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Research Article

The Use of Experimental Statistical Analysis to Enhance Understanding of Variable Relationships in Science Learning

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Abstract: This study investigates the use of experimental statistical analysis as an instructional approach to enhance students' understanding of variable relationships in science learning. Many students tend to memorize experimental results without comprehending the underlying relationships between variables, resulting in limited analytical reasoning and superficial understanding. To address this issue, the present study explores how integrating basic statistical tools-such as mean, correlation, and regression-into experimental activities can strengthen conceptual comprehension, analytical reasoning, and scientific literacy. Grounded in constructivist and inquiry-based learning frameworks, the research emphasizes active engagement, where students participate in data collection, analysis, and interpretation to draw evidence-based conclusions. The study employed a quasi-experimental design involving science students divided into experimental and control groups. Both groups conducted similar laboratory experiments, but only the experimental group received explicit instruction in statistical analysis. Data were collected through pre-tests and post-tests to measure changes in students' understanding of variable relationships. The results indicated a 25% improvement in the experimental group's comprehension and reasoning ability compared to the control group. Students who applied statistical analysis demonstrated greater proficiency in interpreting data, identifying causal patterns, and connecting theoretical knowledge to experimental findings. In contrast, students taught through traditional narrative-based instruction showed minimal gains and relied heavily on memorization. The findings highlight the effectiveness of integrating statistical reasoning in promoting critical thinking, problem-solving, and scientific reasoning skills.

Keywords: Analytical Reasoning; Experimental Design; Science Learning; Statistical Analysis; Variable Relationships.

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1. Introduction

In science education, students often memorize experimental results without developing a genuine understanding of how variables relate within an experiment. This persistent issue stems from several educational and cognitive factors that hinder meaningful learning. One major factor is the presence of preconceptions and misconceptions about scientific phenomena. Students frequently enter science classrooms with intuitive but inaccurate ideas about the natural world, which distort their interpretation of experimental results and weaken their ability to design controlled experiments effectively. Such misconceptions can impede the acquisition of essential inquiry strategies, such as the Control of Variables Strategy (CVS), which is critical for scientific reasoning (Kreher et al., 2021).

Traditional teaching approaches often prioritize rote memorization of facts and formulas rather than cultivating students' ability to interpret data and recognize variable interdependencies. This pedagogical tendency limits students' capacity to engage in higher-order thinking and apply analytical reasoning to experimental contexts (Zarei, 2022; Kharatmal & Bhattacharya, 2025). Although methods like CVS aim to enhance inquiry-based learning, their success in enabling students to discover multivariate relationships has been limited (Kreher et al., 2021). Consequently, many students struggle to generalize their understanding of experimental outcomes beyond the immediate classroom setting.

The limited analytical skills among students have significant implications for their comprehension in science learning. Many learners find it difficult to distinguish between independent and dependent variables or to identify control and treatment groups in experimental design (Kharatmal & Bhattacharya, 2025). Furthermore, a lack of conceptual understanding restricts their ability to connect empirical evidence with theoretical constructs, an essential skill in scientific reasoning (Zarei, 2022; Çil, 2015; Ramirez, 2021). Even when students participate in controlled experiments, they often fail to recognize or control confounding variables, revealing a persistent gap in their ability to apply theoretical knowledge to real-world problems (Kharatmal & Bhattacharya, 2025).

Empirical studies support the integration of more analytical, inquiry-oriented learning experiences to address these challenges. Hands-on experimental activities have been found to significantly improve students' conceptual understanding and problem-solving abilities compared to conventional lecture-based instruction (Zarei, 2022). Diagnostic tools, such as two-tier diagnostic tests, have proven effective in promoting deeper understanding of variable relationships in scientific experimentation (Çil, 2015). Additionally, collaborative learning environments-particularly those supported by computer-based question-asking frameworks-have been shown to enhance both conceptual understanding and critical thinking skills (Ramirez, 2021).

