Exploring the Guided Inquiry Learning Model in Biology Practicum: Its Impact on Students' Scientific Attitudes and Cognitive Knowledge

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Article Info

Article history:

Received Apr 14, 2025
Revised May 14, 2025
Accepted Jun 9, 2025
Online First Jun 22, 2025

Keywords:

Cognitive Knowledge
Food Testing Practicum
Guided Inquiry Learning
Prior Knowledge Control
Scientific Attitude

ABSTRACT

Purpose of the study: The purpose of this study was to determine the differences in scientific attitudes and cognitive knowledge of students between guided inquiry and direct learning models in practical activities by controlling students' prior knowledge.

Methodology: This quasi-experimental study employed a Non-Equivalent Pretest-Posttest Control Group Design. From a population of 88 students, 57 were selected using purposive sampling. Instruments included multiple-choice tests and Likert scale observation sheets. Data were analyzed using Microsoft Excel and IBM SPSS 23 with One-Way MANCOVA and Partial Eta Squared for effect size.

Main Findings: The guided inquiry learning model is effective in improving students' scientific attitudes and cognitive knowledge. The average scientific attitude of students in the experimental class was 85, compared to 70 in the control class. The average post-test cognitive knowledge score was 75.17 in the experimental class and 50.93 in the control class. The One Way MANCOVA test showed significant differences between groups ($p = 0.0001$; partial eta squared = 0.840). Partial eta squared is a measure of effect size that indicates the proportion of variance in the dependent variables explained by the independent variable. A value of 0.840 suggests a large effect, meaning the learning model had a strong influence on students' outcomes.

Novelty/Originality of this study: This study integrates guided inquiry learning into food testing on the digestive system topic, uniquely controlling prior knowledge to examine its impact on scientific attitudes and cognitive outcomes, thus enhancing inquiry-based learning insights.

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1. INTRODUCTION

Scientific attitude is an attitude that has characteristics, namely always wanting to find out how the environment is, having an open mind to all views, and having the belief that there will be consequences and causes for every event. Scientific activities can train students to have elements of scientific attitudes such as, polite attitudes, daring to ask questions, giving opinions, having curiosity, being sensitive to the environment, a spirit of cooperation, being open to each other, being careful, diligent, creative, liking innovation, always being critical in thinking, disciplined, objective and having a very high work ethic [1], [2]. These elements are closely linked to character education because the attitudes developed through science learning are also reflected in an individual's character [3], [4]. Science education in schools provides opportunities for teachers to help shape these positive character traits in students [5]-[7]. Science learning carried out in schools can be an activity that helps teachers shape students' character [8], [9].

Character education embedded in the curriculum aims to improve educational outcomes and the quality of the learning process. The goal is to foster noble morals and balanced, integrated character aligned with the Graduate Competency Standards for each educational unit [10], [11]. The curriculum encourages students to observe, ask questions, and reason based on the knowledge they have acquired [12], [13]. Through a competency- and character-based curriculum, students are expected to use their knowledge actively while internalizing and personalizing values such as noble morals and integrity, which are reflected in their daily behavior.

Students with a strong scientific attitude tend to think fluently during the learning process and show a strong commitment to success, excellence, and motivation to excel academically [13], [14]. Scientific attitude is also crucial in everyday community life because it fosters decision-making based on rational considerations [15], [16]. Therefore, developing students' scientific attitudes significantly influences learning achievement, especially in biology [17], [18]. Monitoring the development of scientific attitudes requires observation based on specific indicators, often through scientific activities such as environmental observation and laboratory practicums [19], [20].

In practicum activities, students must apply scientific methods to demonstrate scientific attitudes. Practicums aim to allow students to test and apply theories using laboratory tools, thus enhancing their conceptual knowledge, scientific method skills, and scientific attitudes [21], [22]. Effective practicum implementation requires appropriate models or procedures that engage students actively in observation, investigation, questioning, data collection, and communicating their findings [23], [24]. Learning models during practicum activities help students discover and solve problems, thereby fostering their scientific attitudes [25], [26].

The ultimate goal of any learning process is to achieve learning outcomes, which include changes in attitudes, skills, habits, knowledge, understanding, and appreciation. These outcomes are often categorized into cognitive (concept understanding), affective, and psychomotor (process understanding) domains [27], [28]. Students who achieve satisfactory learning outcomes demonstrate higher grades and visible engagement in the learning process. Success in learning depends on developing both knowledge and attitudes [29]-[31].

