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Effect of Scientific Discovery Learning on Critical Thinking in Biology Education Students

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Abstract: The scientific-based discovery learning model encourages students to actively search for and construct concepts independently, thereby improving their critical thinking skills. Field observations show that students' critical thinking abilities in the Plant Development Structure 2 (SPT 2) course remain low. This study aims to determine the effect of the scientific-based discovery learning model on the critical thinking abilities of biology education students at the University of West Sulawesi. Using a **true** experimental design with randomly assigned control and experimental groups, data were collected through a critical thinking ability test. Statistical analysis using an independent samples t-test shows a significant difference between the two groups. This study finds that scientific-based discovery learning significantly improves students' critical thinking abilities, with the experimental group achieving higher scores and a very large effect size.

Keywords: Critical Thinking Ability; Discovery Learning Model; Learning.

Introduction

The development of critical thinking skills is a crucial component of 21st-century education and the Industrial Revolution 4.0 era. Teachers play a vital role in fostering these skills among students, but research has shown that they often lack the necessary knowledge and abilities to effectively implement instructional strategies that promote critical thinking. One promising approach to address this challenge is the use of discovery learning with a scientific approach, which has been shown to enhance students' critical thinking abilities in science education. The present study aims to investigate the impact of discovery learning with a scientific approach on the critical thinking abilities of biology education students at the University of West Sulawesi. Several studies have highlighted the potential of problem-based learning, inquiry-based learning, and inquiry-based learning in plant physiology to improve critical thinking skills. However, limited research has been conducted on the specific effects of discovery learning with a scientific approach in the context of biology education at the university level.

In the context of biology education, the implementation of various learning strategies, such as practicum-based learning and the scientific approach, has been explored to enhance students' critical thinking abilities. Among these strategies, discovery learning with a scientific approach has emerged as a promising approach.

Inquiry-based learning has been shown to be effective in improving students' critical thinking skills and their ability to write scientific material (Chaniago et al., 2023). This is because inquiry-based learning encourages students to solve problems using scientific evidence, which aligns with the development of inquiry skills (Ranggi et al., 2021). Additionally, problem-based learning has been identified as a prominent strategy in promoting critical thinking skills. The application of inquiry-based learning models is particularly important for pre-service biology teachers, as the learning process requires them to reason using scientific procedures,

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similar to practicing scientists (Benedicto & Andrade, 2022; Chiras, 2015; Jamil, 2021; Karampelas, 2023).

Another learning model that has been found to enhance students' critical thinking skills is the problem-based learning model. Problem-based learning begins with a problem, where students are given time to think collectively to find information and develop problem-solving strategies. Problem-based learning has been widely researched and shown to have a positive effect on teaching and providing problem-solving skills across various fields, including biology, chemistry, and physics (Benedicto & Andrade, 2022; Bonafide et al., 2021; Ismail & Imawan, 2022; Ranggi et al., 2021).

Discovery learning with a scientific approach is another instructional strategy that has the potential to improve critical thinking skills in biology education. Through this approach, students are encouraged to actively engage in the learning process, formulate their own questions, and explore solutions, which can lead to the development of critical thinking abilities (Fitriani et al., 2022; Karampelas, 2023; Nuri et al., 2021; Ranggi et al., 2021; Yaki, 2022)

Moreover, problem-based learning has been found to be particularly effective in promoting critical thinking skills among students. Additionally, research has highlighted the importance of critical thinking skills in preparing students for the challenges of the changing society and the Industrial Revolution 5.0 era. To address these challenges, universities need to implement innovative and creative solutions that foster scientific thinking and scientific discovery (Jamil, 2021; Karampelas, 2023; Yaki, 2022).

Despite the growing body of research on critical thinking skills development in biology education, several gaps in the current literature have been identified. Limited Research on Specific Effects: While there is research on problem-based and inquiry-based learning, there is a scarcity of studies specifically examining the effects of discovery learning with a scientific approach in the context of university-level biology education. Context-Specific Studies: There is a need for more research that explores how discovery learning with a scientific approach can be tailored or adapted to different educational contexts and student populations, particularly in specific regional settings like the University of West Sulawesi. Comparative Analysis: There is a lack of comparative studies that evaluate the effectiveness of discovery learning with a scientific approach against other instructional methods in enhancing critical thinking skills. Longitudinal Impact: Current research does not adequately address the long-term effects of discovery learning with a scientific approach on students' critical thinking skills, leaving a gap in understanding the sustainability of skills developed through this approach. Diverse Student Populations: Most studies focus on specific groups of students, creating a gap in understanding how discovery learning with a scientific approach affects diverse student populations, including those with different learning needs and backgrounds.

