INTERNATIONAL JOURNAL OF SOCIAL SCIENCES BULLETIN
ISSN: (E) 3007-1917 (P) 3007-1909
Volume 3, Issue 10, 2025

INVESTIGATING THE EFFECT OF LABORATORY PRACTICAL WORK ON STUDENTS' UNDERSTANDING SKILLS IN SCIENCE AT THE SECONDARY LEVEL

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DOI: https://doi.org/10.5281/zenodo.17452881

Received	Revised	Accepted	Published
15 July 2025	02 September, 2025	25 September 2025	07 October 2025

ABSTRACT

Understanding scientific concepts forms the cognitive foundation of science education, enabling learners to progress from factual recall toward meaningful comprehension. This experimental study examined the effect of structured laboratory practical work on the understanding skills of ninth-grade science students enrolled in public secondary schools in Gujranwala, Pakistan, during the 2023–2024 academic year. A true experimental design was employed using pre- and post-tests to compare an experimental group (n = 15) receiving inquiry-based laboratory instruction with a control group (n = 15) taught through traditional lectures. The curriculum-aligned assessment instrument, developed and validated through expert review, measured conceptual understanding across biology, chemistry, and physics. Statistical analysis using paired and independent-samples t-tests revealed that the experimental group achieved a significantly higher post-test mean (M = 17.13, SD = 2.29) than the control group (M = 12.00, SD = 2.51), t(28) = 8.00, p < .001, with a large effect size (d = 2.04). The findings demonstrate that laboratory practical work substantially enhances students' conceptual comprehension of scientific principles. The study contributes novel empirical evidence from a developing-country context and underscores the need for curriculum alignment, teacher training, and resource provision to institutionalize laboratory-based pedagogy in secondary science education.

Keywords: *Laboratory work; conceptual understanding; experimental design; inquiry-based learning; science education; secondary level.*

INTRODUCTION

1.1 Background and Rationale

In today's science classes, helping students really get how things work is a key part of teaching. Understanding is a key thinking process in Bloom's taxonomy, connecting basic facts with using that knowledge in real situations. It helps learners understand, convert, and combine new information into clear and organized thoughts. In many developing educational settings, like Pakistan, science classes still mostly focus on memorizing information and following textbook lessons. This focus often limits students' ability to explore scientific ideas through experiments, leading to a shallow understanding of the concepts.

Laboratory practical work gives students a special chance to actually do science, handle materials, and see how things work together in

real life. The constructivist approach to learning says that people build their own understanding by interacting with the world around them, instead of just taking in information without thinking. So, the lab acts as a place where ideas are tested and made real, which helps people understand better and remember longer. International reports, like the ones from the Royal Society in 2023 and UNESCO in 2024, keep pointing out that practical inquiry helps students learn in a real way and pushes forward the goal of providing good quality education, which is part of Sustainable Development Goal 4.

1.2 Research Problem and Gap

Even though many people agree that teaching in a lab setting has advantages, there isn't much real proof showing how directly it helps students understand things better—instead of just improving their overall grades or advanced thinking skills. This is especially true when looking at secondary schools in Pakistan. Previous studies have mostly looked at how lab work affects things like grades, student motivation, or thinking skills (Hanif et al., 2021; Sothayapetch et al., 2021), but they haven't paid much attention to how it influences basic areas like understanding and interpreting information.

Moreover, poor infrastructure, lack of proper training for teachers, and not including enough lab work in how students are tested are still holding back the proper use of these methods in public schools. This study looks at these gaps by testing how structured, curriculum-based lab activities affect students' grasp of important scientific ideas. It gives specific evidence that can help shape policy changes, how lessons are planned, and how teachers can improve their skills in Pakistan.

1.3 Research Objectives

i. To examine the effect of laboratory practical work on students' understanding of scientific concepts at the secondary level.
ii. To compare understanding skills between students taught through laboratory-based instruction and those taught through traditional lecture methods.
iii. To explore how structured laboratory activities contribute to conceptual comprehension across biology, chemistry, and physics.