In the last five years, many studies have examined the effectiveness of guided inquiry learning models in improving scientific attitudes and student learning outcomes. For example, Rahmawati et al. [32], found that guided inquiry significantly improved students' science process skills, although it did not significantly interact with scientific attitudes. Similarly, Simbolon and Juniar [33], reported that guided inquiry was more effective than direct learning in enhancing science process skills and learning outcomes in thermochemistry. However, most studies focus primarily on cognitive skills and science processes, with less attention to the overall impact of learning models on students' scientific attitudes. Furthermore, research that controls for students' prior knowledge when comparing guided inquiry and direct learning models remains limited.

This study addresses these gaps by evaluating differences in students' scientific attitudes and cognitive knowledge between guided inquiry and direct learning models during practicum activities, while controlling for prior knowledge. It aims to contribute to a more comprehensive understanding of how learning models affect scientific attitudes and learning outcomes holistically. This study is novel in its integrated approach, examining both learning models' effects on scientific attitudes and cognitive knowledge while considering prior knowledge variables. Previous research has often focused separately on cognitive outcomes and science process skills without adequately exploring how prior knowledge influences these results, especially regarding scientific attitudes [34], [35].

Additionally, the use of practical activities as a medium for developing scientific attitudes through guided inquiry has not been thoroughly studied. Therefore, this research offers a holistic and targeted approach by combining scientific methods, learning models, and prior knowledge roles in shaping scientific attitudes and improving student learning outcomes, particularly in science subjects. The purpose of this study was to determine the differences in students' scientific attitudes and cognitive knowledge between guided inquiry and direct learning models in practicum activities, controlling for prior knowledge.

2. RESEARCH METHOD

This study employed a quasi-experimental design with a Non-Equivalent Pretest-Posttest Control Group Design to investigate the effect of guided inquiry versus direct learning models on students' scientific attitudes and cognitive knowledge, while controlling for students' prior knowledge. The independent variable was the learning model (guided inquiry and direct learning), the dependent variables were scientific attitudes and cognitive knowledge, and the covariate was students' initial knowledge before treatment.

The population consisted of 88 eleventh-grade students from three classes at State Senior High School 8 Muaro Jambi in the 2024/2025 academic year. A purposive sampling technique was applied to select 57 students from two classes that met the criteria of similar learning conditions and no class divisions based on ability. One class (Phase F.3) served as the experimental group receiving the guided inquiry model, while the other (Phase F.2) was the control group using direct learning.

Data were collected using a multiple-choice test (20 items) to assess cognitive knowledge and a Likert-scale observation sheet (56 items) to measure scientific attitudes. The test reliability was high (α = 0.89), and observations were conducted by five trained observers during natural classroom activities.

Table 1. Scientific attitude observation sheet grid

No.	Dimension	Indicators
1.	Curiosity	1. Enthusiastic in seeking answers. 2. Pays attention to observed objects. 3. Shows enthusiasm for scientific processes. 4. Plans each step of the activity.
2.	Respect for Data and Facts	1. Objectivity. 2. Does not manipulate data. 3. Free from prejudice. 4. Makes decisions based on facts. 5. Does not mix facts with opinions.
3.	Critical Thinking	1. Proposes temporary findings. 2. Expresses every new change or discovery. 3. Repeats conducted activities. 4. Does not easily accept facts, even minor ones.
4.	Discovery and Creativity	1. Uses facts as a basis for conclusions. 2. Presents reports differently from classmates. 3. Responds to facts with different perspectives. 4. Uses tools in an unconventional way. 5. Designs new experiments. 6. Draws new conclusions based on observation.
5.	Perseverance and Diligence	1. Continues research even after the “truth” is unclear. 2. Repeats experiments despite failures. 3. Completes activities even when peers finish earlier.
6.	Open-mindedness and Cooperation	1. Appreciates others’ opinions. 2. Willingly changes opinions if data is lacking. 3. Accepts suggestions from peers. 4. Does not always feel they are right. 5. Shows enthusiasm for alternative analyses.

The data analysis technique of this research uses descriptive and inferential statistics. First, the data analysis of the scientific attitudes of students in the experimental class and control class, the categories or levels of student scores are presented in the following table 2:

Table 2. Scores and levels achieved by students

Score (%)	Level
0%–20%	Very Weak
21%–40%	Weak
41%–60%	Fair
61%–80%	Strong
81%–100%	Very Strong

The implementation of the syntax of the learning model is obtained from the results of observations during learning. The data obtained are analyzed using the formula:

$$K = \frac{Many\ steps\ have\ been\ taken}{Total\ number\ of\ steps} \times 100\% \qquad \ldots(1)$$

The results of the percentage calculation are analyzed to determine the criteria for the implementation of the syntax of the learning model. These criteria can be seen in Table 3.

