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Effectiveness of pedagogic praxes in teaching matter and kinetic molecular theory at grade 10 in selected schools in the Mthonjaneni circuit in South Africa

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Abstract: When teaching physical sciences, practical methods are crucial for fostering students' conceptual knowledge and practical abilities. The impact of the Practical Investigative Learning (PIL) approach on Grade 10 students' understanding of Matter and the Kinetic Molecular Theory (M-KMT) was investigated in this study. Using a positivist-based quasi-experimental design, a pre-test and a post-test were included. 50 Grade 10 students from two high schools in KwaZulu-Natal's Mthonjaneni circuit were chosen at random. 25 students from the experimental group attended a school with a fully functional science lab, whereas 25 students from the control group attended a school without a laboratory. The experimental group received instruction through PIL, while the control group received traditional instruction from the same qualified physical sciences teacher. An independent t-test ($p > 0.05$) was used to compare the results of the pre-test and post-test after descriptive statistics were applied. The results show that learners' conceptual understanding of M-KMT was greatly improved by the PIL approach, which made abstract ideas more concrete and understandable.

Keywords: *Curriculum, Kinetic molecular theory, Pedagogy, Physical science, Practical investigative learning.*

1. Introduction

According to the Kinetic Molecular Theory (M-KMT) and the concept of matter, matter is composed of particles. First observed in Brownian motion experiments in the early 1820s, KMT is a fundamental model that describes matter as a collection of discrete units, specifically atoms and molecules, in continuous random motion [1]. Furthermore, M-KMT offers a framework for comprehending particle configurations, which aids in the explanation of a number of physical characteristics like evaporation, melting point, and boiling point. Research shows that students frequently struggle to grasp the fundamental idea of matter, even though M-KMT plays a crucial role in chemistry education [1]. According to a number of studies, these difficulties are usually caused by ineffective teaching strategies [2-4].

Many teachers still use the "chalk-and-textbook" method even though the South African Curriculum Assessment Policy Statement (CAPS) suggests pedagogical techniques like Practical Investigative Learning (PIL) for teaching M-KMT. The significance of incorporating experiments into the teaching and learning of M-KMT concepts is specifically emphasized by CAPS. However, many teachers continue to use outdated approaches that mainly rely on lectures and textbooks, which makes lessons too abstract and challenging for students to understand. As a result, static representations like diagrams are frequently used in the conceptualization of M-KMT, which restricts students' ability to see the macroscopic interactions between particles up close. Erceg et al. [5] claim that students find it difficult to understand the fundamentals of M-KMT when they are not involved in experimental activities that demonstrate particle behavior in various states. Furthermore, many academics agree that the use of interactive demonstrations and visual aids significantly improves comprehension [6, 7].

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The idea that matter is composed of incredibly tiny particles moving randomly and continuously forms the theoretical foundation of M-KMT and its explanation of the phases of matter. In order to show and validate how particles behave in each phase of matter and how phase transitions take place, verifiable scientific experiments are necessary for a thorough understanding of M-KMT. Teaching and learning M-KMT through an experimental approach, according to Santos and Arroio [6], greatly improves students' conceptual understanding, encourages active engagement, piques their curiosity, and helps them develop their critical thinking and problem-solving abilities. To support this, the Department of Basic Education [8] clearly describes hands-on activities intended to enhance students' understanding of M-KMT concepts.

In grade 10, M-KMT is introduced as part of the South African curriculum. This helps students grasp more complex subjects like ideal gases, chemical changes, and other ideas covered in grades 11 and 12. According to the Chief Diagnostic Report [9], for example, students continue to perform poorly on the topic of chemical change in Physical Sciences Paper Two of the National Senior Certificate (NSC) exam. South Africa's quality assurance organization, Umalusi, reports that while overall performance in Chemistry Paper Two has slightly improved, learner achievement in the chemical change section is still below the 40% national average. Only a small percentage of the many studies that have looked into the high failure rates in chemistry have explicitly examined the connection between students' performance and teachers' content knowledge [2-4]. Given the dearth of studies investigating the effects of instructional strategies on grade 10 students' academic achievement in matter and kinetic molecular theory, this substantial knowledge gap must be filled immediately.

1.1. Research Questions

1. What is the effect of practical investigative learning (PIL) on Grade 10 learners' comprehension of Matter and the Kinetic Molecular Theory?
2. How does practical investigative learning (PIL) influence Grade 10 physical sciences learners' problem-solving skills in Matter and the Kinetic Molecular Theory?
3. In what ways does practical investigative learning (PIL) impact Grade 10 learners' achievement in Matter and the Kinetic Molecular Theory?

