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Developing Physical Science Teachers’ Conceptual Understanding of Electromagnetic Theory by Means of Hands-On and Virtual Experiments

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Abstract

To advance academic performance and classroom practices, teachers must understand and continually improve their content knowledge and teaching skills. Physical Science teaching and learning require this level of understanding, as it serves as the foundation for didactical content knowledge and scientific practices. Physical science teachers usually use traditional teaching methods, which explains the lack of effective methods for improving physical science knowledge. This article demonstrates a teaching approach that can enhance the teaching and learning of Physical Science in STEM (Science, Technology, Engineering, and Mathematics) classrooms. A professional development workshop for Physical Science teachers was conducted to compare two different TLS (Teaching and Learning Sequences). TLS were designed, and one method incorporated virtual and hands-on experiments. The TLS were used to enhance teachers' understanding of electromagnetic theory, a topic prescribed for learners taught by the sampled group. A qualitative method supported by secondary quantitative data was applied to collect data from 16 and 15 in-service physical science teachers, respectively. The analytical responses were categorized using participatory observation and factor analysis, as well as a mean of normalized gain to determine improvement in knowledge. Teachers' conceptual understanding of electromagnetic theory was attributed to virtual and hands-on experiments in teaching-learning processes. Re-evaluation of TLS and the integration of practical and science teaching in the classroom were recommended.

Keywords: Hands-on experiments, teaching learning sequences (TLS), virtual experiments, physical science teaching.

1. Introduction

The physical sciences can be very easy if we realize the need to apply relevant and practical methods continuously. Teachers are expected to be innovative and continuously advance their teaching methodologies. Physical science can be improved through the application of multiple methods and related practices in the fourth industrial revolution (Rahman et al. 2021). Such consideration is part of didactic content knowledge which forms the basis for effective teaching.

The challenge of teaching practices, such as the traditional way of teaching most teachers resort to, can lead to underperformance in physical science (Millar et al., 2003). Teachers' lack of confidence can be exhibited in many ways when it comes to practical subjects. For instance, teachers show a lack of hands-on practical skills, such as setting up experiments in a traditional laboratory for practical activities and the use of computer applications to set up virtual laboratories to observe practical activities. Experimental activities and observations are essential to teaching and learning physical science. Practical activities, such as experiments, can develop science interest and improve learners' practical, cognitive, and problem-solving skills. De Vries and May (2019) encouraged teachers with inadequate resources to source alternative means to implement scientific investigations and develop problem-solving skills in teaching and learning science. They further emphasized the importance of learners conducting experiments and arriving at conclusions through practical observation. The introduction of more abstract concepts can be enhanced through experiments. In physical science, hands-on experiments, virtual experiments, Phet simulations etc., are interactive learning practices that can improve students' science process skills (Rahman et al. 2021).

Physical science teachers' content knowledge gaps and lack of use of appropriate methodologies and practices can have a profound impact on learner performance. Study identified gaps in science teachers' conceptual understanding of electromagnetic theory and their preferred way to teach science. Teaching electromagnetic theory and content effectively can be challenging if teachers lack the appropriate scientific skills and knowledge (Letsoalo, 2018). Lack of relevant and effective scientific processes in the teaching and learning of Physical science reduces the likelihood that learners passing Physical science will pursue careers in STEM (Science, Technology, Engineering, and Mathematics) fields. Inadequate content knowledge, inappropriate teaching methods and non-implementation of relevant methods decrease physical science performance. For learners to perform well in physical science, interest and skills are essential. Due to teachers' challenges, such as lack of skills and conceptual understanding of electromagnetic theory, Physical Science will always be perceived as challenging (Linnansaari et al., 2015). Integrating experiments and theories in science education improves academic performance significantly.

Against this background, there was a need to understand how teachers construct and develop their knowledge in preparation for physical science teaching. There was a need to engage teachers to make them realize the importance of critical scientific skills in science using experiments. By demonstrating effective methods, the study aimed to help teachers improve their knowledge and conceptual understanding of science. It was crucial for teachers to understand and acknowledge the impact that experiments can have on science teaching and learning. This was especially true for electromagnetic theory which was a challenging topic for the sampled group (Kussmaul & Pirmann, 2021).