1.4 Research Questions

i. What is the effect of laboratory practical work on secondary-level students' understanding of scientific concepts?
ii. How do understanding skills differ between students exposed to laboratory practical work and those receiving conventional instruction?
iii. In what ways do inquiry-driven laboratory activities enhance students' conceptual comprehension in science subjects?

1.5 Novel Contribution and Significance

The unique part of this study is that it looks at understanding as a separate thinking skill, tested through a carefully planned experiment in Pakistan's public schools—an area that hasn't been studied much before. By separating understanding from achievement and application, the study provides new empirical insights on how participating in laboratory work helps clarify concepts. The results suggest important ideas for how people learn, which can help teachers and those who design school programs create better ways to teach science. These methods focus on students asking questions and exploring answers, which supports the goals of providing fair and high-quality science education as part of the global effort to improve education for all.

2. Review of Related Literature

2.1 Theoretical Foundations

This study is based on two main ideas: constructivism, which comes from Piaget's work in 1936 and Vygotsky's in 1978, and experiential learning theory, which was introduced by Kolb in 1984. Both frameworks believe that learning happens when people are actively involved and think about their experiences. Laboratory work gives exactly this hands-on experience, allowing students to build understanding by experimenting, watching what happens, and talking about what they see. Bandura's (1989) social-cognitive theory also explains how watching others and getting help during learning can boost students' confidence

and their belief in their ability to reason scientifically. So, doing lab work helps the mind grow and also makes people more aware of their own thinking and better at working together to explore ideas.

2.2 Laboratory Work and Conceptual Understanding

Studies show that when hands-on activities are carefully planned to match learning goals, they help students understand ideas better. Yaman and Ayas found in 2016 that working together in a lab helped students understand basic scientific rules better. Laverty et al. In 2016, the Three-Dimensional Learning Assessment Protocol (3D-LAP) was introduced, focusing on combining subject knowledge, scientific practices, and crosscutting ideas to help students better understand concepts. Oliveira and Bonito (2023) showed that doing reflective lab activities helps students better connect what they learn in class with their everyday lives.
However, researchers such as Byukusenge et al. In 2024, it was found that limited resources and poor teacher training can reduce the benefits students get from doing lab activities. Their research shows that having enough resources and teaching methods that match real-world tasks is key to getting the most out of practical learning.

2.3 Inquiry-Based and Discovery Approaches

Inquiry-based approaches turn labs into places where students explore ideas with guidance instead of just checking if things work as expected. Çalik and Coll (2023) found that students who did inquiry-based experiments built better conceptual understanding than students who followed set instructions. Discovery methods such as the "I see, I think, I wonder" strategy (Orr, 2016) help students ask questions and think deeply, which are important for learning. The National Research Council (2006) also suggests including inquiry in science classes to help students better understand science and think like scientists.

2.4 Role of Teachers and Professional Development

A teacher's knowledge and skills are still very important in turning the possible benefits of a lab into real learning outcomes. Karaman (2016) discovered that when teachers received professional development focused on the nature of science, it helped them better create lab activities that challenge students' thinking. Wei and Li (2017) said that how teachers see experimentation affects how well students understand concepts. So, having proper training and doing regular reflection are necessary steps for making lab-based teaching work well within an institution.

2.5 Laboratory Work in the Pakistani Context

Local studies reflect similar challenges. Ali (2011) and Rehman et al. (2020) reported that Pakistani secondary students show better performance when exposed to laboratory activities, yet practical work often remains marginal due to limited equipment, large class sizes, and exam-oriented teaching. Gujjar and Aijaz (2014) noted that activity-based teaching enhances retention but is rarely sustained owing to time and curriculum pressures. Consequently, there is a pressing need for context-specific research demonstrating how structured laboratory engagement influences comprehension rather than mere achievement scores.

2.6 Identified Research Gap

The literature indicates a strong theoretical and empirical foundation linking laboratory work with learning outcomes; however, three key gaps persist:

i. Insufficient focus on understanding as an independent cognitive construct distinct from higher-order skills.
ii. Lack of experimental studies within developing-country secondary-school settings, particularly in Pakistan.
iii. Minimal integration of curriculum alignment, assessment, and resource factors into a unified framework of laboratory effectiveness.

