another magnet
C. Either the north pole or the south pole of another magnet
D. None of the above

14. Which object listed below, does not use electricity? (2)

A. Microwave oven
B. Car

C. Candle
D. Light bulb

15. The current that flows in an electric circuit carries…
(2)
A. Chemical energy
B. Mechanical energy
C. Thermal energy
D. Electrical energy

16. A house mother is ironing a bulk of clean clothes using electric iron. What is the main energy conversion that takes place while she continues with the ironing?
(2)
A. Mechanical to Heat
B. Mechanical to Electrical
C. Kinetic to Potential
D. Electric to Heat

17. There is a repulsive force between two charged objects when…
(2)
A. Charges are of unlike sign
B. Charges are of like sign
C. They have the same number of protons
D. They have the same number of electrons

18. There is an attractive force between two charged objects when…
(2)
A. Charges are of unlike sign
B. Charges are of like sign
C. They have the same number of protons
D. They have the same number of electrons

19. Which of the following allows electrons to move through it easily?
(2)
A. Conductor
B. Insulator
C. Fuse
D. Circuit breaker

20. Which of the following does not allow electrons to move through it?
(2)
A. Conductor
B. Insulator
C. Fuse
D. Circuit breaker

21. …Contains a piece of metal that melts if the current becomes too high
(2)
A. Conductor
B. Insulator
C. Fuse
D. Circuit breaker

Appendix 2

GRADE 10 PHYSICAL SCIENCES TEST MEMORANDUM

1. A √√
2. D √√
3. B √√
4. A √√
5. D √√
6. B √√
7. (7.1) C √√
   (7.2) C or F √√
   (7.3) A √√
   (7.4) D √√
   (7.5) E √√
8. B √√
9. D √√
10. D √√
11. B √√
12. A √√
13. B √√
14. C √√
15. D √√
16. D √√
17. B √√
18. A √√
19. A √√
20. B √√
21. C √√