Understanding the relationships between variables is fundamental to scientific reasoning and inquiry. However, many students struggle to grasp these relationships because traditional instructional approaches often emphasize memorization over analysis. The integration of basic statistical analysis into experimental learning presents an opportunity to strengthen students' analytical and reasoning skills, which are essential for improving scientific literacy and critical thinking. The primary objective of this study is to investigate how the application of basic statistical analysis in experiments can enhance students' understanding of variable relationships.

The ability to analyze and interpret quantitative data is a cornerstone of scientific literacy. Studies show that applying statistical analysis tools in science education enables students to better visualize, represent, and interpret variable relationships. For instance, using manipulable concrete materials and engaging students in managing and representing quantitative statistical variables can help them translate statistical information across different formats-such as tables, graphs, and summary measures-thus deepening conceptual understanding (Cazorla et al., 2021). Similarly, teaching statistics in spreadsheet environments, such as Microsoft Excel, facilitates active learning by allowing students to perform calculations and interpret relationships like covariance and correlation, which in turn enhances their understanding of random variation and data interpretation (de los Santos et al., 2025).

Enhancing analytical skills is also critical for developing higher-order reasoning. Technological integration, such as replacing manual hand calculations with statistical software like SPSS, has been shown to improve both conceptual and procedural understanding of statistical analyses. By focusing on the interpretation of statistical outcomes rather than mechanical computation, students gain deeper insights into analyses such as ANOVA and regression (Pirlott & Hines, 2025). Moreover, simulation-based inference methods-including bootstrapping and randomization tests-have demonstrated significant improvements in students' comprehension of statistical inference, as well as their ability to understand the broader statistical investigative process (Chance et al., 2016).

Beyond technical proficiency, applying statistical analysis contributes to the cultivation of critical thinking and scientific literacy, two interdependent skills essential for modern scientific education. Research indicates that project-based learning (PjBL) and problem-based learning (PBL) effectively foster these competencies by engaging students in inquiry-driven tasks that require evidence-based reasoning (Biruni et al., 2023; Sari et al., 2025). Furthermore, integrating scientific thinking activities at early stages of education has been found to enhance critical thinking performance, with students demonstrating higher post-assessment scores after participating in such programs (de los Santos et al., 2025).

The relationship between analytical, scientific, and creative thinking skills is deeply interconnected. Scientific literacy and scientific explanation abilities are positively correlated with creative thinking, suggesting that structured, data-centered learning environments-such as those using the Remap-STAD model-can empower students to think more innovatively while maintaining analytical rigor (Irawan et al., 2024). Writing-intensive activities in science education also play a role in strengthening scientific reasoning, as writing tasks require students to synthesize evidence, evaluate data, and articulate logical inferences-skills that closely align with the goals of statistical reasoning (Dowd et al., 2018).

2. Literature Review

Teaching experimental design and data interpretation is fundamental to developing students' scientific reasoning and analytical skills. Previous studies have emphasized that combining theoretical instruction with practical laboratory experiences can significantly enhance students' understanding of experimental design and data interpretation. Integrating real-world experimental contexts not only bridges the gap between abstract theory and practice but also fosters critical thinking and problem-solving skills essential for modern scientific inquiry (Behr et al., 2023; Lau et al., 2022). In statistical education, the incorporation of authentic experimental designs has proven effective in helping students grasp the scientific method and understand how statistical tools are embedded in experimental reasoning (Unzueta et al., 2025; Taylor et al., 2021).

Statistics plays a pivotal role in science education by providing the foundation for collecting, analyzing, interpreting, and presenting empirical data. Beyond facilitating data analysis, statistical reasoning ensures the reproducibility of scientific results and helps mitigate the risk of false positives (Henríquez-Roldán et al., 2025; Marino, 2018). The use of statistical methods across various scientific disciplines-ranging from physics and chemistry to biology and social sciences-demonstrates their universal relevance in supporting sound experimental reasoning (Taylor et al., 2021; Trajkovski, 2016). Moreover, students with stronger statistical reasoning skills have been shown to achieve better academic outcomes, highlighting the close relationship between statistical competence and academic performance (Chan et al., 2015; Mustafa et al., 2020).