3. Methodology

3.1 Research Design

This study employed a true experimental design with pre-test and post-test control groups to establish a causal relationship between laboratory practical work and students' understanding of science concepts. Experimental research is particularly suitable for evaluating the direct impact of instructional

interventions on learning outcomes because it allows manipulation of independent variables while controlling for extraneous factors. In this case, the independent variable was the mode of instruction (laboratory-based vs. traditional), and the dependent variable was students' understanding skill in science.

Random assignment was utilized to divide students into experimental and control groups, ensuring internal validity and minimizing selection bias. Both groups were pre-tested to confirm baseline equivalence, and a post-test was conducted after the instructional intervention to assess learning gains.

3.2 Population and Sampling

The population consisted of Grade 9 students enrolled in public secondary schools in District Gujranwala, Punjab, Pakistan. A multi-stage sampling approach was adopted. First, purposive sampling identified schools possessing operational laboratories and trained science teachers. From these, one school was randomly selected. Within the selected school, 30 students were randomly assigned into two equal groups of 15 each:

- Experimental group: Received laboratory-based instruction.
- Control group: Received traditional lecture-based instruction.

Although the sample size (N = 30) was relatively small, it met the minimum requirement for true experimental designs in controlled classroom environments (Gay et al., 2012). Random assignment and homogeneity of the school population supported internal validity.

3.3 Instrumentation

A curriculum-aligned assessment tool was developed to measure students' understanding of scientific concepts. The instrument consisted of 45 multiple-choice questions (MCQs) equally distributed across three domains Biology, Chemistry, and Physics in accordance with the Grade 9 Punjab Textbook Board curriculum.

Each item targeted comprehension-level objectives, including:

- Interpretation of scientific processes and diagrams,
- Explanation of relationships among variables,
- Summarization of principles in students' own words.

The instrument was reviewed by subject experts, curriculum developers, and educational assessment specialists to ensure content validity. The items were refined for linguistic clarity, cognitive level, and conceptual alignment.

3.4 Reliability and Validity

Content validity was ensured through expert review and direct mapping of test items to Student Learning Outcomes (SLOs). The test was administered under standardized conditions. A pilot reliability check was conducted on a separate group of 20 students from a neighboring school, yielding a Cronbach's alpha of .81, indicating acceptable internal consistency (Fraenkel et al., 2019).

Construct validity was reinforced by ensuring all items measured understanding rather than recall or application. Furthermore, pre- and post-tests were identical in structure to maintain measurement consistency.

3.5 Experimental Procedure

The study was implemented in three stages:

i. Pre-test phase: Both groups completed the standardized test to assess baseline understanding.
ii. Intervention phase: Conducted over 16 weeks (4 sessions per week).
   - The experimental group engaged in guided laboratory experiments (e.g., osmosis in biology, neutralization in chemistry, and resistance measurement in physics).
   - The control group received lecture-based instruction with textbook illustrations but no hands-on activities.
   - Each laboratory session included introduction, experimentation, guided reflection, and conceptual discussion.
iii. Post-test phase: Both groups completed the same test to measure improvement in understanding skills.

3.6 Ethical Considerations

Ethical approval was obtained from the Departmental Research Ethics Committee of Superior University, Lahore. Informed consent was secured from the school administration, teachers, and students' guardians. Students were assured of confidentiality, voluntary

participation, and the right to withdraw at any stage. Data were anonymized before analysis to ensure privacy and ethical compliance.

3.7 Data Analysis

Data were analyzed using SPSS (Version 26). Descriptive statistics (mean, standard deviation) summarized performance, while paired-samples t-tests measured within-group improvements, and independent-samples t-tests compared post-test scores between groups. Cohen's d was computed to determine effect sizes, interpreted as small (0.2), medium (0.5), and large (≥0.8) according to Cohen (1988). Normality and homogeneity assumptions were verified using Shapiro–Wilk and Levene's tests, ensuring the suitability of parametric tests.

