BIO-INOVED
Jurnal Biologi-Inovasi Pendidikan
Volume 8, Issue 2, June 2026 page. 193-201

P-ISSN : 2684-9062 | E-ISSN : 2714-9803
https://ppjp.ulm.ac.id/journal/index.php/bino
DOI: 10.20527/bino.v8i2.25267

Enhancing critical thinking and cognitive achievement through nearpod-assisted inquiry learning in senior high school biology

Bea Hana Siswati [1] *, Meirica Eradea [1], Bevo Wahono [1], Hikmah Buroidah [1], Ika Sukmawati [2], Mohamed Izzat bin Mohamed Khalil [3]

[1] Department of Biology Education, Faculty of Education, Universitas Jember, Jember, East Java, Indonesia
[2] Department of Biology Education, Faculty of Teacher Training and Education, Universitas Tidar, Magelang, Central Java, Indonesia
[3] Department of Graphic Design and Digital Media, Faculty of Arts and Design, Universiti Teknologi MARA, Shah Alam, Selangor Darul Ehsan, Malaysia

** Corresponding Author Email: beahana.fkip@unej.ac.id*

Article Information

Keyword:
Critical thinking skills; Cognitive learning outcomes; Inquiry-based learning; Nearpod; Biology education

Kata Kunci:
Keterampilan berpikir kritis; Hasil belajar kognitif; Pembelajaran inkuiri; Nearpod; Pendidikan biologi

History:
Received : 20/01/2026
Revised : 09/05/2026
Accepted : 03/06/2026
Published : 08/06/2026

Abstract

Developing students' critical thinking skills and cognitive learning outcomes remains a challenge in biology education, particularly in classrooms where teacher-centered instruction predominates. Although inquiry-based learning is effective in enhancing higher-order thinking skills, its implementation is often hindered by low student engagement and limited use of instructional media. This study aimed to investigate the effect of Nearpod-assisted inquiry learning on senior high school students' critical thinking skills and cognitive learning outcomes in biology. In this study, a quasi-experimental non-equivalent control group design study was adopted and two intact classes in eleventh grade were involved. The experimental group was taught by inquiry learning with Nearpod integration and the control group was taught by traditional teaching. Pre- and post-test data were gathered through standardised essay tests on critical thinking and cognitive achievement and were analyzed by means of analysis of covariance. The findings revealed that students in the experimental group achieved significantly higher critical thinking skills ($F = 4.106$, $p = .048$) and cognitive learning outcomes ($F = 21.675$, $p < .001$) than those in the control group after controlling for pretest scores. These findings indicate that interactive digital platforms in inquiry-based learning can increase student engagement, facilitate scientific reasoning, and support better learning outcomes. This study confirms the potential of technology-enhanced inquiry-based learning to foster meaningful biology learning in various school contexts.

Abstrak. *Pengembangan keterampilan berpikir kritis dan hasil belajar kognitif siswa masih menjadi tantangan dalam pendidikan biologi, terutama pada kelas yang didominasi pembelajaran berpusat pada guru. Meskipun pembelajaran berbasis inkuiri efektif meningkatkan keterampilan berpikir tingkat tinggi, implementasinya sering terkendala oleh rendahnya keterlibatan siswa dan pemanfaatan media pembelajaran. Penelitian ini bertujuan untuk menganalisis pengaruh pembelajaran inkuiri berbantuan Nearpod terhadap keterampilan berpikir kritis dan hasil belajar kognitif siswa SMA pada mata pelajaran biologi. Penelitian ini menggunakan desain kuasi-eksperimen dengan kelompok kontrol nonekuivalen yang melibatkan dua kelas XI. Kelas eksperimen memperoleh pembelajaran inkuiri yang terintegrasi dengan Nearpod, sedangkan kelas kontrol mengikuti pembelajaran reguler yang diterapkan di sekolah. Data pretest dan posttest dikumpulkan melalui tes esai terstandar yang mengukur keterampilan berpikir kritis dan hasil belajar kognitif, kemudian dianalisis menggunakan analisis kovarian (ANCOVA). Hasil penelitian menunjukkan bahwa siswa pada kelompok eksperimen memperoleh keterampilan berpikir kritis yang secara signifikan lebih tinggi ($F = 4,106$; $p = 0,048$) serta hasil belajar kognitif yang lebih baik ($F = 21,675$; $p < 0,001$) dibandingkan kelompok kontrol setelah mengontrol skor pretest. Temuan ini menunjukkan bahwa platform digital interaktif dalam pembelajaran berbasis inkuiri dapat meningkatkan keterlibatan siswa, memfasilitasi penalaran ilmiah, dan mendukung hasil belajar yang lebih baik. Penelitian ini menegaskan potensi pembelajaran inkuiri berbantuan teknologi untuk mewujudkan pembelajaran biologi yang bermakna di berbagai konteks sekolah.*