Table 3. Criteria for the implementation of learning models

Percentage (%)	Description
75 < K ≤ 100	Very Good
50 < K ≤ 75	Good
25 < K ≤ 50	Fair
0 < K ≤ 25	Poor

Data analysis included descriptive statistics and inferential statistics using Microsoft Excel and IBM SPSS 23. To test the hypotheses, a one-way Multivariate Analysis of Covariance (MANCOVA) was conducted. MANCOVA was chosen because it allows simultaneous examination of differences between groups on multiple interrelated dependent variables (scientific attitudes and cognitive knowledge) while statistically controlling for the covariate (initial knowledge) [36], [37]. This approach increases the accuracy of estimating the effect of the learning model by adjusting for prior differences between groups. The main multivariate test used was Wilks' Lambda; a significance level below 0.05 indicated meaningful differences between groups after controlling for the covariate. Additionally, effect size was reported using Partial Eta Squared to measure the proportion of variance in dependent variables explained by the independent variable, providing insight into the practical significance of the findings.

3. RESULTS AND DISCUSSION

3.1. Results of Observations on the Implementation of Learning Models

During the study, the observer also observed the learning implementation process in the experimental and control classes. Observation aims to observe the implementation of each syntax in the learning model applied in the experimental and control classes. Whether or not each syntax in the learning model is implemented is observed and written on the observation sheet. Observations were carried out by five biology education students who acted as observers. The research data is presented in the form of quantitative data by giving a score (1) if the syntax is implemented well and (0) if the syntax is not implemented or not implemented well. The data is processed and presented in the form of a percentage. Data from the observation results will be analyzed by calculating the percentage of learning implementation in both classes. Data from the results of learning observations in the experimental and control classes can be seen in Table 4:

Table 4. Implementation of the Learning Model

No.	Experimental Class		Control Class	
	Percentage (%)	Criteria	Percentage (%)	Criteria
1	100	Very Good	100	Very Good
2	100	Very Good	100	Very Good

Based on Table 4, the percentage of implementation of the learning model in both the experimental and control classes was obtained very well with a percentage of 100%, indicating that every syntax in the learning activity could be implemented optimally.

3.2. Scientific Attitude Data

Data on students' scientific attitudes were obtained through observations made by five observers during the learning process. Observations were conducted twice in both the experimental class and the control class based on the number of learning meetings. Assessment of students' scientific attitudes was conducted using a Likert scale, with categories: (4) Always; (3) Often, (2) Sometimes, (1) Never. Based on the results of the observations, the average value of students' scientific attitudes in the experimental class was 85 and the average scientific attitude in the control class was 70. The average scientific attitudes of students are shown in Figure 1.

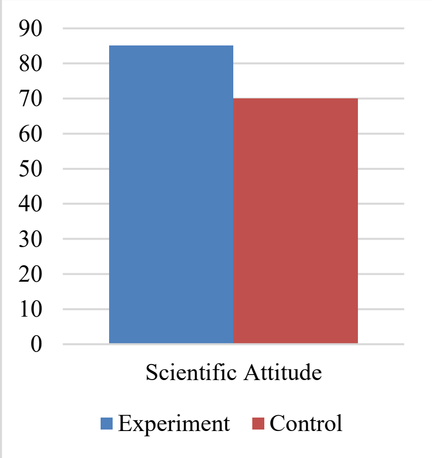

Figure 1. Average Scientific Attitude

3.3. Student Knowledge (Cognitive) Data

Student knowledge (cognitive) data was obtained from the average pre-test score and the average post-test score. The pre-test was given to the experimental class and the control class before being given treatment, to determine students' initial knowledge and the post-test was given after being given treatment to determine the effect of the treatment that had been given on students' final knowledge. Based on the results of the pre-test and post-test, the average pre-test score of the experimental class and the control class was 37.17 and 38.33. While the average post-test score of the experimental class and the control class was 75.17 and 50.93, it can be concluded that the average experimental class was higher than the control class. The average student knowledge (cognitive) score is shown in Figure 2.