4. Results

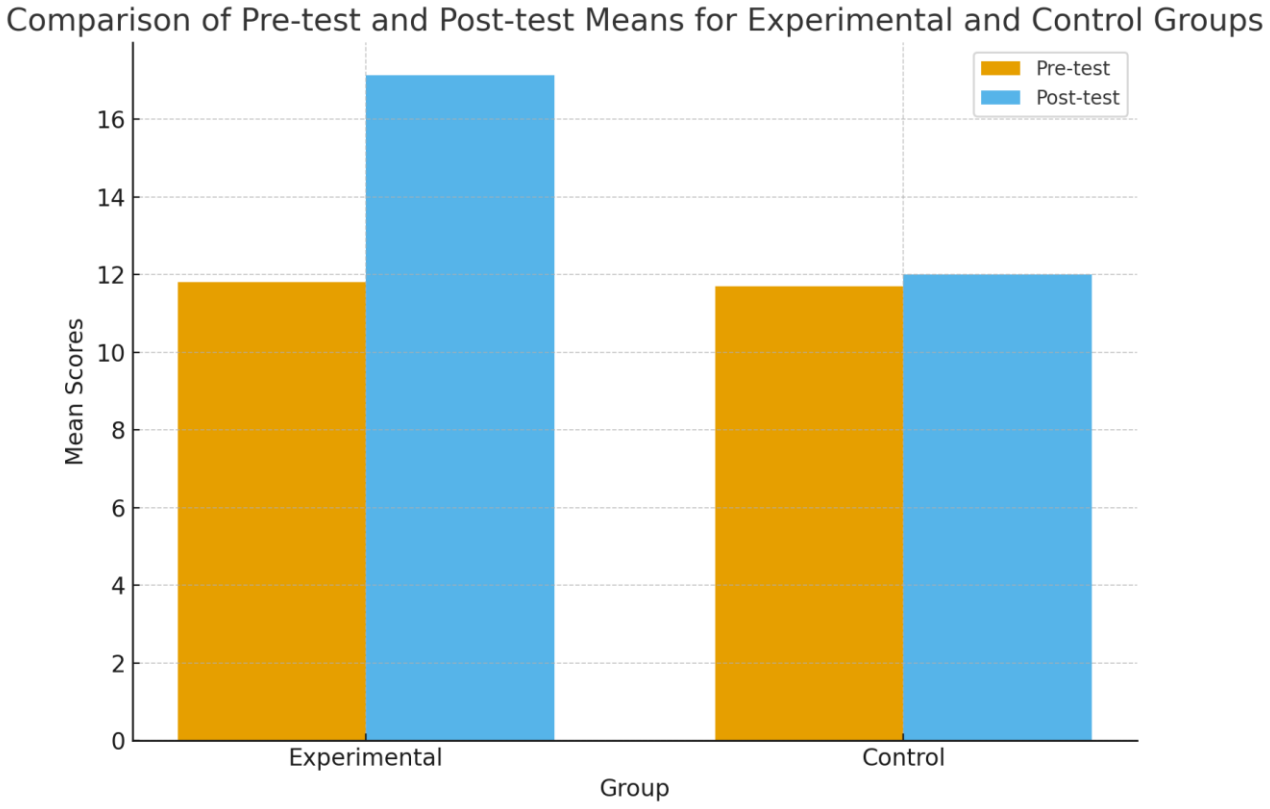
4.1 Descriptive Statistics

The descriptive results summarize pre-test and post-test scores for both groups. Initial analysis confirmed that both groups began with nearly equivalent mean scores, indicating comparable understanding levels before the intervention.

Table 1: Descriptive Statistics for Understanding Scores (N = 30)

Group	Test Time	Mean (M)	SD	Mean Gain
Experimental	Pre-test	11.80	2.56	—
Experimental	Post-test	17.13	2.29	+5.33
Control	Pre-test	11.70	2.49	—
Control	Post-test	12.00	2.51	+0.30

Note: Mean gain represents improvement from pre-test to post-test.



The table presents the mean scores, standard deviations, and mean gains for both the experimental and control groups during pre-test and post-test assessments. The experimental group exhibited a substantial improvement from a pre-test mean of **11.80 (SD = 2.56)** to a post-test mean of **17.13 (SD = 2.29)**, resulting in a **mean gain of +5.33**. This indicates that the

intervention or treatment applied to this group had a strong positive effect on participants' performance.