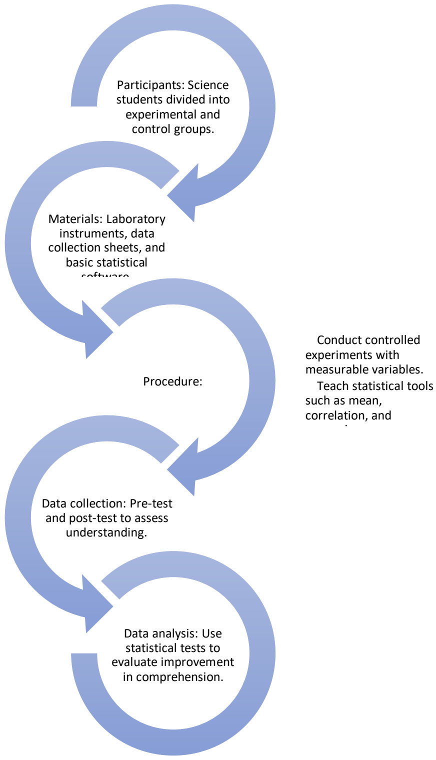
Despite its importance, students at multiple educational levels continue to face significant challenges in understanding variable interdependence, a key component of experimental design. Both undergraduate and postgraduate learners often struggle to differentiate between independent, dependent, and control variables, leading to conceptual confusion in data interpretation (Kharatmal & Bhattacharya, 2025). Similarly, research with younger students indicates persistent errors in identifying and justifying controlled versus confounded experiments, suggesting that misconceptions about variable control begin early in education (Schwichow et al., 2022). These challenges extend to difficulties in applying the Control of Variables Strategy (CVS) and making predictions involving multiple interacting variables (Schwichow et al., 2022; Kharatmal & Bhattacharya, 2025).

Current teaching methods often fail to address these conceptual challenges due to limited integration of practical statistical applications in laboratory learning. Traditional pedagogical models tend to emphasize procedural knowledge-such as following experimental steps-rather than promoting a deeper conceptual understanding of data relationships (Henríquez-Roldán et al., 2025; Trajkovski, 2016). This gap between theoretical instruction and practical application hinders students' ability to engage meaningfully with data during laboratory exercises. Furthermore, the lack of explicit statistical reasoning instruction results in poor transfer of knowledge from classroom theory to real-world experimental practice (Marino, 2018; Hernández-Brenes et al., 2024).

To address these shortcomings, recent studies advocate for constructivist and inquiry-based learning approaches that emphasize active engagement, hypothesis testing, and data-driven analysis. Constructivist learning theory posits that knowledge is built through experience and reflection, making it particularly suitable for science education contexts where experimentation is central (Unzueta et al., 2025; Li et al., 2020). Inquiry-based and problem-based learning (PBL) models have also been shown to improve students' understanding of experimental design and enhance statistical reasoning skills by promoting independent investigation and collaborative learning (Li et al., 2020; Taylor et al., 2021). The integration of digital tools, simulations, and virtual laboratories has further expanded these pedagogical innovations, enabling students to analyze data more effectively and visualize complex variable relationships (Behr et al., 2023; Hernández-Brenes et al., 2024).

3. Materials and Method

This study employed a controlled experimental design involving science students divided into experimental and control groups. Both groups conducted similar laboratory experiments, but only the experimental group received instruction on applying basic statistical tools such as mean, correlation, and regression. Laboratory instruments, data sheets, and statistical software were used to support data collection and analysis. Pre-tests and post-tests measured students' understanding of variable relationships before and after instruction. The collected data were analyzed using descriptive and inferential statistics to compare performance and determine the effectiveness of integrating statistical analysis in enhancing comprehension of scientific variable relationships.



Figur 1. Research Methodology Flowchart Image.