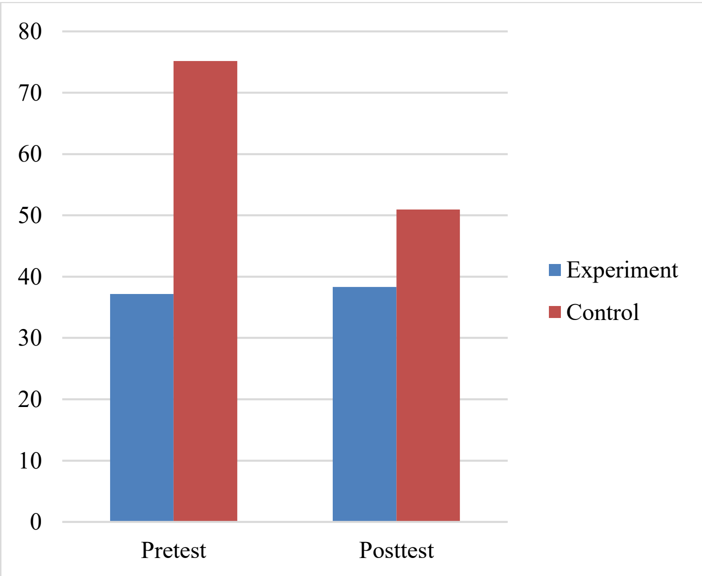

Figure 2. Average Knowledge (Cognitive) of Students

3.3. One Way Mancova Analysis Test

Linearity between dependent variables in each group of independent variables and Linearity between covariates and dependent variables, in each group of independent variables. Scatter plots are generated to analyze the linearity of the relationship between dependent variables in each group of independent variables. The scatter plot results show that the dependent variables show a linear relationship, both in the experimental class and in the control class. The significance value is compared with alpha in other tests using 0.05, and specifically for the homogeneity of the variance-covariance matrix, a very small alpha of 0.001 can be used. The resulting Box's M value is 4.619 (p = 0.218). Because the significance value of 0.218> 0.001, it can be concluded that there is homogeneity of the covariance matrix between groups or can be assumed to be the same as the record of determining Box'M> 0.001.

The homogeneity of the regression slope in each dependent variable is obtained by the p value = 0.064 scientific attitude and knowledge variables in the interaction of independent variables and covariant> 0.05. If the sig.>0.05 then the assumption of the slope of the regression line is homogeneity or fulfilled. Multivariate Normality Test on residual data using the Saphiro-Wilk Test was carried out to analyze the normality of the residual data of scientific attitude and knowledge variables. The results of the analysis inform that the residual data of the knowledge variable [W(df 57)=0.991, p=0.943] is normally distributed. Residual data is normally distributed if the sig.>0.05. However, the residual data of the scientific attitude variable [W(df 57)=0.820, p=0.0001] is not normally distributed because the sig.30 sample value is considered normal in the calculation operation involving regression, because the normality test is intended for data that has a small sample, so that data with a large sample is considered normal.

The fulfillment of the assumption test in this study can be continued with the One Way Mancova hypothesis test. The One Way Mancova test is a covariance analysis in which at least two dependent variables are measured simultaneously to test whether there is a difference in treatment of the dependent variable group adjusted for the influence of the covariate variable. Hypothesis testing using the One Way Mancova test to find out data from students, namely scientific attitude data and knowledge (cognitive) towards classes that use practicums with the Guided Inquiry model and classes that use practicums with the Direct learning model by controlling students' initial knowledge (covariates). The One Way Mancova test is used to answer problem formulations one, two, and three using the help of Microsoft Excel and SPSS 23. The results of the Tests of Between Subjects Effects test can be seen in table 5.

Table 5. Test results of Tests of Between Subjects Effects univariate test

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Model	Scientific Attitude	3379.712	1	3379.712	244.513	.000	.819
	Knowledge	8852.525	1	8852.525	67.769	.000	.557

The results of the Test of Between-Subjects Effect can be seen in the univariate effect of the model row which shows that there is a significant difference in scientific attitudes with learning models in practicum activities, with a significant difference in scientific attitudes, namely [F (1, 54) = 244.513, p = 0.0001, partial eta square = 0.819]. So it can be concluded that by considering the pre-test scores (covariates) of students, the learning model in the practicum class has an effect on students' scientific attitudes. The effect of size using the Partial Eta Square effect size because it is appropriate for the F test, namely 0.819> 0.14 (Large Effect) then it can be concluded that the effect is large. In the same way, it can be concluded on knowledge (cognitive) with significance [F (1, 54) = 67.769, p = 0.0001, partial eta square = 0.557].