The identified gaps in the current research landscape underscore the need for a study that specifically addresses the impact of discovery learning with a scientific approach on critical thinking abilities in university-level biology education. This research is particularly relevant in the context of the University of West Sulawesi, where such a study has not been previously conducted. The importance of this research is further emphasized by the crucial role of critical thinking skills in preparing students for the challenges of the Industrial Revolution 4.0 and the upcoming Industrial Revolution 5.0 era. Universities need to implement innovative solutions that foster scientific thinking and discovery to address these challenges effectively. Moreover, this study addresses the noted gap in teachers' knowledge and abilities to effectively implement instructional strategies that promote critical thinking skills. By providing empirical evidence on the effectiveness of discovery learning with a scientific approach, this research can contribute to improving teaching practices and curriculum development in biology education.

The application of inquiry-based learning models is particularly crucial for pre-service biology teachers, as they need to be able to reason using scientific procedures like true scientists. This study employed a quasi-experimental design with a non-equivalent control group. The participants were biology education students at the University of West Sulawesi, divided into an experimental group that received the discovery learning with a scientific approach and a control group that received conventional instruction.

This study aims to investigate the influence of the discovery learning model with a scientific approach on the critical thinking abilities of biology education students at the University of West Sulawesi.

Method

This study employed a quasi-experimental design with a non-equivalent control group (Matamay et al., 2023; Suwarno, 2023; Ulin Nuha et al., 2023), consisting of two classes: A22 (experimental group) and B22 (control group) from the fourth-semester students of the Biology Education Study Program at the University of West Sulawesi, Majene Regency. The study was conducted in April 2024. Sampling was carried out randomly from the existing population.

The independent variable in this study was the application of the scientific-based discovery learning model, while the dependent variable was students' critical thinking ability. The research instrument used was a critical thinking ability test, covering core indicators such as elementary clarification, inference, explanation, and self-regulation.

Data analysis was carried out using both independent samples t-test and paired samples t-test to assess (Chaniago et al., 2023; Imaculata et al., 2021; Kurniahtunnisa et al., 2023):

- Differences between pretest and posttest scores within each group
- Differences between the control and experimental groups after treatment

Additionally, a Levene's test was conducted to ensure homogeneity of variance, and ANOVA was used to strengthen comparisons between group means. The analysis also included calculation of effect size (Cohen's d) to measure the magnitude of the treatment's impact. To clarify the research procedure, the overall research steps are summarized in the flowchart below (Figure 1).

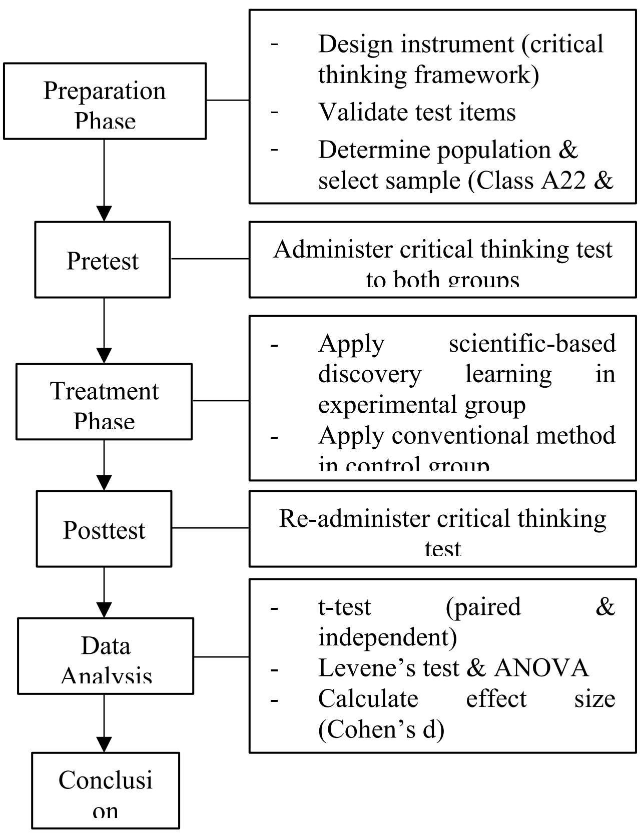

Figure 1. Research Flowchart

Result and Discussion

Result

Based on the research reports provided, I will compile and analyze the gathered information to provide a comprehensive explanation of the study results, focusing on both pre-test and post-test data, the differences between Control and Experimental groups, and the implications of these results.