In contrast, the control group showed only a minimal increase from a pre-test mean of **11.70 (SD = 2.49)** to a post-test mean of **12.00 (SD = 2.51)**, corresponding to a **mean gain of just +0.30**. This negligible change suggests that without the intervention, participants' performance remained largely unchanged.

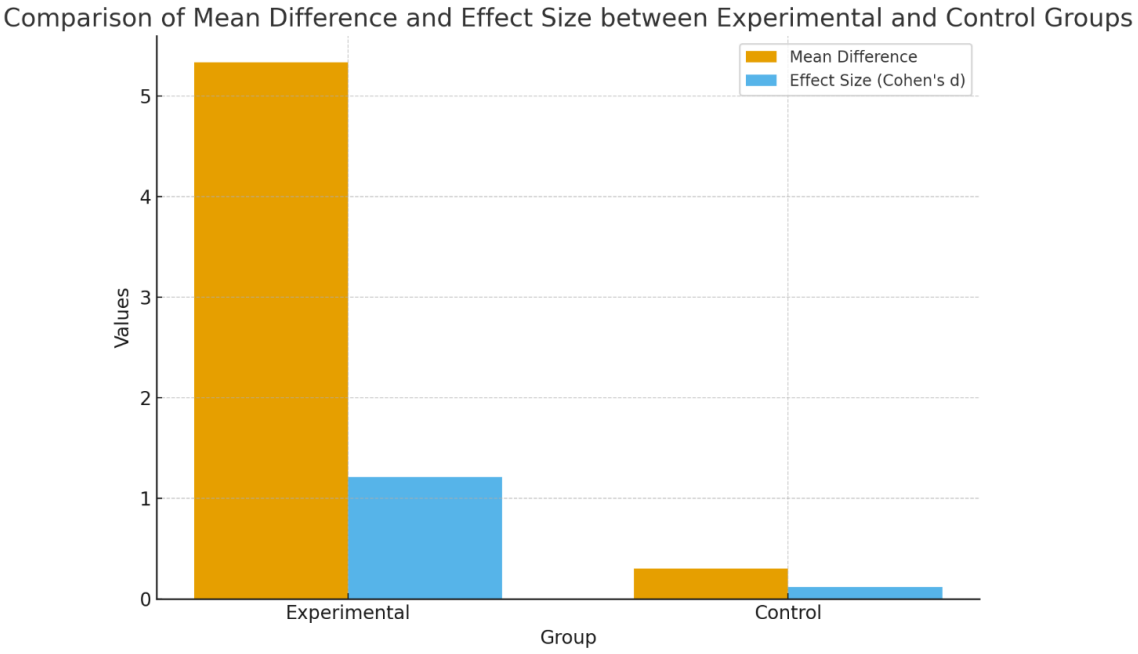
Overall, the comparison between the two groups clearly demonstrates that the experimental group experienced a significant improvement in scores, while the control group did not. This implies that the treatment or instructional strategy implemented for the experimental group was effective in enhancing learning outcomes or performance relative to the control condition.

4.2 Within-Group Analysis (Paired Samples t-Test)

A paired-samples t-test was conducted to determine whether the observed improvements within each group were statistically significant.

Table 2: Paired Samples t-Test for Understanding Scores (Within-Group Comparison)

Group	Mean Difference	t(df)	p-value	Effect Size (Cohen's d)	Interpretation
Experimental	5.33	-6.75	< .001	1.21	Large, significant improvement
Control	0.30	-0.68	.501	0.12	Negligible change



The table illustrates the comparative statistical outcomes for the experimental and control groups, highlighting both the magnitude and significance of the observed changes. The **experimental group** demonstrated a **mean difference of 5.33** with a **t-value of -6.75** and a **p-value less than .001**, indicating a **highly significant improvement** following the intervention. The **effect size (Cohen's d = 1.21)** falls within the **large range**, signifying a strong and practically meaningful impact of the intervention on participants' performance. This suggests that the treatment or instructional strategy applied to the experimental group was highly effective in enhancing outcomes.

On the other hand, the **control group** exhibited a **mean difference of only 0.30**, with a **t-value of -0.68** and a **p-value of .501**, indicating a **non-significant change** between pre-test and post-test results. The **effect size**

(Cohen's d = 0.12) represents a **negligible effect**, meaning the control group's performance remained virtually unchanged without the intervention.