So it can be concluded that by considering the pre-test value (covariate) of students, the learning model in the practicum class has an effect on students' knowledge (cognitive). The effect or not of treatment on the dependent variable is seen from the sig. <0.05 value. The large or small effect using the Partial Eta Square effect size because it is appropriate for the F test, namely 0.557>0.14 (Large Effect) then it can be concluded that the effect is large. Furthermore, for the differences in scientific attitudes and knowledge of students who received practicum treatment with a guided inquiry model and practicum with a direct learning model after controlling for initial knowledge, it can be answered using the Tests of Between Subjects Effects with the help of SPSS 23. The results of the Tests of Between Subjects Effects test can be seen in table 6.

Table 6. Results of Tests of Between-Subjects Effects (Multivariate Test)

Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Model	— Pillai's Trace	.840	138.819^{b}	2.000	53.000	.000	.840
	— Wilks' Lambda	.160	138.819^{b}	2.000	53.000	.000	.840
	— Hotelling's Trace	5.238	138.819^{b}	2.000	53.000	.000	.840
	— Roy's Largest Root	5.238	138.819^{b}	2.000	53.000	.000	.840

The results of the Between-Subjects Effect test can be seen in the multivariate effect of the model row which informs that there is a significant difference in the scientific attitudes and knowledge of students who receive practical treatment with a guided inquiry model and practical work with a direct learning model after controlling their initial knowledge [F (2, 53) = 138.819, p = 0.0001; Wilks Lambda = 0.160, partial eta squared = 0.840. The effect or not of the treatment on the dependent variable is seen from the sig. value. <0.05 which means H0 is accepted. So it can be concluded that the learning model has an effect on students' scientific attitudes and knowledge (cognitive). The large or small effect using the Partial Eta Square effect size because it is appropriate for the F test, namely 0.840> 0.14 (Large Effect) then it can be concluded that the effect is large.

This finding is in line with research by Sidiq et al.[38], who developed the GIReSiMCo model based on guided inquiry. The study found that this model significantly improved students' science process skills and cognitive learning outcomes compared to the regular inquiry model and conventional learning. In addition, research by Kang [39], showed that inquiry-based learning helps students understand science content, master scientific skills, and understand the nature of scientific knowledge. Furthermore, Hofstein et al. [40], highlights the importance of integrating inquiry teaching with an understanding of the nature of scientific inquiry, which requires a high level of self-efficacy from teachers.

Thus, the results of this study strengthen the evidence that the guided inquiry learning model has a significant and large influence on improving students' scientific attitudes and knowledge. The use of this model in science practicums can be an effective strategy to improve the quality of learning and student learning outcomes. This study presents a novelty by integrating the guided inquiry learning model in the context of food testing practicums on the digestive system material, which has previously been rarely applied systematically at the senior high school level phase F. By controlling students' prior knowledge, this study statistically shows that the guided inquiry model not only improves cognitive knowledge, but also significantly shapes students' scientific attitudes simultaneously.

The implications of these findings are very important for educators and educational policy makers, because they show that a guided inquiry-based approach is worthy of being adopted as an effective active learning strategy in biology practicum activities. However, this study has several limitations, including the limited sample size which was only taken from one school and within a certain scope of material, so that generalization of the results to a wider population still requires further studies with a more diverse scope of material, education level, and student background.

4. CONCLUSION

This study concludes that the guided inquiry learning model significantly improves students' scientific attitudes and cognitive knowledge on the digestive system material in the eleventh grade Phase F at State Senior High School 8 Muaro Jambi. The statistical test results showed a significant difference between the experimental and control groups after controlling for students' initial knowledge, with a partial eta squared value of 0.840 indicating a large effect. Therefore, the use of the guided inquiry learning model in practical activities is proven to be more effective than the direct learning model in developing scientific attitudes and enhancing students' cognitive understanding. The application of the guided inquiry model in practicum activities can serve as an alternative learning strategy capable of simultaneously fostering scientific attitudes and improving student learning outcomes. Further research is recommended to examine the effectiveness of the guided inquiry model across different educational levels, subjects, and materials by involving a larger sample to allow for more comprehensive generalization of the results.

ACKNOWLEDGEMENTS

The researcher would like to express his deepest gratitude to all parties who have provided support in the implementation and completion of this research. Special gratitude is conveyed to the Principal and Biology Teacher of State Senior High School 8 Muaro Jambi who have given permission, support, and opportunity to the researcher to conduct research at the school. The researcher also expresses his appreciation to all students of class XI Phase F who have participated actively and enthusiastically in this research process. Hopefully this research can provide a positive contribution to the world of education, especially in improving the quality of science learning through effective learning models.