1.2. Research Objectives

1. To determine the effect of practical investigative learning (PIL) on Grade 10 learners' comprehension of Matter and the Kinetic Molecular Theory.
2. To analyze the influence of practical investigative learning (PIL) on Grade 10 physical sciences learners' problem-solving skills in Matter and the Kinetic Molecular Theory.
3. To evaluate the impact of practical investigative learning (PIL) on Grade 10 learners' academic achievement in Matter and Kinetic Molecular Theory.

2. Literature review

2.1. The concept of Pedagogical Praxis

According to Sirotová [10], praxis pedagogy is a learner-centered strategy that improves student outcomes by integrating ethical viewpoints and critical thinking. Different teaching methods have been used over time to teach various chemistry concepts; each has its own applications and appropriateness based on the concept being taught [11]. Moreover, pre-service teachers can progressively acquire critical professional skills through pedagogical praxis [10]. Professional educators follow their own pedagogical frameworks, which include the ways in which students approach learning, the choices that teachers make about how to teach, and the dynamics of interactions between teachers and students [12]. This highlights the critical importance for teachers to structure M-KMT lessons effectively by applying activity-based and experimental approaches, which promote higher levels of learner participation throughout the teaching-learning process.

Kolesnikova [13] defines a teaching method as the combination of general didactic principles, pedagogical strategies, and management techniques designed to achieve effective classroom instruction. Research indicates that some physical sciences teachers lack deep content knowledge of M-KMT, a challenge compounded by insufficient support from supervisors in the Department of Education [14]. Consequently, teachers need to critically evaluate the teaching methods they employ during lesson preparation and reflect upon their effectiveness after receiving learners' feedback. If the methods prove inadequate, alternative strategies, particularly the activity-based approach, should be explored.

The learner-centred teaching method actively engages learners by involving them directly in the learning process through task-based activities, practical work, experiments, and projects. Teachers serve as facilitators, guiding learners to discover new knowledge while enabling direct interaction with teaching-learning materials to deepen understanding. Conversely, the teacher-centred method, often called the talk-and-chalk approach, is criticised for fostering learner passivity, limiting the use of learning materials, and discouraging collaborative learning.

The Department of Basic Education [15] emphasizes the adoption of learner-centred approaches to foster more practical and effective engagement during the teaching-learning process [14]. This approach is preferred over traditional teacher-centred methods, particularly for M-KMT lessons in high schools, where the teacher's methodology and attitude can greatly influence learner interest and comprehension. Effective science teaching extends beyond content delivery, helping learners understand both the "how" and "what" of knowledge while developing critical thinking, problem-solving, and innovative skills.

Activity-based learning engages students in continuous and meaningful critical and creative thinking (Panko et al., cited in Anwar [16]). This method facilitates collaborative interactions between teachers and learners, guiding them toward achieving learning objectives. Learning by doing is widely recognized as the most effective way for students to acquire knowledge. In this method, teachers explain, demonstrate, and provide teaching aids, while learners engage in activities such as answering questions, exploring materials, discussing charts or diagrams, drawing, and conducting research. Additionally, the learner-centered approach fosters the development of fine motor skills, including reading, writing, and drawing. Through investigation and experimentation, learners discover new ideas, making the activity-based approach particularly significant because the learner remains the focal point of instruction.

Kolesnikova [13] argues that well-planned and creatively designed teaching methods stimulate learners' curiosity, actively engage students, promote critical thinking, focus attention on task-based activities, and foster sustained classroom interaction, thereby enhancing understanding of course content. John et al. [17] further note that experiential learning, defined as "a process through which a learner constructs knowledge, skills, and values from direct experiences" (p. 234), supports this perspective. Similarly, experimental teaching nurtures problem-solving skills, encourages innovation, and promotes comprehensive understanding. Therefore, employing experimental approaches in teaching M-KMT allows learners to construct their own knowledge, reduces abstraction in lessons, and helps teachers connect content to practical, real-life contexts.

Koopman et al. [14] highlight that although the South African curriculum includes practical work, physical sciences teachers often report insufficient time to complete experiments. This lack of hands-on activities contributes to learners' struggles with fundamental M-KMT concepts. To address this, the Department of Basic Education [18] recommends formal experiments on M-KMT in grade 10 as a strategy to enhance learners' conceptual understanding. In conclusion, the experimental approach to learning through direct experience guides learners toward deeper comprehension and fosters innovative thinking in science education.