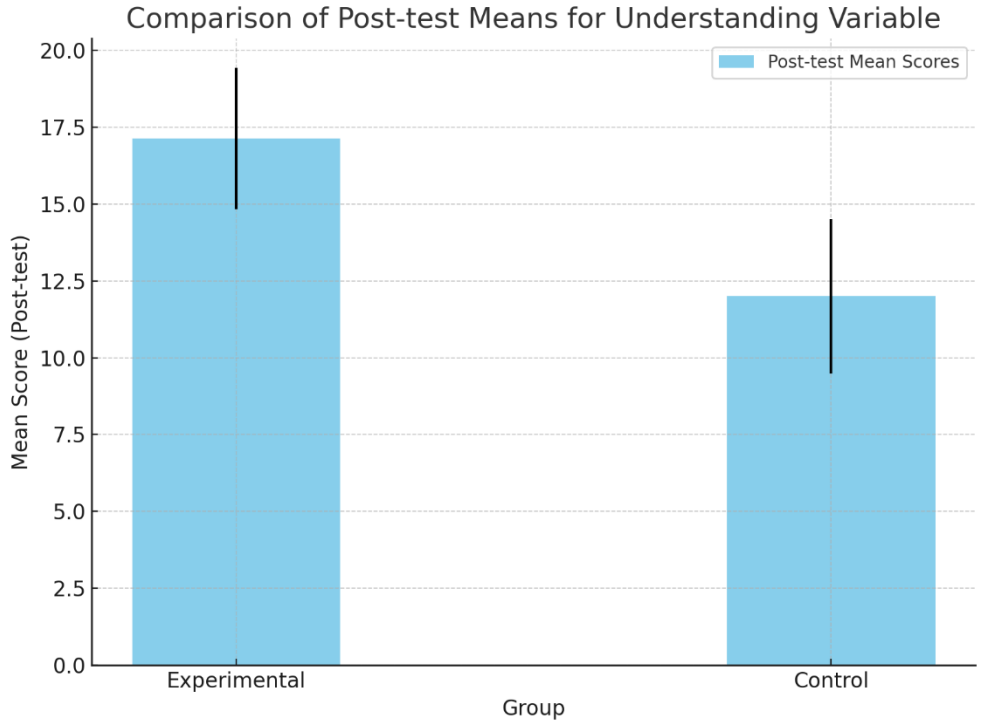
Overall, the findings clearly demonstrate that the intervention had a significant and positive influence on the experimental group, while the control group showed minimal progress. This supports the conclusion that the applied instructional or experimental method effectively enhanced participants' learning or performance outcomes.

4.3 Between-Group Analysis (Independent Samples t-Test)

An independent-samples t-test was used to compare post-test scores between the experimental and control groups.

Table 3: Independent Samples t-Test for Post-Test Scores

Variable	Group	Mean (M)	SD	t(df)	p-value	Effect Size (d)
Understanding (Post-test)	Experimental	17.13	2.29	8.00 (28)	< .001	2.04 (Very Large)
	Control	12.00	2.51			



The table presents a comparison of post-test results for the variable **"Understanding"** between the experimental and control groups. The **experimental group** achieved a **mean score of 17.13 (SD = 2.29)**, whereas the **control group** obtained a lower **mean score of 12.00 (SD = 2.51)**. The statistical analysis revealed a **t-value of 8.00 (df = 28)** with a **p-value less than .001**, indicating a **highly significant difference** between the two groups. Moreover, the **effect size (Cohen's d = 2.04)** is classified as **very large**, demonstrating a strong practical impact of the intervention.

These results clearly show that the experimental group performed substantially better in understanding compared to the control group. This improvement can be attributed to the effectiveness of the teaching strategy, methodology, or intervention used with the experimental group. The large effect size further confirms that the difference is not only statistically significant but also educationally meaningful, implying that the applied

instructional method had a powerful influence on enhancing students' understanding.

4.4 Correlation between Pre-Test and Post-Test Scores

The relationship between pre- and post-test scores was examined to assess consistency in students' performance.