AUTHOR CONTRIBUTIONS

Conceptualization, F. and L.G.F.; Methodology, F. and L.G.F.; Software, F.; Validation, F., L.G.F. and M.T.G.T.; Formal Analysis, F.; Investigation, F.; Resources, L.G.F. and M.T.G.T.; Data Curation, F.; Writing – Original Draft Preparation, F.; Writing – Review & Editing, F., L.G.F. and M.T.G.T.; Visualization, F.; Supervision, L.G.F. and M.T.G.T.; Project Administration, L.G.F.; Funding Acquisition, M.T.G.T.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

USE OF ARTIFICIAL INTELLIGENCE (AI)-ASSISTED TECHNOLOGY

Not applicable.

REFERENCES

[1] J. Miranda *et al.*, "The core components of education 4.0 in higher education: three case studies in engineering education," *Comput. Electr. Eng.*, vol. 93, no. June, 2021, doi: 10.1016/j.compeleceng.2021.107278.

[2] G. J. Hwang and S. Y. Chien, "Definition, roles, and potential research issues of the metaverse in education: an artificial intelligence perspective," *Comput. Educ. Artif. Intell.*, vol. 3, no. May, p. 100082, 2022, doi: 10.1016/j.caeai.2022.100082.
[3] Lukman *et al.*, "Effective teachers' personality in strengthening character education," *Int. J. Eval. Res. Educ.*, vol. 10, no. 2, pp. 512–521, 2021, doi: 10.11591/ijere.v10i2.21629.
[4] E. N. Setiyani, Z. Hazmi, Z. Baharin, and S. N. Jesse, "The effectiveness of predict observe explain (POE) model with phet to improve critical thinking skills of senior high school students," *J. Educ. Technol. Learn. Creat.*, vol. 1, no. 2, pp. 78–87, 2023, doi: 10.37251/jetlc.v1i2.792.
[5] C. A. Dewi, M. Erna, Martini, I. Haris, and I. N. Kundera, "Effect of contextual collaborative learning based ethnoscience to increase student's scientific literacy ability," *J. Turkish Sci. Educ.*, vol. 18, no. 3, pp. 525–541, 2021, doi: 10.36681/tused.2021.88.
[6] M. Saimon, Z. Lavicza, and T. (Noah) Dana-Picard, "Enhancing the 4Cs among college students of a communication skills course in Tanzania through a project-based learning model," *Educ. Inf. Technol.*, vol. 28, no. 6, pp. 6269–6285, 2023, doi: 10.1007/s10639-022-11406-9.
[7] P. Ayyildiz and A. Yilmaz, "'Moving the Kaleidoscope' to see the effect of creative personality traits on creative thinking dispositions of preservice teachers: The mediating effect of creative learning environments and teachers' creativity fostering behavior," *Think. Ski. Creat.*, vol. 41, p. 100879, Sep. 2021, doi: 10.1016/j.tsc.2021.100879.
[8] F. Hardiansyah and M. Mas'odi, "The implementation of democratic character education through learning of social science materials of ethical and cultural diversity in elementary school," *J. Innov. Educ. Cult. Res.*, vol. 3, no. 2, pp. 234–241, 2022, doi: 10.46843/jiecr.v3i2.101.
[9] F. Hardiansyah and Mulyadi, "Improve science learning outcomes for elementary school students through the development of flipbook media," *J. Penelit. Pendidik. IPA*, vol. 8, no. 6, pp. 3069–3077, 2022, doi: 10.29303/jppipa.v8i6.2413.
[10] M. J. Susilo and B. Kartowagiran, "Alternative curriculum model: mosque-based education integration," *J. Educ. Learn.*, vol. 17, no. 3, pp. 462–471, 2023, doi: 10.11591/edulearn.v17i3.20714.
[11] A. Asman, M. Muliani, and A. Amin, "Integration of islamic values and science in integrated Islamic boarding school-based Islamic schools," *EDUSOSHUM J. Islam. Educ. Soc. Humanit.*, vol. 5, no. 3, pp. 313–324, 2025.
[12] R. Hare, S. Ferguson, and Y. Tang, "Enhancing student experience and learning with iterative design in an intelligent educational game," *Br. J. Educ. Technol.*, no. September 2024, pp. 551–568, 2024, doi: 10.1111/bjet.13526.