2.2. Effective Pedagogic Practices for Science Education

A conscious move away from traditional teacher-centered approaches and toward more successful pedagogical practices is necessary to improve students' engagement and comprehension in science classes. A deeper understanding of science, critical thinking abilities, and active learning can all be fostered by effective teaching strategies. These practices include a number of evidence-based methods. Inquiry-based learning, or IBL, is a cornerstone of successful science pedagogy [19]. By empowering students to pose questions, plan experiments, gather and evaluate data, and reach conclusions based on solid evidence, this learner-centered approach positions them as active investigators. IBL fosters a feeling of scientific ownership, critical thinking, and problem-solving abilities [20]. The benefits of IBL for students' motivation, engagement, and content knowledge acquisition are highlighted by research by Minner et al. [21].

Project-based learning (PBL) broadens the scope of inquiry through the presentation of real-world problems that call for students to integrate several scientific concepts [22]. PBL exercises frequently require teamwork, communication, and the application of scientific concepts to real-world situations. According to research by Krajcik et al. [22], PBL fosters student participation, problem-solving skills, and content mastery [23]. Cooperative learning settings, where students work in small groups toward common objectives, are also beneficial in science classrooms [24]. Peer interaction, knowledge exchange, and the growth of collaborative abilities are all promoted by this method. Research by Slavin [23] indicates that in science classrooms, cooperative learning improves student performance, lowers anxiety, and fosters social skills.

Integration of technology offers more opportunities to improve science instruction. Online data-analysis tools, interactive visualizations, and simulations can help bring abstract scientific ideas to life. Technology has the ability to support active learning, make complex phenomena easier to understand, and accommodate a variety of learning styles, according to Jonassen [24]. According to Jonassen [24], students are assisted in developing a more thorough understanding when scientific material is presented using a variety of modalities, including text, diagrams, models, and hands-on activities. Ainsworth's [25] research demonstrates how multiple representations can enhance science learning outcomes. Therefore, a shift away from rote memorization and passive learning is necessary for effective science pedagogy. An interesting and stimulating learning environment is produced by combining technology-enhanced instruction, inquiry-based learning, project-based learning, cooperative learning, and multiple representations. These exercises develop critical thinking skills, problem-solving aptitudes, and a greater understanding of the scientific method.

2.3. Effect of Teachers' Pedagogical Content Knowledge on Teaching and Learning Matter and Kinetic Molecular Theory

Teachers' content knowledge (CK) refers to their mastery of subject matter and is considered a reflection of what is taught in the classroom Akhtar et al. [26]. Lawson and Chinnappan [27] argue that teachers' CK significantly influences how knowledge is accessed and applied during lesson planning and instruction. However, Novak and Tassell [28] caution that possessing extensive CK alone does not guarantee effective teaching. Classroom management and instructional strategies, non-content knowledge collectively referred to as pedagogical knowledge (PK), are also critical for effective knowledge dissemination.

Rosenkränzer et al. [29] define PK as non-content knowledge encompassing classroom management, instructional approaches, and professional expertise applied during teaching. Therefore, effective instruction in M-KMT requires both strong content knowledge and the appropriate pedagogical approach. Teachers with limited pedagogical and content knowledge (PCK) may inadvertently promote rote learning, which often results in poor learner performance.

Educators with robust PCK in M-KMT are able to design rich conceptual representations, address learners' preconceptions and misconceptions, and strategically sequence the curriculum to optimize learning outcomes [28]. Well-structured and creative pedagogical practices in the delivery of M-KMT content enhance learners' active participation and understanding. For instance, explaining energy changes across the phases of matter requires clear visual representations, necessitating that teachers possess strong PCK complemented by practical experience. Arnold and Mundy [30] further corroborate that exemplary teaching of M-KMT depends on a comprehensive understanding of the integrated characteristics of praxis pedagogy.

3. Theoretical Framework

Dewey's Pragmatic Theory of Truth was used to frame this study. John Dewey developed a distinctive perspective on truth by rejecting the idea that it exists independently of human experience, instead framing it as "warranted assertibility" [31, 32]. According to Dewey, claims must be warranted through evidence, systematic inquiry, and experimentation to ensure their reliability [33]. However, the truth is assertible, which means it is put to the test through theories that have real-world applications and direct how people interact with the outside world [33]. Dewey also emphasized that scientific research is fundamentally social because knowledge is produced by scientists working together, discussing, and critiquing one another rather than by lone individuals [34]. In addition to improving supported claims, this collaborative and iterative process increases the reliability and validity of scientific knowledge.

Inquiry, proof, and real-world applications are emphasized as being essential to the advancement of scientific knowledge in Dewey's pragmatic theory of truth (1859–1952). This theory offers insights for teaching concepts like matter and the Kinetic Molecular Theory (KMT), which students often find difficult in science education. Misconceptions and superficial understanding are often caused by the abstract nature of atoms and molecules, as well as the challenges of relating microscopic structures to macroscopic observations [35, 36]. These difficulties are frequently made worse by traditional lecture-based instruction, which frequently fails to actively engage students or connect material to relevant, real-world contexts [37]. However, Dewey's pragmatic framework emphasizes relevance and inquiry, providing ways to overcome these obstacles and enabling students to gain a deeper conceptual understanding.