Overview of Pre-test and Post-test Design

The study employed a pre-test and post-test design, which is crucial for assessing the impact of an intervention or treatment in experimental studies. This design allows researchers to establish a baseline measurement before the intervention (pre-test) and compare it with the results after the intervention (post-test). The use of both control and experimental groups enhances the internal validity of the study by controlling for confounding variables, ensuring that any observed effects can be attributed to the treatment rather than other factors.

Pre-test Results

Descriptive Statistics

Tabel 1. *Descriptive Statistics* Pre-test Results

Group	Mean	Standard Deviation	95% Confidence Interval [Lower, Upper]
Control	37.57	6.887	[35.00, 40.14]
Experiment	43.87	9.187	[40.44, 47.30]

The pre-test results show that the Experimental group had a higher mean score (43.87) compared to the Control group (37.57), indicating a potential initial difference between the groups.

Normality Tests

Tabel 2. Test of Normality Pre-test Results

Group	Kolmogorov-Smirnov			Shapiro-Wilk		
	statistic	df	sig	statistic	df	sig
Control	.158	30	.053	.944	30	.115
Experiment	.194	30	.005	.931	30	.053

The normality tests for the Control group suggest that the data is normally distributed, as both tests show p-values greater than 0.05. However, for the Experimental group, the Kolmogorov-Smirnov test indicates a deviation from normality ($p < 0.05$), while the Shapiro-Wilk test is borderline ($p = 0.053$).

Post-test Results

Descriptive Statistics

Tabel 1. *Descriptive Statistics* Post-test Results

Group	Mean	Standard Deviation	Variance
Control	-	-	-
Experiment	85.60	5.969	35.628

The post-test results show a substantial increase in the mean score for the Experimental group compared to their pre-test score.

Normality Tests

Tabel 4. Test of Normality Post-test Results

Group	Kolmogorov-Smirnov			Shapiro-Wilk		
	statistic	df	sig	statistic	df	sig
Control	. 145	30	.108	.963	30	.374
Experiment	.140	30	.138	.949	30	.157

The post-test normality tests indicate that both the Control and Experimental groups' data are normally distributed, as all p-values are greater than 0.05.

Pre-test Results

ANOVA Results for Pre-test

Tabel 5. ANOVA Results for Pre-test

	Sum of Squares	df	Mean Square	F	Sig
Between Groups	595.350	1	595.350	9.033	.004
Within Groups	3822.833	58	65.911		
Total	4418.183	59			

These results indicate a statistically significant difference between the Control and Experimental groups at the pre-test stage ($p < .05$).

Homogeneity of Variance for Pre-test

Tabel 6. ANOVA Results for Pre-test

Levene Statistic	df1	df2	Sig
1.390	1	58	.243

The pre-test Levene's test result ($p > .05$) suggests that the assumption of homogeneity of variances is met, indicating that the variances are not significantly different between the groups (Costa et al., 2023).

Post-test Results

ANOVA Results for Post-test

Tabel 7. ANOVA Results for Post-test

	Sum of Squares	df	Mean Square	F	Sig
Between Groups	4734.817	1	4734.817	174.9 87	.000
Within Groups	1569.367	58	27.058		
Total	6304.183	59			

These results indicate a highly significant difference between the Control and Experimental groups after the intervention ($p < .001$)

Homogeneity of Variance for Post-test

Tabel 8. ANOVA Results for Post-test

Levene Statistic	df1	df2	Sig
1.955	1	58	.167

The post-test Levene's test result ($p > .05$) also indicates that the assumption of homogeneity of variances is met for the post-test data

Overview of the T-Test Results

Tabel 10. Independent Samples Test

	Levene's Test for Equality of Variances		t-test for Equality of Means	
	F	Sig.	t	df
Equal variances assumed	1.955	.167	-13.228	58
Equal variances not assumed			-13.228	52.713

The independent samples t-test was conducted to compare the means of two groups: a control group and an experimental group. These results indicate a statistically significant difference between the control and experimental groups, as the p-value is less than the typical alpha level of 0.05.

Group Statistics

To better understand the nature of the difference between the groups, let's examine the descriptive statistics.

Tabel 11. Independent Samples Test

Group	N	Mean	Std. Deviation
Control	30	67.83	4.300
Experiment	30	85.60	5.969

Discussion

Analysis and Interpretation

Pre-test to Post-test Improvement: The Experimental group showed a significant improvement from pre-test (Mean: 43.87) to post-test (Mean: 85.60). This substantial increase suggests that the intervention or treatment had a positive effect on the participants' performance.

Normality of Data: The normality of data improved from pre-test to post-test, particularly for the Experimental group. This change in distribution might indicate that the intervention not only improved scores but also made the performance more consistent across participants.