[13] A. Prabowo, D. Suryadi, D. Dasari, D. Juandi, and I. Junaedi, "Learning obstacles in the making of lesson plans by prospective mathematics teacher students," *Educ. Res. Int.*, vol. 2022, 2022, doi: 10.1155/2022/2896860.
[14] B. B. Wiyono and H. H. Wu, "Increased number of scopus articles from Indonesia from 1945 to 2020, an analysis of international collaboration, and a comparison with other ASEAN Countries from 2016 to 2020," *Adm. Sci.*, vol. 12, no. 3, 2022, doi: 10.3390/admsci12030099.
[15] I. N. Tika and I. G. A. T. Agustiana, "The Effect of a Blended Learning Project Based Learning Model on Scientific Attitudes and Science Learning Outcomes," *J. Ilm. Sekol. Dasar*, vol. 5, no. 4, pp. 557–566, 2021, doi: 10.23887/jisd.v5i4.39869.
[16] A. Astalini *et al.*, "Motivation and attitude of students on physics subject in the middle school in Indonesia," *Int. Educ. Stud.*, vol. 12, no. 9, p. 15, 2019, doi: 10.5539/ies.v12n9p15.
[17] O. Kumnuanek, U. Aranyawat, and P. Pongsopon, "Study of students' moral reasoning on modern biotechnology applications using bioethics for informed decision modules," *J. Turkish Sci. Educ.*, vol. 19, no. 2, pp. 511–524, 2022, doi: 10.36681/tused.2022.134.
[18] F. Almasri, G. I. Hewapathirana, F. Ghaddar, N. Lee, and B. Ibrahim, "Measuring attitudes towards biology major and non-major: Effect of students' gender, group composition, and learning environment," *PLoS One*, vol. 16, no. 5 May, pp. 1–35, 2021, doi: 10.1371/journal.pone.0251453.
[19] L. Somerwill and U. Wehn, "How to measure the impact of citizen science on environmental attitudes, behaviour and knowledge? a review of state-of-the-art approaches," *Environ. Sci. Eur.*, vol. 34, no. 1, p. 18, Dec. 2022, doi: 10.1186/s12302-022-00596-1.
[20] M. Mohzana, H. Murcahyanto, M. Fahrurrozi, and Y. N. Supriadi, "Optimization of management of laboratory facilities in the process of learning science at high school," *J. Penelit. Pendidik. IPA*, vol. 9, no. 10, pp. 8226–8234, 2023, doi: 10.29303/jppipa.v9i10.5249.
[21] M. T. Sakliressy, W. Sunarno, and F. Nurosyid, "Students scientific attitude in learning physics using problem based learning model with experimental and project methods," *J. Ilm. Pendidik. Fis. Al-Biruni*, vol. 10, no. 1, pp. 59–70, 2021, doi: 10.24042/jipfalbiruni.v10i1.8347.
[22] D. P. Lestari, Supahar, Paidi, Suwarjo, and Herianto, "Effect of science virtual laboratory combination with demonstration methods on lower-secondary school students' scientific literacy ability in a science course," *Educ. Inf. Technol.*, vol. 28, no. 12, pp. 16153–16175, 2023, doi: 10.1007/s10639-023-11857-8.
[23] S. Korucu-Kış, "Preparing student teachers for real classrooms through virtual vicarious experiences of critical incidents during remote practicum: A meaningful-experiential learning perspective," *Educ. Inf. Technol.*, vol. 26, no. 6, pp. 6949–6971, 2021, doi: 10.1007/s10639-021-10555-7.
[24] J. Firmansyah, W. Widiasih, H. Saputra, D. Phon Kamilah, and V. Ginting, "The effectiveness of project online collaboration laboratory in improving science process and critical thinking skills," *J. Pendidik. MIPA*, vol. 25, no. 2, pp. 827–846, 2024, doi: 10.23960/jpmipa/v25i2.pp827-846.
[25] B. Wu, X. Peng, and Y. Hu, "How to foster pre-service teachers' STEM learning design expertise through virtual internship: a design-based research," *Educ. Technol. Res. Dev.*, vol. 69, no. 6, pp. 3307–3329, 2021, doi: 10.1007/s11423-021-10063-y.
[26] A. Prianto, U. N. Qomariyah, and Firman, "Does student involvement in practical learning strengthen deeper learning

competencies?," *Int. J. Learn. Teach. Educ. Res.*, vol. 21, no. 2, pp. 211–231, 2022, doi: 10.26803/ijlter.21.2.12.

