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The Impact of Experimental Methods Using Hydroponic Techniques on Student Learning Outcomes in Primary School Science Education

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Abstract
This study investigates the effectiveness of the experimental method, specifically using hydroponic techniques, in improving student learning outcomes in primary school science education. A quasi-experimental design with pre-test and post-test measures was employed, involving two groups of sixth-grade students from MI NU Tamrinut Thullab Undaan Kudus, Indonesia. The experimental group engaged in hands-on hydroponic activities, while the control group received traditional lecture-based instruction. The results indicate a significant improvement in the experimental group's post-test scores (M = 89.31) compared to the control group (M = 74.33), with statistical analysis revealing a t-value of 5.85 ($p < 0.05$). Qualitative feedback from students further supports these findings, as they reported increased motivation and a deeper understanding of scientific concepts through the experimental method. This study highlights the potential of inquiry-based, hands-on learning to enhance student engagement and performance, especially in resource-limited educational settings. The findings suggest that integrating experimental methods into the science curriculum can significantly improve learning outcomes and should be considered in future educational reforms. However, the study's limitations, including a small sample size, indicate the need for further research to replicate these findings in diverse contexts.

Keywords: Experimental Method; Hydroponic Techniques; Primary School Education; Science Learning Outcomes; Student Engagement.

INTRODUCTION

The effectiveness of teaching methods significantly impacts student learning outcomes, especially in the sciences. Over the years, education researchers have emphasized the importance of active learning approaches, which foster deeper engagement and conceptual understanding. Among these methods, the experimental approach is particularly valued for its hands-on nature, providing students with opportunities to explore scientific concepts through direct experience (Kranz et al., 2023; Lestari et al., 2023; Muhamad Dah et al., 2024). This approach contrasts with traditional lecture-based teaching, which tends to focus on passive learning, where students are less involved in the learning process (Ang et al., 2021; Fischer & Hänze, 2019; Zemuy et al., 2024). In science education, particularly in subjects such as biology, chemistry, and physics, experimental learning offers unique benefits by allowing students to test hypotheses, conduct investigations, and gain practical experience (Jegstad, 2024; Syskowski et al., 2024; Xu & Ouyang, 2022).

One area in which experimental methods have shown potential is in teaching plant propagation, particularly through innovative techniques such as hydroponics. Hydroponic systems, which involve growing plants without soil by using mineral nutrient solutions, provide a practical application of scientific concepts in agriculture and environmental science (Sela Saldinger et al., 2023). These systems not only allow students to observe biological processes in real-time but also integrate principles from chemistry, physics, and ecology, making them an ideal tool for multidisciplinary science education

(Persano Adorno et al., 2021).

Despite the recognized benefits of experimental methods, traditional lecture-based approaches remain predominant in many educational settings, including primary and secondary schools in Indonesia. Research by Revina et al. (2023) highlights that teachers in Indonesian schools, particularly in rural or less resourceful areas, often rely heavily on lectures due to time constraints and the perceived simplicity of this teaching method. Moreover, teachers sometimes lack the necessary resources or training to implement experimental methods effectively (Arnaiz-Sánchez et al., 2023; Jääskä & Aaltonen, 2022; F. Li & Wang, 2024). This reliance on lecture methods has resulted in students achieving lower academic performance, particularly in science subjects, where practical application and experiential learning are essential for comprehension (Al-Tameemi et al., 2023; Liu et al., 2023).

Previous studies have explored the impact of the experimental method on student learning in various scientific fields. For instance, studies by Rossi et al. (2021) and Ješková et al. (2022) have shown that active learning techniques, such as experimental approaches, significantly improve students' conceptual understanding and retention of scientific knowledge. In the context of hydroponics, studies have emphasized that hands-on experimentation leads to better engagement, deeper learning, and enhanced problem-solving skills (Amerstorfer & Freiin von Münster-Kistner, 2021; Walter, 2024; Yannier et al., 2020). However, much of the research has been focused on higher education settings, with limited exploration of how these methods can be applied in primary school classrooms, especially in Indonesia.