© 2026 BIO-INOVED : Jurnal Biologi-Inovasi Pendidikan

A. Introduction

Enhancing students' critical thinking skills and cognitive learning has become a major focus in modern science education, especially in biology education that requires concept understanding, reasoning, and decision making based on evidence. Critical thinking is considered an essential skill for 21st century education so students can understand scientific knowledge, critically assess evidence, construct arguments and address real world issues. And these are far from trivial demands, as in Biology students are required to not only acquire knowledge of scientific concepts, they are also asked to analyse biological processes, to evaluate experimental data, and to make decisions about questions with social and environmental or health components. Therefore, biology education needs to be shifted from traditional teacher-dominated method and memorization method to the learning environment that takes students as the center and stimulates students to do research, discuss with others, and think reflectively. When students build knowledge actively, rather than assimilate information passively, when they connect new knowledge to their past experiences, when they approach learning from a meaningful perspective, and when they undergo multiple encounters with new knowledge from multiple perspectives, they have a better chance of forming more robust conceptual understanding and achieving better cognitive outcomes (OECD, 2019; OECD, 2021). Thus, promoting critical thinking and cognitive learning in biology should be a major goal of biology teaching and a natural component in the development of successful teaching methods.

Although there is such an emphasis, it is still true that much of secondary classroom practice is dominated by teacher centered teaching that provides few opportunities for pupils to question, reason and solve problems. These teaching strategies are, according to previous findings, often related to lower cognitive achievement and critical thinking skills (Soomro et al., 2025), particularly in theoretical areas of biology, for instance, the human physiological system. The problem is compounded in rural and industrial-agricultural districts where the dissemination of creative learning media and interactive teaching strategies is hard to come by.

Inquiry learning is considered to be an appropriate pedagogical strategy for overcoming challenges in biology students' critical thinking and cognitive development (Akuma & Callaghan, 2018; Arifin et al., 2025). View Full-Text Abstract: Rooted in constructivism, IBL students participate in discussions, ask questions, make predictions, test hypotheses, and draw conclusions through evidence-based practices. From these learning activities, students have been able to think critically, reason scientifically, and understand biology deeply (Harahap & Nurlina, 2021). Review of the literature Studies have consistently shown that inquiry-based learning positively affects students' critical thinking dispositions and cognitive abilities in comparison to more traditional teacher-centered methods of instruction (Fatikasari et al., 2020; Anjani et al., 2017). In addition to this, by stimulating active learning and knowledge construction, IBL offers students a way to bridge theoretical aspects of biology with practical problems found in the real world of biology. Thus, inquiry-based learning is a good candidate for an effective instructional strategy to improve critical thinking and cognitive achievement in the biology classroom.

Nevertheless, it is still difficult to apply inquiry-based learning into classrooms. Inquiry activities tend to be time-consuming and need the right scaffolding to guide students in their learning (Petersen, 2022). In case of insufficient guidance and appropriate learning material, students might need more help to conduct meaningful inquiries and thinking at the higher order level – this appears especially true for secondary educational context (Urdanivia Alarcon et al., 2023). To overcome these issues, a new line of research has been focusing on the use of digital technologies for mediating inquiry-based learning to improve student learning (Hinostroza et al., 2024). Thus, the combination of digital technologies and IBL could seem a promising approach to increasing student involvement and to enhancing the efficiency of the inquiry process.

Interactive digital learning platforms offer new opportunities to support inquiry-based instruction by facilitating student engagement, formative assessment, and immediate feedback. Among them is Nearpod, a web application which makes it possible for teachers to create interactive lessons that include multimedia content, quizzes, simulations and collaborative activities in real time. Previous research has shown that Nearpod increases student engagement, motivation, and conceptual comprehension (Ellianawati et al., 2025; Abdullah et al., 2022) by converting traditional passive learning settings into interactive learning environments. From a pedagogical perspective, Nearpod can support inquiry processes by facilitating interactive investigation, visualizing abstract concepts, and maintaining active teacher–student interaction throughout the learning process.