[27] D. Efendi *et al.*, "The effect of virtual reality on cognitive, affective, and psychomotor outcomes in nursing staffs: systematic review and meta-analysis," *BMC Nurs.*, vol. 22, no. 1, pp. 1–15, 2023, doi: 10.1186/s12912-023-01312-x.

[28] H. J. Yun and J. Cho, "Affective domain studies of K-12 computing education: a systematic review from a perspective on affective objectives," *J. Comput. Educ.*, vol. 9, no. 3, pp. 477–514, 2022, doi: 10.1007/s40692-021-00211-x.

[29] Z. Zen, Reflianto, Syamsuar, and F. Ariani, "Academic achievement: the effect of project-based online learning method and student engagement," *Heliyon*, vol. 8, no. 11, 2022, doi: 10.1016/j.heliyon.2022.e11509.

[30] J. Kareem, R. S. Thomas, and V. S. Nandini, "A conceptual model of teaching efficacy and beliefs, teaching outcome expectancy, student technology use, student engagement, and 21st-century learning attitudes: a STEM education study," *Interdiscip. J. Environ. Sci. Educ.*, vol. 18, no. 4, p. e2282, 2022, doi: 10.21601/ijese/12025.

[31] I. V. Rossi, J. D. de Lima, B. Sabatke, M. A. F. Nunes, G. E. Ramirez, and M. I. Ramirez, "Active learning tools improve the learning outcomes, scientific attitude, and critical thinking in higher education: E experiences in an online course during the COVID-19 pandemic," *Biochem. Mol. Biol. Educ.*, vol. 49, no. 6, pp. 888–903, 2021, doi: 10.1002/bmb.21574.

[32] R. Rahayu, S. Siswanto, C. A. Ramadhanti, and B. Subali, "Guided Inquiry Learning Model Using Scientific Argumentation Activities to Improve Concept Understanding on Optical and Light," *J. Pendidik. Fis. Indones.*, vol. 19, no. 1, pp. 55–64, 2023, doi: 10.15294/jpfi.v19i1.36626.

[33] A. Juniar and D. I. Simbolon, "Effects of guided inquiry learning models in improving students' scientific process skills and learning outcomes for thermochemical materials," *9th Annu. Int. Semin. Trends Sci. Sci. Educ. 2022*, vol. 0, pp. 313–320, 2023, doi: 10.2478/9788367405195-043.

[34] Hasmawati, M. S. Ali, and M. Arsyad, "Influence of the guided inquiry learning model and scientific attitude in physics on students' science process skills," *J. Penelit. Pendidik. IPA*, vol. 9, no. 12, pp. 11484–11496, 2023, doi: 10.29303/jppipa.v9i12.4729.

[35] N. J. Hunsu, O. O. Adesope, and S. R. Yli-Piipari, "A path model analysis of preform students' factors and comprehension strategies on cognitive learning outcomes associated with text comprehension," *Front. Educ.*, vol. 9, no. April, 2024, doi: 10.3389/feduc.2024.1239261.

[36] K. P. Jayalath and H. K. T. Ng, "A graphical alternative for multiple group comparisons in analysis of covariance," *Appl. Stoch. Model. Bus. Ind.*, vol. 38, no. 6, pp. 1172–1195, Nov. 2022, doi: 10.1002/asmb.2706.

[37] G. Vallejo, M. P. Fernández, and P. E. Livacic-Rojas, "Multivariate analysis of covariance for heterogeneous and incomplete data.," *Psychol. Methods*, vol. 29, no. 4, pp. 731–747, Aug. 2024, doi: 10.1037/met0000558.

[38] M. Senisum, H. Susilo, H. Suwono, and Ibrohim, "GIReSiMCo: A learning model to scaffold students' science process skills and biology cognitive learning outcomes," *Educ. Sci.*, vol. 12, no. 4, 2022, doi: 10.3390/educsci12040228.

[39] J. Kang, "Interrelationship between inquiry-based learning and instructional quality in predicting science literacy," *Res. Sci. Educ.*, vol. 52, no. 1, pp. 339–355, 2022, doi: 10.1007/s11165-020-09946-6.

[40] R. B. Toma, I. Yánez-Pérez, and J. Á. Meneses-Villagrá, "Measuring self-efficacy beliefs in teaching inquiry-based science and the nature of scientific inquiry," *Sci. Educ.*, no. 0123456789, 2024, doi: 10.1007/s11191-024-00553-9.