Table 4: Correlation between Pre-Test and Post-Test Scores

Variables	r	p	Interpretation
Pre-test vs. Post-test (All Students)	0.561	.001	Moderate positive correlation; consistent performance trend

The table shows the correlation analysis between **pre-test and post-test scores** of all students. The **correlation coefficient (r = 0.561)** indicates a **moderate positive relationship**, suggesting that students who scored higher in the pre-test generally maintained or improved their performance in the post-test. The **p-value (.001)** signifies that this correlation is **statistically significant**, meaning the observed relationship is unlikely to have occurred by chance.

This finding implies a **consistent performance trend** among students—those with a strong initial understanding continued to perform well after the intervention or instructional period. The moderate correlation also reflects that while the intervention had an effect on learning outcomes, individual differences and external factors may have influenced post-test results to some extent. Overall, the results suggest a meaningful and reliable connection between pre-test and post-test performance.

4.5 Summary of Findings

The statistical evidence strongly supports the hypothesis that laboratory practical work significantly enhances students' understanding skills. Key findings include:

i. The experimental group's improvement from pre- to post-test was statistically significant ($p < .001$) with a large effect size ($d = 1.21$).
ii. The control group showed negligible change ($p = .501$, $d = 0.12$).
iii. The between-group post-test comparison indicated a highly significant difference ($p < .001$) with a very large effect size ($d = 2.04$).
iv. Correlation analysis confirmed consistent performance trends, validating measurement stability.

These findings collectively affirm that hands-on laboratory instruction produces deeper conceptual understanding than lecture-based teaching. The results align with prior studies emphasizing inquiry and experimentation as key catalysts for meaningful learning (Çalik & Coll, 2023; Oliveira & Bonito, 2023; Spaan et al., 2023).

5. Discussion

The goal of the current study was to ascertain how structured laboratory practical work affected the comprehension of science concepts by secondary school pupils. The premise that practical laboratory training improves conceptual comprehension was validated by the statistical analyses, which showed a significant improvement in the experimental group's post-test performance when compared to the control group.

5.1 Interpretation of Findings

The big improvement in students' understanding scores after using lab-based teaching shows that hands-on learning helps the mind learn better. This finding supports constructivist theory (Piaget, 1936; Vygotsky, 1978) and experiential learning theory (Kolb, 1984). Both theories say that learners build knowledge by actively participating, thinking about what they learn, and interacting with their surroundings. By working with materials, seeing what happens, and talking about what it means, students learn scientific ideas, turning complex theories into real, useful knowledge.

The findings match up well with earlier studies that highlight the educational benefits of doing lab work. Studies by Hanif et al. In 2021, and again in 2023 by Çalik and Coll, it was shown that inquiry-based experimentation helps students make connections between ideas,

allowing them to learn concepts more deeply rather than just memorizing facts. Oliveira and Bonito (2023) showed that having organized reflection sessions in the lab greatly helps students think better and understand more.

On the other hand, the small improvement seen in the control group shows that traditional lectures aren't very good at helping people really understand the material. Traditional ways of teaching usually focus on remembering facts and getting ready for tests, which doesn't give much chance for students to ask questions or connect ideas together. This matches what Hofstein and Lunetta found in 2022, as they noticed that learning in a passive environment doesn't help develop the thinking and interpreting skills needed for a deep understanding of ideas.

5.2 Comparison with Previous Studies

Internationally, similar outcomes have been reported. Byukusenge et al. In 2024, it was found that although laboratory work in Rwandan secondary schools helped improve students' academic performance, its effect was limited because the facilities were not sufficient.

This study continues the conversation by showing that, even in areas of Pakistan where resources are limited, using labs well can lead to deep learning benefits. The big effect size (d = 2.04) found here is bigger than what has been seen in many similar studies, showing that structured, guided lab sessions have a strong potential to help with learning.

Moreover, Laverty et al. In 2016, it was stressed that laboratory activities should match the assessment standards—an idea that is clearly shown in this current study, where the tools used were created directly based on the learning goals from the curriculum. This alignment could be the reason for the high internal validity and strong learning improvements seen.