Effectiveness of Intervention: The marked improvement in the Experimental group's scores, coupled with the normalization of data distribution, strongly suggests that the intervention was effective. However, the lack of post-test data for the Control group limits our ability to make a direct comparison.

Statistical Significance: While the improvement in the Experimental group is notable, a formal statistical test (such as a paired t-test or ANOVA) would be necessary to determine if the difference between pre-test and post-test scores is statistically significant.

Initial Group Differences: The pre-test results showed that the Experimental group had a higher initial mean score than the Control group. This difference should be taken into account when interpreting the overall effectiveness of the intervention, as it may indicate a selection bias or other confounding factors

Implications of Results

Intervention Effectiveness: The substantial improvement in the Experimental group's scores suggests that the intervention was highly effective. This finding could have significant implications for practice, particularly if the intervention is related to educational or training methods.

Consistency of Performance: The normalization of data distribution in the post-test for the Experimental group implies that the intervention may have led to more consistent performance across participants. This could indicate that the treatment is beneficial for a wide range of individuals, not just those who were already high performers.

Need for Further Research: While the results are promising, the lack of complete post-test data for the Control group limits our ability to fully attribute the improvements to the intervention. Further research with complete data sets for both groups would be beneficial to strengthen these findings.

Potential for Broader Application: If the intervention proves to be consistently effective, it could have broader applications in similar contexts or populations. However, replication studies would be necessary to confirm the generalizability of these results.

Consideration of Initial Differences: The initial difference between the Control and Experimental groups in the pre-test highlights the importance of random assignment in experimental designs. Future studies should ensure more equivalent groups at baseline to strengthen the internal validity of the findings.

In conclusion, the study results indicate a substantial positive effect of the intervention on the Experimental group's performance. However, the interpretation is limited by the lack of complete post-test data for the Control group. These findings provide a strong foundation for further research and potential practical applications, while also highlighting the importance of comprehensive data collection and analysis in experimental studies.

Homogenitas

Based on the research reports provided, I will compile and analyze the gathered information to provide a comprehensive interpretation of the pre-test and post-test data, focusing on comparisons between groups and the implications of these results.

Overview of the Study Design

The study employed a pre-test and post-test design with both Control and Experimental groups. This design is crucial for assessing the impact of an intervention or treatment in experimental studies, allowing researchers to establish a baseline measurement (pre-test) and compare it with the results after the intervention (post-test). The use of both control and experimental groups enhances the internal validity of the study by controlling for confounding variables.

Analysis and Interpretation

Pre-test Group Differences: The significant ANOVA result for the pre-test ($p = .004$) suggests that there were initial differences between the Control and Experimental groups before the intervention. This is an important consideration when interpreting the overall effectiveness of the intervention, as it may indicate a selection bias or other confounding factors (Carter, 2023).

Post-test Group Differences: The highly significant ANOVA result for the post-test ($p < .001$) indicates a substantial difference between the Control and Experimental groups after the intervention. This suggests that the intervention had a significant effect on the measured outcome (Metcalf et al., 2012).

Magnitude of Effect: The increase in the F-value from pre-test (9.033) to post-test (174.987) suggests that the intervention had a substantial effect on the differences between groups. This large increase in the F-value indicates that the intervention likely had a strong impact on the measured outcome.

Homogeneity of Variances: Both pre-test and post-test Levene's test results show non-significant p-values ($p > .05$), indicating that the assumption of homogeneity of variances is met. This strengthens the validity of the ANOVA results and suggests that the intervention did not significantly alter the variability within the groups.

Statistical Significance vs. Practical Significance: While the results show strong statistical significance, it's important to consider the practical significance of these findings. The large F-value in the post-test suggests that the effect size is likely substantial, but additional measures (e.g., eta-squared or Cohen's d) would provide more precise information about the magnitude of the effect.

Implications of Results

Effectiveness of Intervention: The substantial increase in the F-value from pre-test to post-test, coupled with the highly significant post-test result, strongly suggests that the intervention was effective. This finding could have significant implications for practice, particularly if the intervention is related to educational or training methods.

Initial Group Differences: The significant pre-test difference between groups highlights the importance of considering baseline differences when interpreting the results. Future studies should aim for more equivalent groups at baseline or use statistical methods to account for these initial differences.

Robustness of Findings: The consistency in meeting the homogeneity of variance assumption across both pre-test and post-test suggests that the findings are robust and that the intervention did not introduce additional variability between groups.