Inquiry-based learning (IBL) is a key component of Dewey's philosophy because it views students as active contributors to the creation of knowledge [19]. In keeping with Dewey's idea of "warranted assertibility" [31], students are urged to research phenomena, pose questions, and support their assertions regarding matter and KMT with facts. Students can, for instance, use practical experiments to investigate the characteristics of solids, liquids, and gases before connecting their findings to microscopic particle motion and arrangement. This procedure not only enables them to test theories but also closes the gap between the invisible atomic structures that underlie observable phenomena. IBL makes Dewey's idea of science education a reality by fostering students' curiosity, critical thinking, and evidence-based reasoning.

Additionally, Dewey emphasized the social aspect of inquiry, highlighting the importance of teamwork and communication in science education [34]. Models and visualizations are crucial for creating a common understanding in the context of KMT. Building atomic models, representing atoms with spheres, or engaging with computer simulations of gas behavior are examples of activities that give students tangible visual aids to help them visualize abstract concepts. Building collaborative models improves understanding while mirroring the collaborative character of scientific research, in which information is improved via peer review and discussion. Additionally, relating KMT to actual occurrences like gas laws in balloon inflation, diffusion in daily life, or refrigeration processes illustrates what James [38] called the "cash value" of knowledge. These applications help students see science as a tool for comprehending and influencing the world by demonstrating the usefulness of scientific concepts in real-world situations. Dewey's pragmatic approach offers a transformative framework for teaching science, even though careful planning and scaffolding are required to address misconceptions and support effective inquiry [21]. It moves education away from rote memorization and toward an interesting, purposeful process of discovery where students actively create knowledge and hone abilities necessary for practical application, critical thinking, and problem-solving.

4. Methodology

4.1. Research Paradigm

The positivist paradigm, which holds that legitimate knowledge is obtained through scientific investigation, was adopted in this study [39]. Since positivism emphasizes that knowledge comes from human experience and is verified by methodical research, it is closely related to empiricism [40]. According to Creswell and Creswell [39], positivists in this framework rely on quantifiable observations that enable statistical analysis, guaranteeing the validity and reliability of research findings. Furthermore, positivism holds that factual knowledge can only be obtained through observation and measurement using the senses, enhancing the credibility of findings. In line with this perspective, the study examined participants' understanding of matter and the Kinetic Molecular Theory (M-KMT) using a Practical Investigative Learning (PIL) approach that emphasizes experimentation and observation as avenues for acquiring knowledge.

4.2. Research Approach

A quantitative research methodology was used to investigate instructional strategies aimed at enhancing students' understanding of matter and the Kinetic Molecular Theory (KMT). According to Creswell and Creswell [39], this method places a strong emphasis on the methodical gathering and examination of numerical data in order to quantify variables, test theories, and find correlations. Because it made it easier to employ a quasi-experimental design, which exposed students to various teaching techniques in order to evaluate their efficacy, this method was especially well-suited for the study. Pre-test and post-test results were compared in order to statistically assess the effects of particular pedagogical interventions, offering unbiased proof of the approaches that improved students' comprehension of matter and KMT. The quantitative method thus made sure that the results were supported by evidence and applicable outside of the current study context.

4.3. Research Design

Pedagogical strategies to improve academic performance in matter and the Kinetic Molecular Theory (KMT) were examined using a quasi-experimental design. In order to investigate the effects of interventions, a quasi-experimental design uses pre-existing groups rather than random assignment [39]. Because students were already divided into groups in the classroom, random reassignment was both impractical and morally problematic, so this method was appropriate. In order to assess the efficacy of various teaching techniques in actual classroom environments, the researcher compared the pre-test and post-test results of these groups. This design maintained scientific rigor in evaluating students' comprehension of matter and KMT while enabling the practical measurement of pedagogical interventions.

4.4. Population of the Study

The entire group of people, things, or occurrences that are the subject of a study and from which the researcher hopes to derive conclusions is referred to as the research population. Teachers of physical sciences and high school students in KwaZulu-Natal (KZN), South Africa's Mthonjaneni circuit, made up the study's population. In order to ensure that the study captured both instructional approaches and student understanding in the regional context, participants were chosen based on their insights into physical science learning outcomes and teaching practices.