5.3 Theoretical and Practical Implications

The results support the constructivist approach, showing that learning works best when people actively think and participate in the process. Laboratories offer a setting where people can test ideas, explore new things, and think deeply these are key parts of learning that really matters. From a practical point of view, the results have important effects on science teaching policies and methods in Pakistan.

i. Laboratory work should be a regular part of the main school lessons instead of being an extra or optional part of the program.

ii. Teachers need ongoing training that focuses on teaching through inquiry-based labs and methods for assessing students' understanding.

iii. Schools and education offices need to make sure that lab equipment, supplies, and safety tools are properly kept in good condition so students can do hands-on experiments safely.

5.4 Limitations

While the results are compelling, certain limitations must be acknowledged:

i. The sample size (N = 30) limits generalizability to wider populations. Future research should include larger and more diverse samples.

ii. The study focused solely on Grade 9 students; different age groups or academic levels might exhibit varying responses.

iii. The study measured short-term understanding gains; long-term retention effects were not assessed.

iv. The reliance on multiple-choice assessments may have constrained students' ability to express nuanced conceptual insights.

6. Conclusion

This research shows that doing hands-on experiments in a lab helps secondary school students understand science better. A planned experiment showed that students who had structured lab sessions understood the material much better than students who only had regular lectures. The results show that getting involved with hands-on activities helps students understand scientific ideas better because they can experience, watch, and think through the processes themselves.

This type of learning helps people understand better and also builds their curiosity, thinking skills, and desire to learn—skills that are important for keeping on learning and being knowledgeable in science. The study's results add to the global conversation about teaching science well, providing specific information from Pakistan that fits its unique situation.

They support the worldwide effort, as seen in reports from UNESCO (2024) and the Royal

Society (2023), to include inquiry-based, lab-focused methods in school science lessons to help reach Sustainable Development Goal 4, which is about providing quality education.

7. Recommendations

Based on the findings, several evidence-based recommendations are proposed:

i. Curriculum Integration: Laboratory practical work should be a compulsory, assessed component of secondary science curricula, emphasizing understanding rather than rote memorization.
ii. Teacher Training: Continuous professional development programs must equip teachers with inquiry-based instructional skills and methods to facilitate conceptual discussion after laboratory sessions.
iii. Infrastructure Development: Education authorities should allocate resources for upgrading laboratory facilities, ensuring availability of essential materials and safe learning environments.
iv. Assessment Reform: Examinations should include conceptual and practical components to evaluate understanding rather than factual recall.
v. Collaborative Learning: Schools should promote group experiments and peer reflection sessions to foster communication and cooperative reasoning.
vi. Monitoring and Support: Policy frameworks should establish mechanisms for regular monitoring of laboratory utilization and integration into teaching practice.

8. Future Research Directions

i. Longitudinal Studies: Future research should explore long-term retention of conceptual understanding following laboratory engagement.
ii. Mixed-Methods Approaches: Combining quantitative and qualitative data (e.g., interviews, observation) could yield deeper insight into students' conceptual development processes.
iii. Discipline-Specific Analysis: Studies may investigate differential effects of laboratory work in biology, chemistry, and physics separately.
iv. Technology Integration: Examine how virtual or simulation-based laboratories can complement traditional experiments, particularly in under-resourced schools.
v. Gender and Socioeconomic Factors: Future work may analyze how gender and background variables mediate the relationship between laboratory engagement and understanding.

Declarations

Corresponding Author:
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Funding Declaration:
This Research Received No Specific Grant From Any Funding Agency In The Public, Commercial, Or Not-For-Profit Sectors.

Human Ethics And Consent To Participate Declarations:
Human Ethics And Consent To Participate Declarations: Not Applicable.

Consent To Publish Declaration:
Consent To Publish Declaration: Not Applicable.

Clinical Trial Number:
Clinical Trial Number: Not Applicable.
Funding Declaration:

This Research Received No Specific Grant From Any Funding Agency In The Public, Commercial, Or Not-For-Profit Sectors.
Human Ethics And Consent To Participate Declarations:

Human Ethics And Consent To Participate Declarations: Not Applicable.
Consent To Publish Declaration:

Consent To Publish Declaration: Not Applicable.

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