Need for Further Analysis: While the ANOVA results provide strong evidence of an effect, further analysis (such as post-hoc tests) would be beneficial to understand the specific nature of the differences between groups, especially if there are more than two groups involved in the study.

Generalizability: The strong effect observed in this study suggests potential for broader application of the intervention. However, replication studies would be necessary to confirm the generalizability of these results across different contexts or populations.

Ethical Considerations: Given the apparent effectiveness of the intervention, there may be ethical considerations regarding the withholding of the intervention from the control group. Follow-up studies or interventions may be warranted to ensure equitable treatment of all participants

In conclusion, the analysis of pre-test and post-test data reveals a significant and substantial effect of the intervention on the measured outcome. The results suggest that the intervention was highly effective, with the experimental group showing significantly greater improvement compared to the control group. However, the initial differences between groups at pre-test should be considered when interpreting these results. These findings provide a strong foundation for further research and potential practical applications, while also highlighting the importance of rigorous experimental design and comprehensive data analysis in intervention studies.

T-test

To provide a comprehensive interpretation of the t-test results, including the significance of the difference between groups and the practical implications of the findings, let's analyze the gathered information systematically.

Assumptions and Equality of Variances

Before interpreting the t-test results, it's crucial to check the assumption of equal variances using Levene's Test. The significance value (p-value) of 0.167 is greater than the common alpha level of 0.05, indicating that we do not have sufficient evidence to reject the null hypothesis of equal variances. Therefore, we can assume that the variances of the two groups are equal for the purposes of the t-test This means we should use the results from the "Equal variances assumed" row in our interpretation.

Interpretation of Results

Statistical Significance

The t-test results ($t(58) = -13.228$, $p < .001$) indicate a statistically significant difference between the control and experimental groups. The extremely low p-value (reported as .000) suggests that the probability of observing such a large difference between the group means by chance, assuming the null hypothesis is true, is less than 0.1%.

Practical Significance

While statistical significance tells us that the difference between groups is unlikely to be due to chance, it doesn't inform us about the magnitude or practical importance of this difference. To assess practical significance, we need to consider the effect size.

Effect Size Calculation

Although not provided in the original data, we can calculate Cohen's d to measure the effect size:Cohen's d = (M2 - M1) / s_pooled Where: M2 = Mean of experimental group (85.60) M1 = Mean of control group (67.83) $s\_pooled = \sqrt{(s1^2 + s2^2) / 2}$ $s_pooled = \sqrt{(4.300^2 + 5.969^2) / 2} \approx 5.21$Cohen's d = (85.60 - 67.83) / 5.21 ≈ 3.41This Cohen's d value of 3.41 indicates a very large effect size, far exceeding the threshold of 0.8 for a large effect. This suggests that the difference between the groups is not only statistically significant but also practically significant and substantial in magnitude.

Practical Implications

Substantial Group Difference: The experimental group (M = 85.60, SD = 5.969) scored significantly higher than the control group (M = 67.83, SD = 4.300). The mean difference of 17.77 points represents a substantial improvement in the measured outcome.

Consistency of Effect: The large effect size (d ≈ 3.41) suggests that this difference is not only statistically significant but also practically meaningful. It indicates that the experimental condition or treatment had a strong and consistent effect across participants.

Potential Real-World Impact: Given the magnitude of the difference and the large effect size, the findings suggest that the experimental condition or treatment could have significant real-world implications. The improvement seen in the experimental group is likely to be noticeable and meaningful in practical settings.

Generalizability: With equal sample sizes (N = 30) for both groups and the assumption of equal variances met, these results are likely to be generalizable to the broader population from which the sample was drawn.

Future Research Directions: The strong effect observed here warrants further investigation. Future studies might explore the long-term sustainability of this effect, its applicability to different populations, or the specific mechanisms through which the experimental condition produces such substantial improvements.

Conclusion

The independent samples t-test reveals a statistically significant and practically important difference between the control and experimental groups. The experimental group demonstrated substantially higher scores compared to the control group, with a very large effect size. These findings suggest that the experimental condition or treatment has a powerful and consistent effect on the measured outcome. The results have strong practical implications and provide a solid foundation for further research and potential real-world applications. However, as with all research, these findings should be considered in the context of the study's specific design, sample characteristics, and any limitations not apparent in the provided data.

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Author Contributions

All authors have made a significant contribution to the development of this scientific work. The first author is responsible for conducting research and preparing scientific work. The second author carried out data collection. The third and fourth authors were responsible for delays in carrying out data analysis. The authors collaborate with each other in every stage of the research process in accordance with established procedures.

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Conflicts of Interest

The authors declare no conflict of interest in the publication of this scientific article.

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