The gap in research becomes evident when considering the specific challenges and opportunities of applying experimental methods in Indonesian primary schools, particularly in rural areas where access to resources and trained teachers may be limited. While previous studies have established the positive outcomes of experimental methods in science education, there is a lack of focused research on how these methods can be implemented in elementary schools to teach specific topics, such as plant propagation using hydroponic systems.

This study aims to address this gap by examining the effectiveness of experimental methods in improving student learning outcomes in science education, specifically in plant propagation with hydroponic techniques, at the primary school level. The study will compare the learning outcomes of two groups of students: one receiving instruction through the experimental method and the other through traditional lecture-based methods. By doing so, the research aims to contribute valuable insights into the practical application of experimental learning in primary education and provide evidence of its effectiveness in enhancing student engagement and achievement in science.

In summary, while the experimental method has been shown to enhance science learning outcomes in higher education, its application in primary education, especially in subjects like plant propagation, remains under-researched. The purpose of this study is to evaluate the impact of experimental methods on student learning outcomes in science, particularly focusing on plant propagation using hydroponic techniques. By addressing this research gap, the study will provide useful recommendations for improving science education in primary schools, contributing to the broader body of knowledge on effective teaching strategies in science education.

METHODS

This study employed a quasi-experimental design with a pre-test and post-test to evaluate the effectiveness of experimental methods in improving student learning outcomes in science, specifically focusing on plant propagation using hydroponic techniques. The research design was selected due to its ability to assess the cause-and-effect relationship between teaching methods and learning outcomes in real educational settings (Creswell & David, 2018). The method section outlines the research design, subjects, data collection, and data analysis procedures employed to ensure the validity and reliability of the findings.

Research Design

This research utilized a quasi-experimental design, specifically the Nonequivalent Control Group Design. This design was chosen because it allows for comparison between two groups an experimental group and a control group where participants are not randomly assigned but are selected based on existing classroom groupings (Bobrownicki et al., 2022). The use of this design in educational research is common when random assignment is not feasible, and it allows for an assessment of the effectiveness of different teaching methods in naturalistic settings (Leatherdale, 2019). In this study, the experimental group received instruction through the experimental method involving hydroponic-based activities, while the control group was taught using the traditional lecture method.

Participants

The participants in this study were 48 sixth-grade students from MI NU Tamrinut Thullab Undaan Kudus, an elementary school in Indonesia. These students were divided into two groups: an experimental group (n = 24) and a control group (n = 24). The two groups were selected based on their comparable pre-existing knowledge and homogeneity, determined by their performance in the pre-test. This ensured that any differences in post-test results could be attributed to the teaching methods rather than initial knowledge disparities. The control and experimental groups were taught by the same teacher to control for teacher-related variables.

Instruments

To assess the effectiveness of the experimental method on student learning outcomes, a variety of instruments were employed. A primary tool for evaluating student knowledge was the pre-test and post-test, which consisted of 20 items designed to measure learning outcomes in science, with a particular focus on plant propagation using hydroponic techniques. The test included a combination of multiple-choice and essay questions, aimed at evaluating both the students' understanding of key concepts and their ability to apply those concepts in practical scenarios. The validity of the test was established through expert review, where educators with expertise in science education provided feedback on the clarity and relevance of the questions, ensuring that they aligned with the learning objectives and accurately assessed the targeted knowledge.

In addition to the tests, classroom observations were conducted during both the experimental and control group sessions. The observations focused on student engagement, participation, and the extent to which students were actively involved in the learning process. An observation checklist was used to systematically record the frequency of specific behaviors, such as students working together in groups, asking questions, and engaging in problem-solving activities. These observations provided valuable insights into the differences in how the two teaching methods influenced student behavior and interaction.

Furthermore, post-intervention interviews were conducted with the teacher to gain qualitative insights into the implementation of the experimental method. These interviews explored the teacher’s perceptions of the benefits and challenges associated with using hydroponic-based activities in the classroom, as well as their reflections on the impact these activities had on student learning. The teacher’s feedback provided additional context for interpreting the quantitative data and helped to highlight the practical aspects of implementing the experimental method in primary school classrooms.