4.5. Sample and Sampling Techniques

A random sampling technique was used to select 50 Grade 10 physical sciences learners from two high schools in the Mthonjaneni circuit of KwaZulu-Natal (KZN), South Africa. Inclusion criteria required learners to be enrolled in Grade 10 physical sciences. Random selection improved representativeness by guaranteeing that the sample appropriately represented the target population's demographics. Participants were split equally between the two schools: 25 students from the experimental group, which had a fully stocked science lab, and 25 students from the control group, which did not. Through this grouping, academic performance and the results of instructional interventions were compared across schools with varying resources, offering a structured framework to evaluate how well pedagogical strategies improved students' comprehension of physical science concepts, such as matter and the Kinetic Molecular Theory. The statistical formula developed by Krejcie and Morgan [41], which proposed that the population characteristics should be within 5%, provided support for the sample size calculation. As a result, 5% precision was the target level for this study. The sample size was determined using the 95% confidence level formulas developed by Krejcie and Morgan [41], which are described below:

$$s = \frac{X^2NP(1-P)}{d^2(N-1)+X^2P(1-p)}$$

s = required sample size.
X^2 = the table value of chi-square for 1 degree of freedom at the desired confidence level (1.96).
N = the population size.
P = the population ratio (assumed to be 0.50 since this would provide the maximum sample size).
d = the degree of accuracy expressed as a proportion (0.05).

$$s = \frac{1.96^2 \times 65 \times 0.5(1-0.5)}{0.05^2(65-1)+1.96^2 \times 0.5(1-0.5)}$$

$s \approx 50$

4.6. Data Collection Instruments

Pre-test and post-test measures were used to gather data. Both the experimental and control groups took the pre-test, which was created around tasks pertaining to the Matter and Kinetic Molecular Theory (M-KMT), in order to gauge their prior knowledge. The same certified physical science teacher then instructed both groups, albeit with distinct teaching strategies. The control group was instructed using the conventional method, while the experimental group was given the Practical Investigative Learning (PIL) method. To assess learning outcomes, both groups were given the same post-test following instruction. The PIL intervention was integrated into the experimental group's instruction, allowing performance comparisons between the intervention and conventional techniques. With this design, results could be measured at two different points in time: a pre-test to determine learners' baseline knowledge and a post-test to evaluate the impact of the PIL intervention. This allowed for a clear comparison of how the approach affected learners' comprehension of M-KMT.

4.7. Validity and Reliability of the Instruments

Several procedures were used to guarantee the validity and reliability of this investigation. A quasi-experimental design that had distinct experimental and control groups improved construct validity and made it possible to measure precisely how pedagogical interventions affected students' comprehension of matter and KMT. To preserve content validity, curriculum-aligned pre-test and post-test instruments were created and reviewed by seasoned Grade 10 physical science teachers, whose input improved their appropriateness and clarity. Standardizing the teaching processes and using the same tests consistently for both groups helped to ensure reliability so that variations in results could be ascribed to the instructional strategies rather than inconsistent teaching or assessment. Furthermore, participants were chosen at random, which increased the sample's representativeness and supported the study's findings' generalizability and consistency.

4.8. Data Analysis

Descriptive statistics such as means, frequencies, percentages, standard deviations, and line graphs were used to analyze the data and assess the effectiveness of the instructional interventions. To determine baseline equivalence, the pre-test scores of the experimental and control groups were first compared using an independent samples t-test. This revealed no significant difference ($p > 0.05$), confirming that the groups had similar prior knowledge of M-KMT. Following the intervention, the experimental group, which received the PIL approach, and the control group showed a statistically significant difference ($p < 0.05$) in post-test scores when analyzed again using an independent samples t-test. This suggests that the PIL method had a positive impact on learners' comprehension of M-KMT.

5. Results

Data were collected before and after applying the two teaching methods, namely practical investigative learning (PIL) and traditional teaching methods. Initially, a baseline pre-test was administered to both the control and the experimental learners to ensure that both groups had similar prior knowledge of M-KMT. The data were then analyzed using an independent t-test, as shown in Table 1.

Table 1.
Results of the independent t-test on the pre-test of both groups.

Group	N	Mean	SD	Mean diff	df	T	Sig (2-tailed)
Control	30	9.60	3.08	-0.39	48	-0.59	0.56
Experimental	30	9.10	3.47		47.21		

Note: T-value is significant at $p < 0.05$.

Table 1 shows that the control group achieved a mean score of 9.60, while the experimental group obtained a mean score of 9.10. The mean difference of 0.39 produced a T-value of 0.59, and the p-value of 0.56 ($p > 0.05$) indicates that there was no statistically significant difference between the two groups prior to the application of the teaching methods. This confirms that both groups had comparable baseline knowledge of M-KMT before the intervention. Following the instructional period, an independent t-test was conducted to examine whether the applied teaching methods had a significant effect on learners' performance. The analysis reveals whether the PIL approach led to measurable improvements in the experimental group compared to the control group. It assessed the effectiveness of this pedagogic strategy in enhancing learners' understanding of matter and the Kinetic Molecular Theory.