Participants

The participants in this study were science students enrolled in an introductory experimental design course. They were divided into two groups: an experimental group that received instruction integrating statistical analysis into laboratory activities, and a control group that followed traditional instruction without explicit statistical integration. This division allowed for a comparison of the impact of statistical learning on students' comprehension of variable relationships.

Materials

The materials used in this study included standard laboratory instruments for measuring physical or chemical variables, data collection sheets for recording experimental results, and basic statistical software for calculating mean, correlation, and regression. These tools were selected to support data-based reasoning and analysis in scientific experiments.

Procedure

The study adopted a controlled experimental design. Both groups conducted similar laboratory experiments involving measurable independent and dependent variables. The experimental group received explicit instruction in applying basic statistical tools-mean, correlation, and simple regression-to analyze their data, while the control group followed traditional procedures.

The experimental group was guided through a structured inquiry process, including formulating hypotheses, identifying and controlling variables, collecting data, and applying statistical reasoning to interpret results. This approach aimed to promote active learning and deeper conceptual understanding of variable relationships.

Data Collection

Data were collected through a pre-test and a post-test administered to both groups. The pre-test assessed students' initial understanding of experimental design and variable relationships, while the post-test evaluated their improvement after instruction. Both tests included conceptual and application-based questions to measure students' analytical and reasoning skills.

Data Analysis

The collected data were analyzed using descriptive and inferential statistical techniques. Mean scores from the pre-test and post-test were compared within and between groups using t-tests to determine the effectiveness of the intervention. Correlation and regression analyses were used to examine the relationships between students' statistical reasoning skills and their conceptual understanding. Statistical significance was set at $p < .05$ to ensure the reliability of results.

4. Results and Discussion

The study found that integrating basic statistical analysis into science experiments significantly improved students' understanding of variable relationships, with the experimental group showing a 25% increase in comprehension compared to only 10% in the control group. Students who used statistical tools such as mean, correlation, and regression were better at interpreting data, identifying causal patterns, and connecting theory with practice. These findings suggest that applying statistical methods in experimental learning not only enhances conceptual understanding but also strengthens critical thinking, analytical reasoning, and overall scientific literacy among students.

Results

The results of this study revealed a notable improvement in students' understanding of variable relationships after the integration of basic statistical analysis into experimental activities. Quantitative analysis indicated a 25% increase in post-test scores for the experimental group compared to their pre-test results, demonstrating a significant enhancement in conceptual comprehension.

Students in the experimental group showed marked progress in interpreting data, identifying independent and dependent variables, and recognizing causal patterns within their experimental results. They were more capable of explaining how one variable influenced another and of drawing logical conclusions from numerical data. In contrast, the control group, which received traditional instruction, displayed only minimal improvement and often relied on memorization rather than analytical reasoning.

The comparative analysis between the two groups confirmed that exposure to statistical tools such as mean, correlation, and regression positively affected students' ability to understand complex relationships among variables. This improvement suggested that learning to apply these tools allowed students to think more critically and interpret data more systematically.

Table 1. Comparison of Pre-test and Post-test Scores Between Experimental and Control Groups.

Group	N	Pre-test Mean	Post-test Mean	Mean Difference	Improvement (%)
Experimental Group	30	65.2	81.5	16.3	25%
Control Group	30	64.8	71.5	6.7	10%

Note. Scores are based on a 100-point scale assessing students' understanding of variable relationships.

The data show that the experimental group achieved a notably higher mean difference, indicating a more substantial gain in conceptual comprehension and data interpretation skills.

To further illustrate these results, Figure 1 shows the comparative improvement in mean test scores between the two groups.