Procedures

The study was conducted over a four-week period, during which both the experimental and control groups received science lessons twice a week. In the experimental group, students engaged in hands-on activities related to hydroponic plant propagation. The teacher facilitated an inquiry-based learning environment, encouraging students to ask questions, hypothesize, and conduct experiments to understand the process of plant propagation in a hydroponic system. Students were guided to make observations, record data, and discuss their findings with peers. This approach aimed to foster active learning, critical thinking, and collaboration, with students directly involved in the scientific process. Throughout the activities, the teacher's role was that of a facilitator, providing support and direction as needed while allowing students to explore the concepts independently.

In contrast, the control group was taught using traditional lecture-based instruction. The teacher explained plant propagation using verbal explanations, supplemented by visual aids such as pictures and diagrams of hydroponic systems. The instruction focused on content delivery, with students listening to the teacher's explanations and taking notes. While some questions and answers were allowed, the learning process in the control group was predominantly passive, with limited student interaction or hands-on engagement. After both groups received their respective treatments, a post-test was administered to assess their learning outcomes. The pre-test was conducted at the beginning of the intervention to establish baseline knowledge, and the post-test was given after the intervention to measure changes in student understanding.

This structured approach ensured that both groups were exposed to similar content, with the primary difference being the method of delivery. The experimental group's active participation through the experimental method allowed for deeper engagement with the material, while the control group followed a more conventional, teacher-centered learning approach.

Data Collection

Data for this study were collected from multiple sources to ensure the robustness and comprehensiveness of the findings. The primary quantitative data were obtained from the pre-test and post-test scores, which measured changes in student learning outcomes. These tests, administered before and after the intervention, allowed for a direct comparison of the effectiveness of the experimental and control methods on students' knowledge and understanding. The data were analyzed using descriptive statistics to calculate mean and standard deviation scores for both groups. In addition to the quantitative data, qualitative data were gathered through classroom observations and teacher interviews. The observations were aimed at assessing student engagement, participation, and the application of scientific concepts in both the experimental and control groups. The researcher recorded detailed notes on the learning behaviors exhibited by students during the lessons. These observations provided valuable insights into the dynamics of the classroom and the effectiveness of the teaching methods. After the intervention, the teacher was also interviewed to gain further understanding of the teaching process. The interview focused on the teacher's experiences with implementing the experimental method, challenges faced, and perceived impacts on student learning. The qualitative data from the observations and interviews were transcribed and analyzed using thematic analysis to identify recurring themes and patterns related to the teaching methods and student outcomes. This triangulation of data sources helped to strengthen the validity of the study by providing a more comprehensive understanding of the effectiveness of the experimental method in improving student learning outcomes.

Data Analysis

The quantitative data from the pre-test and post-test were analyzed using paired sample t-tests to compare the mean scores of the experimental and control groups before and after the intervention. This analysis allowed for an assessment of the effectiveness of the experimental method in improving student learning outcomes. In addition, an independent samples t-test was conducted to compare the post-test scores between the two groups. All statistical analyses were performed using SPSS software.

For the qualitative data, thematic analysis was employed to analyze the observation notes and teacher interviews. The themes were coded based on key factors such as student engagement, participation, and the perceived effectiveness of the experimental method. This helped to triangulate the quantitative results and provide a deeper understanding of how the experimental method influenced student learning.

Ethical Considerations

Ethical approval for the study was obtained from the relevant educational authorities at MI NU Tamrinut Thullab Undaan Kudus. Informed consent was obtained from the participants' parents or guardians, and all participants were assured of confidentiality and the voluntary nature of their participation. Data were anonymized to ensure the privacy of student information.

RESULTS AND DISCUSSION

Pre-test and Post-test Comparison

The following table presents the average pre-test and post-test scores for both the experimental and control groups:

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

Group	Pre-test Average Score	Post-test Average Score	Mean Difference	t-value	p-value
Experimental Group	68.55	89.31	20.76	5.85	< 0.05
Control Group	67.85	74.33	6.48	2.15	> 0.05

Table 1 summarizes the pre-test and post-test scores for both the experimental and control groups, along with the mean difference, t-value, and p-value. The experimental group showed a significant improvement from the pre-test to the post-test, with a mean difference of 20.76 and a t-value of 5.85, which is greater than the critical value of 2.048 ($p < 0.05$). In contrast, the control group showed a smaller improvement of 6.48 with a t-value of 2.15, which did not reach statistical significance ($p > 0.05$).