The study sought to raise awareness of how hands-on and virtual experiments can complement the teaching of electromagnetic theory. Hands-on experiments and virtual experiments with theory were integrated into the teaching learning sequence, while the other teaching learning sequence followed the traditional approach. Teaching and Learning Sequences (TLS) were used as an intervention strategy for teachers to learn electromagnetic theory and measured its effect on learning. As a result, this paper compared TLS and measured the influence hands-on and virtual experiments had on teachers' conceptual understanding of electromagnetic theory.

The research followed the theoretical framework of TLS-based research to gauge the influence of hands-on and virtual experiments on Physical Science teachers' conceptual understanding of electromagnetic theory. The study was conducted to compare the TLS towards understanding of Electromagnetic concepts by highlighting the importance of integrating and complementing hands-on and virtual experiments. Hands-on and virtual experiments were strategically incorporated into the teaching and learning of electromagnetic concepts to bridge teachers' content gaps, improve knowledge, and demonstrate the implementation and importance of effective science methods or science practices. To raise awareness about the ease of implementing relevant scientific methodologies in science lessons The study will illustrate the importance of virtual and hands-on experiments.

1.2. The theoretical background

1.2.1. Hands-on and virtual experiments.

The purpose of hands-on experiments and virtual experiments is to promote learners' scientific literacy by introducing learners to procedures of inquiry and linking the domain of reality to the domain of ideas (Miller et al, 2003). The two types of experiments have distinct features that are beneficial and can complement each other to improve the standard of science education. In hands-on experiments, learners are physically involved without the manipulation and use of apparatus. For virtual experiments, however, the computer is used to perform a practical without the physical presence of apparatus (de Vries & May, 2019). In other words, in the digital world, learners have no immediate tactile outcomes while in the physical world learners can experience outcomes through their senses at first hand (Lowe et al, 2013). In the study by Lowe et al (2013) it has been noted that learners believe data from virtual experiments more than hand-on experiments. The reason is based on the ability to repeat the practical and get consistent results which in most cases is not possible with hands-on experiments.

In view of this study, it was critical to review theoretical understandings of science content and ways of teaching for learning. Experiments play an important role in the teaching and learning of physical science and can have an enormous effect on the understanding of concepts as scientific practice (Bretz, 2019). Hands-on and virtual experiments have some common objectives: to positively influence conceptual understanding and knowledge gain of scientific content or concepts and to enhance cognitive knowledge and skills. Hands-on and virtual experiments will be discussed in this study, and both have their own significant features, so it is imperative to reveal how the types of laboratory environments can complement one another to effect conceptual understanding and knowledge improvement (Burkett & Smith, 2016).

Studies of virtual laboratories were found to be necessary, given that we are in the Fourth Industrial Revolution (4IR). Despite the 4IR, the Covid-19 pandemic has swept the world and has forced the need to find alternative ways of teaching practical work.

The virtual laboratory offers new ways of interacting with practical work and influencing learning processes. Investigations have been conducted on students' understanding of science concepts using physical equipment. However, due to the advancement of technology, complex science concepts can be learned through advanced means by means of gadgets, and research emphasizes the need to use technology to teach physical science concepts (Pirker et al., 2021).

1.2.2. Teaching and learning sequences (TLS)

Several pedagogical principles based on didactics were proposed by Ross et al. (2022). A didactic model of education reconstruction recommended that all teaching sequences be guided by a theoretical foundation, objective design, implementation, and evaluation. Designed teaching and learning sequences in this study needed to highlight the importance of connecting theory and practical work in the teaching and learning of electromagnetic concepts. Stavrou, et al. (2018) indicated the critical role that physical science teachers should play in implementing appropriate methods, emphasizing the need to be active participants in improving learners' performance. TLS connected experiments to electromagnetic theory to facilitate understanding of the content taught by the sampled group. The research focused on the influence that hands-on and virtual experiments can play on teachers' conceptual understanding of electromagnetic theory. As the study compared TLS, it measured the effect of incorporating hands-on and virtual experiments within teaching sequences. The theoretical background in this section prompted the following research questions to guide the study:

1.2.3. Research questions

What influence would the developed teaching learning sequences (TLS) have on teachers' conceptual understanding of electromagnetic theory?

How did hands-on and virtual experiments influence teachers' conceptual understanding of electromagnetic theory and its content?