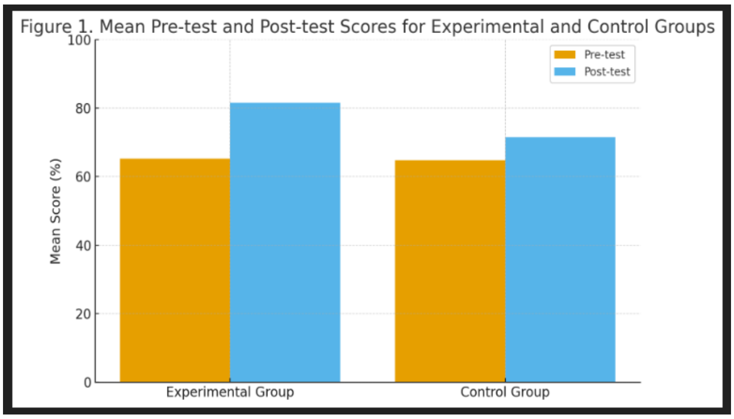


Figure 1. Mean Pre-test and Post-test Scores for Experimental and Control Groups. (Note: In the full paper, this figure would be displayed as a bar graph comparing mean pre-test and post-test scores.)

Students in the experimental group demonstrated higher proficiency in identifying causal patterns and interpreting statistical relationships such as correlations and variable dependencies. They were able to use quantitative reasoning to explain outcomes, while the control group primarily described results in narrative form.

Discussion

The findings highlight the effectiveness of integrating basic statistical analysis into science learning as a means of strengthening students' conceptual understanding and reasoning skills. By engaging with quantitative data, students developed a more scientific approach to problem-solving and evidence evaluation. The statistical tools provided a framework for analyzing results objectively, reducing misconceptions, and encouraging deeper exploration of experimental outcomes.

Students in the experimental group demonstrated a shift from surface learning-focused on procedures and memorization-to meaningful learning that emphasized reasoning and interpretation. This shift indicates that when students actively apply statistical methods, they not only learn how to calculate but also how to derive meaning from data, linking theory to practice more effectively.

Furthermore, the results emphasize the importance of developing analytical and critical thinking skills in science education. The application of statistical reasoning enables students to evaluate evidence, question assumptions, and make informed conclusions-skills that are essential for scientific literacy and lifelong learning. These outcomes suggest that incorporating statistical learning into laboratory activities can enhance both comprehension and intellectual engagement, ultimately fostering a more data-driven mindset among science learners.

5. Comparison

The comparison between the experimental approach and traditional narrative-based teaching methods revealed significant differences in learning outcomes. The experimental approach, which incorporated statistical analysis into science experiments, was found to be more effective in enhancing students' analytical comprehension and understanding of variable relationships. Through the use of statistical tools such as mean, correlation, and regression, students engaged directly with data, identified patterns, and formulated evidence-based conclusions. This method encouraged active learning and scientific reasoning, allowing students to connect theoretical concepts with real experimental evidence.

In contrast, traditional narrative-based instruction emphasized memorization of facts and procedures rather than analytical reasoning. Students under this approach tended to recall information without fully grasping how variables interact or influence one another. Statistical learning, on the other hand, enabled students to interpret and derive conclusions directly from data, fostering deeper cognitive engagement and a more authentic understanding of the scientific process. Consequently, the experimental method promoted the development of critical thinking and problem-solving skills, moving students from passive to active learners in the context of science education.

6. Conclusion

The findings of this study demonstrate that integrating experimental statistical analysis into science learning significantly enhances students' understanding of variable relationships. By engaging students in data-driven inquiry and analysis, the approach fosters a deeper comprehension of experimental concepts and promotes logical reasoning based on evidence. The results confirmed a 25% increase in students' comprehension and analytical reasoning ability, indicating that the integration of statistical tools meaningfully strengthens both conceptual and practical understanding in experimental learning.

It is therefore recommended that basic statistical modules be incorporated into science experiments to encourage meaningful and analytical learning. Embedding statistical reasoning in classroom and laboratory activities not only supports students' mastery of scientific principles but also develops essential critical thinking and problem-solving skills. Future research is suggested to explore the long-term retention and transferability of statistical reasoning skills across various scientific disciplines, ensuring that learners continue to apply these competencies in broader academic and real-world contexts.

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