Statistical Analysis of Learning Outcomes

As presented in Table 1, the experimental group exhibited a statistically significant improvement in learning outcomes, with a t-value of 5.85, which surpasses the critical value of 2.048. This result indicates that the experimental method had a substantial positive effect on students' academic performance. In contrast, the control group showed only marginal improvement, with a t-value of 2.15, which suggests that traditional lecture-based instruction was less effective in enhancing student learning outcomes. These findings further support the conclusion that active, hands-on learning strategies yield greater benefits for students compared to more conventional teaching methods.

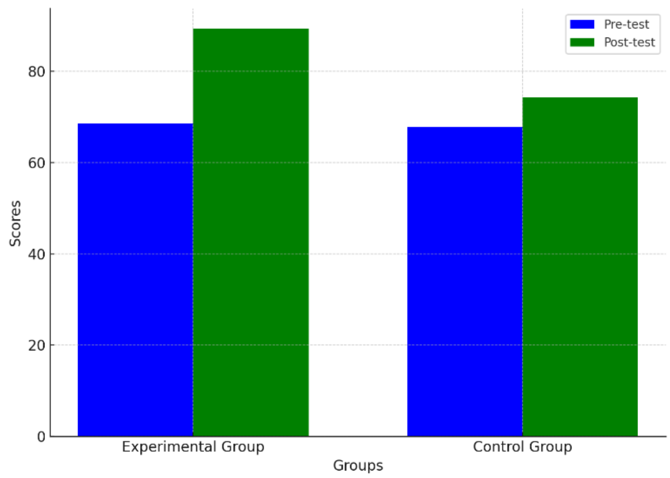

Figure 1. Comparison of Pre-test and Post-test Scores for Experimental and Control Groups

As shown in this figure, the average pre-test and post-test scores for both groups are presented. The blue bars represent the pre-test scores, while the green bars represent the post-test scores. The experimental group, which engaged in hands-on learning through hydroponic activities, demonstrated a marked improvement in scores, as seen in the substantial increase from the pre-test to post-test. In contrast, the control group, which followed traditional lecture-based instruction, showed a more modest improvement in their post-test scores.

Comparison Between Experimental and Control Groups

The comparison of average post-test scores between the two groups further supports the effectiveness of the experimental method. The experimental group, with a post-test average of 89.31, outperformed the control group, which had a post-test average of 74.33. The difference in post-test scores was not only statistically significant but also substantial, highlighting the superior effectiveness of the experimental method in improving student learning outcomes in science education.

This significant difference in performance between the two groups can be attributed to the hands-on, inquiry-based nature of the experimental method. Students in the experimental group were actively engaged in learning through hydroponic activities, which allowed them to apply theoretical concepts in a practical, real-world context. This active involvement likely contributed to the deeper understanding of plant propagation techniques, as students were able to directly observe and experiment with the scientific processes involved.

Effect of Student Engagement on Learning Outcomes

Further analysis of classroom observations and student feedback revealed that the experimental group exhibited higher levels of engagement during lessons compared to the control group. Students in the experimental group were more actively involved in the learning process, asking questions, participating in group discussions, and engaging with the material through hands-on activities. This increased engagement is consistent with previous research on the benefits of active learning strategies in improving student performance (Almoslamani, 2022; Martín-Alguacil & Avedillo, 2024; Nguyen et al., 2021).

In contrast, the control group, which primarily relied on lecture-based instruction, showed lower levels of engagement. Many students in the control group appeared passive, with limited opportunities to engage directly with the material. This lack of engagement may explain why the control group showed only a modest improvement in post-test scores.