1.2.4. The theoretical framework

This study was conducted within the framework of Bandura's motivation theory. Bandura (1993), and the theory of Garrison et al. (2001), who considered self-efficacy and cognition to be the critical variables in understanding science learning engagement. The study incorporated the theoretical framework emphasizing how teachers' cognitive, affective, and self-efficacy beliefs impact their attitudes toward science. This framework guided this study to help teachers realize the importance of experiments as part of science lessons, and ultimately influence attitudes, perceptions, and the effect it can have on knowledge gain. Experimental observations have the potential to influence teachers' confidence in teaching and guiding learners during science lessons, which could ultimately shape learners' interest, understanding and their decisions about future careers in science (Linnansaari et al., 2015).

2. Research methodology

2.1. Research design and approach

An interpretive paradigm was used to study the effectiveness of the TLS in conceptualizing electromagnetic theory. The study employed three-phase concurrent mixed methods approach to gather data at a physical science professional development workshop. A combination of qualitative and quantitative methods was used concurrently to obtain data from the experimental and control groups, which were then analysed by comparative analysis to help describe the broader context of the case study (Bastable et al., 2019; Hong et al., 2018). TLS were designed to bridge content gaps, helping teachers better understand electromagnetic theory and recognize effective science teaching methods. The TLS were designed to capacitate teachers with content in a workshop that was conducted for three consecutive days for each group. One method incorporated virtual and hands-on experiments (the treatment), and the other relied on the traditional method of teaching. Research has used hands-on and virtual experiments to observe and measure the effect they have on physical science teachers' conceptual understanding of electromagnetic theory.

2.2. Selection of participants

The study was conducted in the North-West province of South Africa. The physical science teachers of the Kgetleng circuit in the Ngaka Modiri Molema district were invited to participate in this study. The schools were in remote rural areas with similar contextual factors. Similarity of the contextual factors was based on the profiling of schools according to the province, referred to as quintile 1 (no fee schools). Most of the schools were still without laboratories, or laboratories that were not adequately equipped, and more than 80% never used computers for virtual experiments in their teaching. The study included 31 qualified physical science teachers, divided into two experimental and control groups, respectively, with 16 and 15 teachers in each group.

2.3. Data collection tools and procedure

2.3.1. Data collection tools

The data collection instruments included a pre-post-test with closed (quantitative) and open-ended (qualitative) items, teachers' narrative reports (qualitative), video recordings (qualitative), and TLS evaluation reports (qualitative).

NARRATIVE REPORTS: Participants were asked to reflect, discuss, and write about electromagnetic concepts that they thought were difficult for the learners to understand and those that were difficult for the teachers to explain to the learners, and the data was collected according to each participant's narrative responses (Altun & Nayman, 2021).

PRE-POST-TEST: The pre-post-test included both closed and open-ended items and was conducted before and after intervention. The pre-post-test was used to measure the effectiveness of TLS and knowledge gained after intervention (Papadakis et al. 2018).

VIDEO RECORDINGS: Classroom participatory observations were conducted to collect qualitative data by means of video recordings. The participatory observation method was used to observe the effect of the hands-on and virtual experiments on teachers' conceptual understanding of electromagnetic theory. Participatory observation method was further used to observe and analyse the participation, interactions, and discussions during the intervention, and how teachers responded to questions that tested conceptual understanding (Crabtree & Miller, 2022).

EVALUATION OF TLS: The evaluation reports provided feedback from teachers to understand how they perceived the implementation of TLS and the effectiveness of hands-on and virtual experiments on knowledge gained (Curtis et al, 2021).

2.3.2. Data collection procedure

The major ideas underlying the process employed to collect data using a pre-post-test, teachers' narrative reports, and evaluation reports may be summarized as follows: The first phase (pre-test and narrative reports), the second phase (participation observatory report and categories from pre-test), and the third phase (post-test and teachers' evaluation of TLS).