Table 2.
Results of an independent t-test on the post-test of both groups.

Group	N	Mean	SD	Mean diff	df	T	Sig (2-tailed)
Control	30	12.53	5.05	0.61	48	-5.86	0.00
Experimental	30	15.53	4.44		47.21		

Note: T-value is significant at $p < 0.05$.

Table 2 indicates that the control group achieved a mean score of 12.53, whereas the experimental group, which received instruction through the Practical Investigative Learning (PIL) approach, scored a higher mean of 15.53. A T-value of -2.44 and a p-value of 0.00 ($p < 0.05$) were obtained from the mean difference of 0.61, suggesting that the difference between the groups is statistically significant. This finding shows that the experimental learners' comprehension of matter and the Kinetic Molecular Theory (M-KMT) was significantly improved by the use of PIL as a teaching strategy. The results indicate that interactive, inquiry-based learning improves conceptual understanding more successfully than conventional teaching techniques.

5.1. Comparing the Overall Performance Between the Control and Experiment Learners per Question in the Pre-Test

The performance percentages for each question in the experimental and control groups prior to the implementation of the two teaching strategies are contrasted in Table 3. The experimental group scored

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42% on Question 1, which evaluated students' recall of definitions and examples of M-KMT terminology, compared to 40% for the control group. Conceptual understanding, practical knowledge, and visualization abilities were assessed in Questions 2, 3, and 4. The control group achieved 31% and 26% for Questions 2 and 3, respectively, compared to 29% and 26% for the experimental group. For Question 4, which further assessed applied understanding, the control group scored 20%, while the experimental group scored 21%.

Table 3.
Comparing the performance between the control and experiment group per question in the pre-test.

Item	Descriptions of problem solution	Percentage score by the control group	Percentage score by experimental group
Question 1	Recall, definition, and examples of Matter.	$\frac{14}{35} = 40\%$	$\frac{15}{35} = 42\%$
Question 2	Conceptual understanding of M-KMT.	$\frac{11}{35} = 31\%$	$\frac{10}{35} = 29\%$
Question 3	Conceptual understanding, practical knowledge, & visualization skills of M-KMT.	$\frac{09}{35} = 26\%$	$\frac{09}{35} = 26\%$
Question 4	Practical knowledge of M-KMT.	$\frac{7}{35} = 20\%$	$\frac{7.5}{35} = 21\%$

A line graph was used to further illustrate the pre-test scores, showing baseline performance across the control and experimental groups. The graph in Figure 1 visually represents the percentage scores for each question, highlighting similarities and differences between the two groups before the teaching interventions were applied.

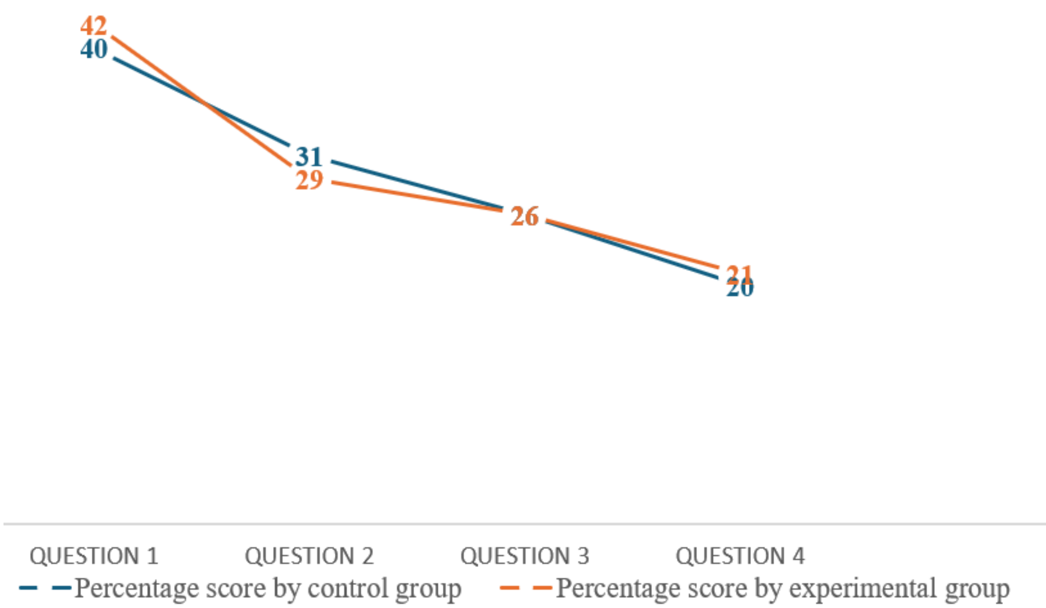

Figure 1.
Line graph showing the pre-test score per question for the control and experimental groups.