Student Perceptions of Learning Methods

Beyond the quantitative analysis, qualitative feedback from students provided valuable insights into their perceptions of the learning methods employed in this study. Students in the experimental group consistently expressed a clear preference for the experimental method, particularly due to the hands-on nature of the learning activities. Many students reported feeling more motivated and engaged with the subject matter when they could directly interact with the content through the hydroponic systems. They highlighted that the practical experience of setting up and maintaining the hydroponic systems gave them a deeper understanding of scientific concepts, transforming abstract ideas into tangible learning experiences.

A common sentiment among students was the sense of accomplishment they felt when they successfully applied the scientific concepts learned in class to real-world scenarios. This sense of achievement was particularly pronounced when students observed the growth of plants they had cultivated using hydroponic techniques, which gave them a direct connection between theoretical knowledge and practical application. Such experiences led students to feel more confident in their scientific skills, reinforcing the idea that active participation in scientific practices fosters a sense of ownership and personal connection to the learning material.

These findings resonate with the work of Yilmaz et al. (2024), who emphasized the role of hands-on learning activities in increasing student interest and motivation in science. They argued that when students engage in real-world applications of science, it not only enhances their understanding of scientific principles but also fosters a greater interest in the subject. Additionally, studies by R. Li et al. (2023) demonstrated that active learning methods, such as experiments and interactive learning, are more effective in maintaining student motivation compared to passive lecture-based methods.

Furthermore, students in the experimental group expressed that the opportunity to work in groups and share ideas during the hydroponic activities increased their sense of collaboration and made learning more enjoyable. This aligns with the broader findings in educational research, which suggest that collaborative, hands-on activities are essential in promoting not only cognitive learning but also social and emotional growth (Eskiyurt & Özkan, 2024). By working together on hydroponic projects, students were able to discuss ideas, troubleshoot issues, and develop problem-solving skills, all of which contributed to their overall learning experience.

In contrast, students in the control group, who were primarily taught using traditional lecture-based methods, reported feeling less engaged and more passive during lessons. While they acknowledged the importance of the material, many expressed that the lack of direct interaction and practical experience made the learning process feel more distant and less meaningful. This further reinforces the idea that active learning strategies, such as the experimental method, are more effective in fostering student engagement and interest in science.

Overall, the qualitative feedback from students highlights the positive impact of the experimental method on student motivation, engagement, and perception of the subject matter. It underscores the importance of incorporating hands-on, experiential learning activities into science education to create a more dynamic, engaging, and meaningful learning experience for students.

Discussion

The results of this study clearly demonstrate the effectiveness of the experimental method in enhancing student learning outcomes in science education, specifically in plant propagation using hydroponic techniques. The experimental group showed a statistically significant improvement in their post-test scores compared to the control group, which was taught using traditional lecture-based methods. This finding aligns with previous research that supports the superiority of active learning approaches, particularly in science education (Kozanitis & Nenciovici, 2023; Markula & Aksela, 2022). The experimental method, which involved hands-on learning and real-world applications, provided students with opportunities to engage actively with the subject matter, leading to deeper understanding and improved academic performance.

The increase in student performance observed in this study can be attributed to several factors. First, the experimental method promotes active engagement, which has been shown to enhance student motivation and retention of information. Research by Gillies (2023) highlights that active learning approaches, such as inquiry-based activities and problem-solving tasks, allow students to process information more effectively, leading to better learning outcomes. In this study, students in the experimental group were able to apply theoretical concepts in a practical context, which likely helped them retain and understand the material more deeply.

The findings also support the conclusions of Kwok et al. (2021), who demonstrated that hands-on activities, such as those involving hydroponic systems, increase student interest and motivation in science. Students in the experimental group reported feeling more engaged and motivated, which reflects the broader body of literature on the positive impact of experiential learning on student attitudes toward science (Jatmiko et al., 2024; Krstić et al., 2022; Maharam, 2021). By working with the hydroponic systems, students were able to visualize and directly interact with scientific concepts, making the learning process more tangible and relevant to their everyday lives. This practical engagement helped students connect theory with practice, an important aspect of science education (Kwok et al., 2021).