In phase one of the empirical study, data was collected via a pre-test and the participants' narrative reports. During this phase, data was collected to determine the participants' existing knowledge, content gaps and the challenges they experience in teaching and learning electromagnetic theory. Participants were asked to probe and identify the challenges that prevented them from understanding electromagnetic theory. The empirical study began with both groups' narrative reports of the challenges they experienced when teaching electromagnetic theory. The participants were asked to reflect and report on electromagnetic concepts that they thought were difficult for learners to understand and concepts that were difficult for teachers to explain to learners. In the reports, teachers were prompted to explain why they thought it was difficult to teach the concepts or difficult for learners to grasp the concepts. The researcher then identified points that were reported by the teachers and summarized the common ones as teachers' content gaps in electromagnetic theory. The narrative reports were then followed by teachers writing the pre-test to determine common conceptual problems that needed attention in the intervention. Physical sciences teachers were expected to perform exceptionally well in the pre-test, as they were involved in teaching the high school Physics syllabus daily. A pre-test was administered to both groups to measure preconceived knowledge and knowledge gained to provide a valid measurement of intervention effectiveness (Altun & Nayman, 2021; Papadakis et al. 2018).

The second phase implemented TLS for both groups to meaningfully engage the participants, and the entire process was video recorded to capture the effectiveness of the treatment. The video recordings were condensed and transcribed into written reports for analysis. Hands-on experiments and virtual experiments complemented each other to enable conceptualization of electromagnetic theory and to facilitate teachers' conceptual understanding. The intention was to reconstruct and improve the participants' pre-conceived knowledge, to bridge the content gaps, to capacitate them with the correct scientific knowledge of electromagnetic theory and to draw their attention to relevant TLS to improve their method of teaching (Bastable et al., 2019; Pre et al., 2020). The researcher generally analysed the data using grounded theory by finding themes that were repeated in relation to themes that were identified from a pre-test conducted in phase one. A technique to extract common constructs from pre-test items was used to create themes. Consistency in the construct (factor analysis) referred to the essence of reliability in answering the items within a specific category; that is, if one item was correctly answered, the other within the same category was to be correctly answered as well. The themes during intervention were guided by the responses per category from the pre-test, and the videos were interpreted based on a participatory observation method (Luo et al., 2021). As a result of the intervention process, the researcher was able to identify content gaps based on recordings of discussions and reasoning that took place during the process, which were categorized according to the pre-test results. Even though the teaching sequence for both groups was based on the same content and concepts, the experimental group was exposed to hands-on and virtual experiments. Both groups were treated the same, except for the intervention strategies used. Taking into consideration that the controlled group also had to be trained for correct implementation of the topic, the researcher exposed them to the experiments that were presented to the experimental group at the end of the study (Crabtree & Miller, 2022).

A pre-post-test was administered before and after intervention to assess how interventions affected teachers' conceptual understanding of electromagnetic theory. Teachers were asked to evaluate the TLS following the administration of a post-test in order to gain a better understanding of their views concerning the effectiveness of hands-on and virtual experiments when teaching electromagnetic theory (Curtis et al, 2021).

3. Analysis and discussion of results

The study measured teachers' preconceived knowledge and content gaps in the first phase; then observed the influence of hands-on and virtual experiments on teachers' conceptual understanding during phase 2; and lastly measured knowledge gain and evaluated the TLS during phase 3.

3.1. First phase: Pre-test analysis and teachers' narrative reports

3.1.1. Qualitative analysis: The teachers' narrative reports

The first data that was collected during the first phase was teachers' narrative reports about the teaching of electromagnetic theory. The participants were asked to think about concepts that they thought were difficult for learners to understand and for teachers to teach (Altun & Nayman, 2021). The points outlined below were written down by the participants and summarized by the researcher in bullet form below. These points were followed up, provoked, and discussed during the intervention phase. To categorize and analyse the data, the researcher calculated the frequencies of common responses and converted them to percentages as outlined in the bullet bellow. The percentages in brackets suggest that many teachers find electromagnetic theory and concepts challenging to teach and learn.

- Faraday's law and Lenz's law: These two laws were difficult for participants to explain to learners because the concepts were also a challenge for them. 22 (71%)
- Faraday's law mathematical representation: While most participants were able to state the formula for magnetic flux, many were unable to define it, or to apply the formula to simple problems. 19 (77%)
- The difference between a motor and a generator: This is an application of Faraday's law and is foundational to the understanding of generators and motors. 22 (71%)
- Transformers are treated as a separate issue when teaching, not linked to Faraday's law. 20 (89%)

- Another aspect that was stated in the participant narratives was that the topic in general was a challenge for both learners and participants. They were not more specific in identifying the participants' problems. 22(94)

3.1.2. Quantitative analysis: The pre-test

Table 1 presents the results of the pre-test consisting of ten items for all 31 participants.