5.2. Comparing The Overall Performance Between the Control and Experiment Group per Question in the Post-Test

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Table 4 presents a comparison of performance percentages per question between the control and experimental groups after implementing the two teaching methods. The experimental group received a combination of experimental and investigative learning approaches, while the control group was taught using the traditional method. For Questions 1 and 2, the control group scored 67 percent and 63 percent, respectively, compared to 91 percent and 94 percent for the experimental group. For Questions 3 and 4, the control group achieved 60 percent and 46 percent, whereas the experimental group scored 94 percent and 97 percent. The results indicate that although both groups showed improvement following the interventions, the experimental group demonstrated significantly higher performance, suggesting that the blended investigative and experimental learning approach was more effective in enhancing learners' understanding of M-KMT than the traditional teaching method.

Table 4.
Comparing the performance between the control and experiment group per question in the post-test.

Item	Descriptions of problem solution	Percentage score by control group	Percentage score by experimental group
Question 1	Recall, definition, and examples of Matter.	$\frac{24}{35} = 67\%$	$\frac{33}{35} = 94\%$
Question 2	Conceptual understanding of M-KMT	$\frac{22}{35} = 63\%$	$\frac{32}{35} = 91\%$
Question 3	Conceptual understanding, practical knowledge, and visualization skills of M-KMT	$\frac{21}{35} = 60\%$	$\frac{33}{35} = 94\%$
Question 4	Practical knowledge of M-KMT	$\frac{16}{35} = 46\%$	$\frac{34}{35} = 97\%$

The post-test results were further illustrated using a line graph in Figure 2. The graph shows that the control group scored 67% and 46%, while the experimental group achieved 94% and 97% for Questions 1 and 4, respectively. On average, the experimental group scored 94%, compared to 59% for the control group. Question 1 assessed learners' ability to recall definitions of matter and provide examples. As shown in Figure 2, both groups demonstrated improvement, but the experimental group consistently outperformed the control group. These findings indicate that the Practical Investigative Learning (PIL) approach is more effective than the traditional teaching method in enhancing learners' conceptual understanding of M-KMT.

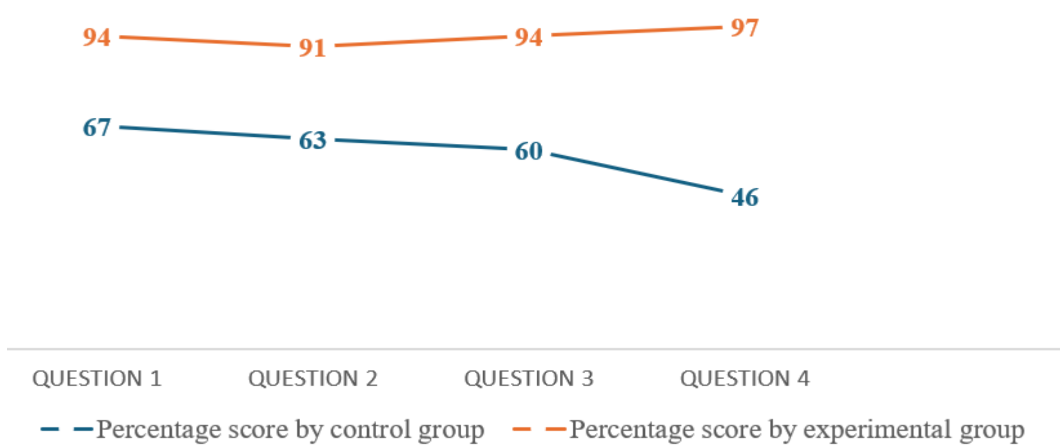

Figure 2.
A line graph presenting the pre-test score per question for the control and experimental groups.

6. Discussion

This study examined how Grade 10 students' comprehension of Matter and the Kinetic Molecular Theory (KMT) was impacted by Practical Investigative Learning (PIL). Both the experimental and control groups took a baseline test prior to instruction, and then a post-test following the use of two different teaching strategies. Although the experimental group continuously outperformed the control group, comparisons of the results in Tables 3 and 4 showed that both groups improved. On Question 1, which tested memory for definitions and examples of the phases of matter, both groups did well. However, the experimental group scored higher on Questions 3 and 4, which called for conceptual knowledge and real-world problem-solving. These results are consistent with those of Alamina and Etokeren [11], who observed that when phase changes are not readily apparent, students frequently have difficulty understanding Kinetic Molecular Theory (KMT). In order to improve comprehension, other researchers stress the value of incorporating visual and investigative approaches into teachers' pedagogical content knowledge [1, 4, 6]. This study, which is based on Dewey's Pragmatic Theory of Truth, demonstrates how the PIL approach successfully improved students' conceptual grasp of matter and KMT while encouraging purposeful, long-term learning through inquiry-based, hands-on interaction with abstract scientific ideas.