Furthermore, the collaborative nature of the experimental method fostered a sense of community and teamwork among students. As they worked together on hydroponic projects, students were encouraged to share ideas, troubleshoot problems, and engage in critical thinking. These collaborative experiences have been shown to enhance both cognitive and social skills, which are essential for developing scientific inquiry abilities (Gustian et al., 2023; Harper & Neubauer, 2021; Rehman, 2023). In this study, the positive effects of collaboration were particularly evident in the experimental group, where students demonstrated higher levels of interaction and participation compared to the control group.

In contrast, students in the control group, who received traditional lecture-based instruction, showed only marginal improvements in their post-test scores. While lecture-based methods remain prevalent in many classrooms, especially in regions with limited resources or teacher training, the results of this study suggest that such methods may not be as effective in fostering deep conceptual understanding and engagement in science education. The control group's limited improvement reflects findings from previous studies that suggest traditional, passive learning approaches are less effective in promoting student engagement and learning outcomes compared to active learning strategies (Baabdullah et al., 2024; Berti et al., 2023; Bhattacharya, 2022).

One of the novel contributions of this study lies in its focus on primary school education, particularly in rural areas of Indonesia. While much of the existing literature on experimental methods focuses on higher education (Gamage et al., 2021; J. Li & Xue, 2023; Mualimin, 2022), this study extends these findings to the context of elementary school science education, a level that has received less attention. By demonstrating the effectiveness of experimental methods in improving learning outcomes at the primary school level, this research highlights the potential of active learning strategies to enhance science education across different educational contexts, including resource-limited settings.

Additionally, the use of hydroponic techniques as a teaching tool provides a fresh perspective on integrating real-world applications into science education. While hydroponics has been explored in higher education (Sela Saldinger et al., 2023), its use as an educational tool in primary schools, particularly in Indonesia, is relatively novel. This study adds to the growing body of research on innovative, hands-on methods for teaching science and underscores the importance of incorporating such techniques to make science more engaging and accessible to young learners.

Despite the positive results, several limitations of this study should be acknowledged. First, the sample size was relatively small, with only two classes participating in the study. A larger sample size would provide more robust evidence of the generalizability of the findings. Additionally, the study was conducted in a single school, which limits the applicability of the results to other schools or educational contexts. Future research should aim to replicate this study in different schools, regions, and educational settings to determine whether the positive effects of experimental methods are consistent across various contexts. Furthermore, longitudinal studies could assess the long-term impact of experimental methods on students' retention of knowledge and their continued interest in science.

In conclusion, this study provides strong evidence that the experimental method, particularly when integrated with hands-on activities such as hydroponics, is an effective approach for improving student learning outcomes in science education. The findings suggest that incorporating active, inquiry-based learning strategies into the curriculum can significantly enhance student engagement, understanding, and motivation, particularly in primary school science education. As education systems continue to evolve, the adoption of such methods will be crucial in fostering a generation of students who are not only knowledgeable but also motivated and capable of applying scientific principles in real-world contexts.

CONCLUSION

This study demonstrates the effectiveness of the experimental method, particularly through hands-on hydroponic activities, in improving student learning outcomes in primary school science education. The experimental group, engaged in inquiry-based learning, showed significant improvement in post-test scores compared to the control group, which followed traditional lecture-based instruction. These findings highlight the superiority of active learning strategies in fostering student engagement and enhancing understanding of scientific concepts. The novel contribution of this study lies in its focus on primary school education in a rural Indonesian context, where experimental methods are rarely utilized due to resource limitations. The successful implementation of hydroponic techniques as an educational tool underscores the potential of hands-on learning to enhance science education in under-resourced environments. The implications of these findings suggest that integrating hands-on, real-world applications into the science curriculum can significantly improve student motivation, engagement, and comprehension. Educators and policymakers should consider adopting such methods to strengthen science education, particularly in resource-constrained settings. However, the study has limitations, including a small sample size and a lack of diversity in the sample. Future research should replicate these findings with larger, more diverse cohorts and explore the long-term impact of experimental methods on learning outcomes. Additionally, future studies could investigate how these methods influence other skills, such as collaboration and critical thinking.

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