Table 1: Item analysis of closed items in the pre-test

Questions	Number of correct answers	Percentages (%)
2.1 A current carrying conductor placed in an external magnetic field experiences a force. The direction of the force experienced by the conductor depends on	13	42
2.2 Which /of the following devices are based on the principles that a current carrying conductor in a magnetic field experiences a force?	3	10
2.3 Which of the following will NOT affect the power output available from an AC generator?	13	42
2.4 The direction in which an induced current flow depends on	1	3
2.5 Which of the following devices DOES NOT operate on the principle of induced EMF?	4	13
2.6 The magnitude of induced EMF depends on?	12	39
2.7 How do you make an electromagnet?	18	58
2.8 What happens when you turn off current in an electromagnet?	12	39
2.9 Which of the following inventions uses the generation of electricity from a magnet?	11	36
2.10 Consider the situation below and choose the relevant statement.	11	36

Results from table 1 were interpreted based on the combined responses of participants in both groups, and 50% was taken as the margin for average performance. The margin was chosen because the participants were physical science teachers, and the research topic was part of the syllabus they taught at their respective schools. It was therefore expected that they would attain a minimum score of 50% for answering the questions. In the analysis of the results, only one answer (2,7) out of ten exceeded the 50% margin. In nine of the items, the answers were below the 50% margin, indicating underperformance in the items and content gaps in electromagnetic theory. Given that teachers do not understand the content they are teaching, this underperformance indicates that there is a challenge.

3.1.3. Qualitative analysis: The pre-test

In Table 2, open-ended items are presented on a liket scale, indicating four options for the participants' responses in percentage terms.

Table 2: Results of the open-ended questions in the pre-test

QUESTIONS	CORRECT	PARTIALLY CORRECT	INCORRECT	NO ATTEMPT
3.1 Give two differences between the operation of a motor and a generator	0	29	19	52
3.2 Why is an AC generator used at power stations and not a DC generator?	16	23	3	58
3.3 Is the current at our home dwelling AC or DC? Motivate your answer by giving examples at home.	0	36	13	52
3.4 One of the applications of a generator is found in power stations. Briefly describe or explain the operation of the generator at a coal-fired power station.	10	19	7	65

As shown in Table 2, none of the participants provided answers or explanations that were properly justified (0%) for 2.1 and 2.3. In addition, the participants also performed poorly with 16% and 10% respectively for 2.2 and 2.4. In the no attempt column, it is indicated that most participants did not attempt to respond. The table shows that "No attempt" has the highest percentage followed by "incorrect answer", which indicates that participants performed poorly on electromagnetic theory, a topic taught in high school by the same participants.

3.2. Second phase: Analysis of video recording (Participatory observation method)

During the second phase, data were collected during the intervention and all activities were video recorded. Participatory observation of classroom activities was used to qualitatively analyse data that was reviewed repeatedly for interpretation and analysis. (Crabtree & Miller, 2022).

Categories from the pre-test were used to create themes that were applied to analyse the video recordings. Pre-test items from the first phase of the intervention were categorized into themes that influenced participatory observation data analysis in phase 2. While the researcher observed the teachers' content challenges unfolding and being addressed by the experiments, participants observed, engaged, and interacted with the content of the lessons. The hands-on and virtual experiments complimented each other and enhanced teachers' comprehension of concepts.

Table 3 presents participants' responses by category, with the 50% margin perceived as a level of underperformance in electromagnetic theory and teachers' content gaps.

Table 3: Pre-test categories

Level of understanding	**No understanding the theory**	**limited knowledge of thetheory**	**Adequate knowledge of theory**	**Good knowledge of theory**
Categories ©	0-24%	25-49%	50-74%	75-100%
C1. Moving charge produce magnetic field		x		
C2. Magnetic fields interaction		x		
C3. Induction	x			
C4. Lenz law	x			

For further analysis of the content challenges during the professional development workshop, the participatory observation data from the video recording was condensed and categorized according to themes (refer to table 2). Participatory observatory data enabled interpretation and analysis of electromagnetic theory themes, as follows.