Research on the effects of PIL on the problem-solving abilities of Grade 10 Physical Science students in Matter and M-KMT shows that PIL significantly improved students' conceptualization of the subject. The experimental group outperformed the control group in terms of improvements in practical knowledge and visualization abilities, as indicated in Tables 3 and 4. Similarly, mean score comparisons (Tables 1 and 2) showed that experimental learners consistently outperformed their counterparts, even though both groups demonstrated progress in the post-test. This demonstrates that PIL is a more successful teaching strategy for M-KMT than conventional techniques. This study shows that PIL improves learners' spatial reasoning, leading to deeper conceptual understanding, in addition to increased achievement. These results imply that learner comprehension is significantly impacted by teachers' instructional design. According to researchers like Pólya [42], students build meaningful understanding through active, hands-on engagement with materials. This is supported by the claims made by Bates [43] that constructive learning is encouraged by practical participation. Furthermore, Santos and Arroio [6] point out that when particle behavior is not visible, students have trouble with M-KMT. According to Dewey's Pragmatic Theory of Truth, problem-solving abilities and conceptual mastery are strengthened through inquiry, experimentation, and discovery. Consequently, PIL becomes a useful teaching method for increasing students' comprehension of M-KMT.

The findings on the impact of PIL on Grade 10 learners' achievement in KMT highlight differences in performance between the control and experimental groups. As shown in Table 1, there was no significant difference in mean scores between the groups before the introduction of the teaching methods. However, Table 2 reveals a significant difference after PIL was applied to the experimental group. Although both groups improved in the post-test, the experimental group outperformed the control group (see Table 4). This suggests that the experimental learners' enhanced performance resulted from knowledge construction facilitated by PIL. These results align with Santos and Arroio [6], who emphasize that pedagogical content knowledge should address misconceptions through investigative learning. Similarly, Sanchez [44] and Sanchez [1] confirm that experimental approaches significantly improve learner achievement in M-KMT. This indicates that integrated strategies such as PIL are highly effective.

7. Implications

The study indicates that the Practical Investigative Learning (PIL) instructional approach strengthened the spatial visualization skills of learners in the experimental group, which are essential for understanding concepts in the Kinetic Molecular Theory (KMT). This finding contributes to existing knowledge by demonstrating that practical investigative learning enables learners to construct mental images that support the conceptual understanding of KMT while minimizing misconceptions.

The study employed a quasi-experimental design, incorporating a pre-test to assess baseline performance and a post-test aligned with M-KMT tasks. This approach demonstrates that quasi-experimental methods are essential in producing valid outcomes in educational studies. It provides a practical and rigorous means of evaluating teaching methods and generating evidence to improve learning outcomes.

The results of this study are significant because they reveal that physical sciences learners were able to grasp how reasoning functions, making lessons more concrete and meaningful. This provides evidence to physical science teachers that the PIL instructional approach effectively enhanced learners' conceptual understanding, practical skills, and spatial reasoning in M-KMT.

8. Conclusion

This study investigated how Grade 10 students' comprehension of Matter and the Kinetic Molecular Theory (KMT) was impacted by Practical Investigative Learning (PIL). The findings showed that learners' comprehension of these concepts was greatly improved by the PIL approach. Students in the experimental group consistently outperformed their peers in conceptual understanding, problem-solving, visualization, and spatial reasoning, according to baseline and post-test assessments, even though both the experimental and control groups demonstrated some improvement. The research indicates that providing students with practical, inquiry-based activities helps them build meaningful knowledge, clarify misconceptions, and relate abstract scientific ideas to real-world occurrences. Based on Dewey's Pragmatic Theory of Truth, the study demonstrates how active experimentation and inquiry-based learning promote long-term understanding and problem-solving abilities. These findings highlight the importance of teachers' pedagogical content knowledge (PCK) in creating effective learning experiences and show how incorporating PIL into physical science education can significantly enhance student achievement. Consequently, PIL is a highly effective method for teaching complex scientific concepts in secondary education.

Institutional Review Board Statement:

This study received ethical clearance from the University of Zululand's Ethics Committee (UZREC 1711 10D30) on 12th June 2023. This authorized and guided the collection of data for the research.

Transparency:

The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

Copyright:

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