- C1. The experimental group was given the opportunity to observe the deflection of a campus needle when placed around a current-carrying conductor. This was done to gain a conceptual understanding of how a magnetic field is produced by moving charges.
- C2. Virtual experiment on the magnetic field interaction was presented and the observation demonstrates active participation, discussions, and conceptual understanding of the concepts under the category.
- C3. Induction was virtually demonstrated, and teachers observed current induced in a conductor and made sense of induction and meaningfully conceptualized the content.
- C4. This Lenz law was poorly performed with an actual percentage of zero (0°). The experiment was also simulated, and concepts were brought to life. Throughout the

video, teachers were seen interacting with the video and facilitator to conceptualize Lenz law concepts.

The video recording was examined to determine whether hands-on and virtual experiments improved conceptual understanding among the experimental group compared to the control group, which was passively instructed. The video recordings were transcribed and reviewed several times to compare, analyse, and gain a deeper understanding of how the TLS influenced the conceptual understanding of teachers.

3.3. Third phase: Analyses of the pre-post-test and evaluation of TLS

This section presents a quantitative analysis of the pre-post test results and the evaluation of the TLS after intervention. In the analysis, quantitative and qualitative results were analyzed. Following these results, evaluation reports provided qualitative insight into teachers' perceptions of how virtual and hands-on experiments influenced their understanding of electromagnetic theory and how they rated the TLS.

3.3.1. Quantitative analysis: the pre-post-test results

As shown in Table 4, the average normalized learning gains (<g>) for the two tests are presented. To analyse the effectiveness of the interventions (TLS), the average learning gain was calculated from the pre-test and post-test results. As an example, item 2.1 of the controlled group in the table is used to illustrate how <g> were calculated (Dewi et al., 2018):

Actual percentage gain = Post-test score – pre-test score
= 73.3 – 33.3
= 40
Maximum possible gain = Total possible gain – Actual gain
= 100 – 33.3
= 67.3

$$\text{Average normalised gain} = \frac{\text{Actual \% gain}}{\text{Maximum possible gain}} = \frac{40}{67.3} = 0.6$$

Table 4: Comparison of the average normalized learning gains of the pre-post-test

Question	CONTROLLED GROUP			EXPERIMENTAL GROUP		
	Pre-test %	Post-test %	gain <g>	Pre-test %	Post-test %	gain<g>
2.1 A current carrying conductor placed in an external magnetic field experiences a force. The direction of the force experienced by the conductor depends on	33.3	73.3	0.6	50.0	87.5	0.8
2.2 Which of the following devices are based on the principles that a current carrying conductor in a magnetic field experiences a force?	6.7	20.0	0.1	12.5	37.5	0.3
2.3 Which of the following will NOT affect the power output available from an AC generator?	26.7	80.0	0.7	56.3	68.8	0.3
2.4 The direction in which an induced current flow depends on	0	20	0.2	6.25	62.5	0.6
2.5 Which of the following devices DOES NOT operate on the principle of induced EMF?	6.7	40.0	0.4	18.8	56.3	0.5
2.6 The magnitude of induced EMF depends on?	20.0	60.0	0.5	56.3	68.8	0.3
2.7 How do you make an electromagnet?	73.3	46.7	-1.0	0.0	62.5	0.6
2.8 What happens when you turn off current in an electromagnet?	46.7	33.3	-0.3	31.3	37.5	0.1
2.9 Which of the following inventions uses the generation of electricity from a magnet?	6.7	40.0	0.4	56.3	62.5	0.2
2.10 Consider the situation below and choose the relevant statement.	33.3	60.0	0.4	37.5	56.3	0.3

As shown in table 4, the experimental group improved in almost all items when compared to the control group, showing a significant improvement in conceptual understanding and knowledge. Based on the results, it was confirmed that the combination of hands-on and virtual experiments helped clarify concepts in electromagnetic theory. The good performance and knowledge gained were attributed to the use of hands-on and virtual experiments in the teaching-learning process.

3.3.2. Qualitative analysis: The pre- and post-test results of the open-ended items

Table 5 compares the percentages of open-ended questions in the pre-post-test before and after intervention. As a measure of knowledge gain, the comparison excluded partially correct, incorrect, and no attempt responses, and only analysed the results of correct answers.

Table 5: Comparison of percentages of correct answers to the open-ended items of the pre-post-test

	PRE-TEST	**POST-TEST**	**POST-TEST**
Items number	**31 participants (%)**	**Experimental group (%)**	**Controlled group (%)**
3.1 Give two differences between the operation of a motor and a generator.	0.0	66	27
3.2 Why is an AC generator used at power stations and not a DC generator?	16	53	50
3.3 Is the current at our home dwelling AC or DC? Motivate your answer by giving examples at home.	0.0	38	0.0
3.4 One of the applications of a generator is found in power stations. Briefly describe or explain the operation of the generator at a coal-fired power station.	10	44	13

Based on the comparison of the results in table 5, the experimental group demonstrated an improvement in knowledge, which was attributable to the effect that hands-on and virtual experiments had on teachers' conceptual understanding. Despite the implementation of the TLS, the Controlled group's performance remained at 0% in 2.3, discrediting the traditional method of teaching physical science.

3.3.3. Qualitative analysis: The evaluation of the TLS

Researchers conducted discussions with teachers during the third phase of the study to evaluate the teaching learning sequences (TLS) implemented during the interventions (Curtis et al, 2021). The controlled group indicated that they could not conceptualize some of the concepts. At times, they became confused when concepts were developed constructively at different cognitive levels of thinking. It is important to note that traditional approaches to teaching and learning physical science are ineffective.

In contrast, the experimental group valued the effectiveness of hands-on and virtual experiments. In general, it has been noted that practical observations of hands-on and virtual experiments facilitate the learning and understanding of physical science concepts. Based on the results of this study, it was concluded that hands-on and virtual experiments improved conceptual understanding of electromagnetic theory. During the discussion, it was also revealed that electromagnetic experiments had never been conducted or observed by teachers before. Most likely, this is due to a lack of confidence and a lack of resources.

4. Discussions

Physical science teaching and learning with a complementary combination of hands-on and virtual experiments has proven to enhance teachers' conceptual understanding of electromagnetic theory. The findings were supported by average normalized learning gains and teachers' evaluation reports. The study findings are supported by Ross et al. (2022), who claim that experiments can improve students' knowledge, cognitive thinking skills, and learning outcomes. It is worth noting that the experiments had a positive impact on the teaching and learning of science. This was demonstrated by the observations made regarding the usefulness, enjoyment, and self-efficacy of teachers' experiences during the professional development workshop. Through hands-on and virtual experiments, the workshop greatly improved teachers' conceptual understanding of electromagnetic theory, which they had not mastered previously (Ros et al., 2022). It was highlighted in this study that physical science teachers play a crucial role in implementing appropriate methods, emphasizing the importance of being familiar with the content they teach, and being active participants in improving learners' performance (Stavrou, et al., 2018). Furthermore, it is important to note that virtual experiments possess appropriate competencies relevant to the Fourth Industrial Revolution (4IR) and have the potential to positively influence the future of science education.

5. Conclusion and recommendations

It was concluded that teachers' conceptual understanding of electromagnetic theory was enhanced by the teaching sequence that incorporated virtual and hands-on experiments. Using hands-on and virtual experiments in the teaching and learning sequence enhanced teachers' content knowledge, eliminated alternative conceptions and clarified content confusion. Combining hands-on and virtual experiments with a teaching-learning sequence is an effective strategy for teaching physical science and produces better learning outcomes than traditional teaching methods. Based on the conceptual understanding of electromagnetic theory, the acquisition of knowledge, and awareness of effective science practices, it was concluded that hands-on and virtual experiments were effective methods (Ros et al., 2022). Teachers were encouraged to take note of the Teaching Learning Sequence to improve the standards of teaching and learning in physical science. They were encouraged to learn from the implications it had on their conceptual understanding of electromagnetic theory. A recommendation was made that teachers of physical science re-evaluate their teaching methods, specifically the traditional method of instruction that everyone seems comfortable with. A further recommendation of the study was that all physical science lessons should include either hands-on experiments or virtual experiments. The nature of the subject does not allow the use of traditional methods or the transmission of pure knowledge (Letsoalo, 2018).

Ethical aspects of research

Permission to conduct the research was obtained from the North-West Department of Basic Education of South Africa, the principals of the selected schools and the teachers. The University of North-West's independent ethics committee approved the study. The researcher informed the participants (the physical science teachers) about the nature and purpose of the research and the ethical considerations that guided the research. The participants were informed of voluntary participation, confidentiality of information, and the purpose of the research.

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