From a cognitive standpoint, Nearpod's may improve inquiry learning by prompting students' information processing in complex learning tasks. Based on the Cognitive Theory of Multimedia Learning (Mayer, 2020), students have better learning outcomes when verbal information is presented with relevant visual information. Interactive diagrams, animations and other multimedia tools in biology can enable students to structure and connect knowledge about complex physiological processes. Furthermore, the real-time feedback of Nearpod quizzes allows

students to assess their knowledge, detect errors and improve their reasoning during the process of inquiry. These capabilities can enable analysis and conceptual understanding that are generally not attainable with static materials alone.

Recent educational studies have started to emphasize more the importance of the use of digital technologies in inquiry-based learning environments. Research indicates technology-based inquiry learning facilitates students to develop higher order thinking skills, motivation, and learning performances in comparison to inquiry learning without technology support (Akuma & Callaghan, 2018). For instance, inquiry activities mediated by technology contributed to students' scientific reasoning and conceptual understanding with engaging learning experiences (Akuma and Callaghan, 2018). Again, he also revealed that inquiry-based science pedagogy were aided by digital learning media in motivating, thinking critically, and enhancing their academic performance. Moreover, digital inquiry-based science environments such as virtual laboratories and inquiry learning platforms can help promote an active student participation and enhance the scientific learning quality within inquiry instructions (de Jong et al., 2021). Hence, digital tools have been established as a key element of modern-day inquiry-based science education.

However, studies on technology-supported inquiry learning for teaching biology are rare. Prior research has concentrated on either general science learning environment or digital learning in generalized education setting without specifically focusing on learning biology and the idiosyncratic conceptual space of biology. In addition, only a few studies have explored the fusion of inquiry-based learning with interactive digital tools such as Nearpod to enhance students' critical thinking abilities and cognitive learning results in high school biology classes, especially in rural schools. This discrepancy is important, as biology education often calls on students to work with complex concepts while linking scientific knowledge to real-world and sustainability-related problems. The present study, therefore, investigates the use of technology-enhanced inquiry-based learning through the application of Nearpod in a rural high school biology classroom and its potential impact on students' critical thinking and cognitive learning performance.

Based on this gap, the present study positions itself as supportive of previous inquiry-based learning research while extending it through the integration of an interactive digital platform. This research is intended to investigate the influence of the NAL (Nearpod-assisted inquiry learning) model toward the critical thinking skills and cognitive learning outcomes of senior high school students in the subject of biology. Concentrating on the human circulatory system, the study attempts to provide evidence of how technology-supported inquiry learning can promote meaningful learning, promotes higher order thinking, and increases cognitive gain in biology learning. The results of this study are anticipated to enhance pedagogical practice by providing an instructional approach that is theoretically sound, as well as feasible for implementation, within a variety of school settings.

The human circulatory system was chosen as the topic of instruction because it involves intricate, dynamic processes that are challenging for students to visualize and comprehend. Students must integrate several interrelated physiological processes to understand concepts like blood flow pathways, heart chamber roles, and oxygen transport. Hence this theme is well suited for realizing the question, if (and how) technology-supported inquiry learning enhances conceptual understanding and critical thinking in biology.

B. Material and method

Research design

This study employed a quasi-experimental design using a nonequivalent control group structure to examine the effects of Nearpod-assisted inquiry-based learning on students' critical thinking skills and cognitive learning outcomes in biology. This design was considered appropriate because random assignment of students was not feasible within the existing school setting, where students were already organized into intact classes (Shadish et al., 2002; Creswell & Creswell, 2023). A pretest–posttest approach was implemented in both groups to assess baseline equivalence and strengthen the validity of treatment comparisons (Campbell & Stanley, 1963).

The participants were selected using purposive sampling. From the available eleventh-grade biology classes, two classes with comparable academic characteristics, class size, and prior biology achievement were selected in consultation with the school administration and biology teacher. One class was assigned as the experimental group, while the other served as the control group.

Participants and research context

The study was carried out at a public senior high school in the industrial–agricultural region of East Java, Indonesia in the first semester of the 2023/2024 school year. The participants were two intact classes of 11th-grade biology students. Participants were recruited through purposive sampling. Two classes of the eleventh grade were selected from the list of eleventh grade classes in discussion with the biology teacher and school management based on similarity of academic performance and class strength/pupil numbers. A class (n=28) was assigned as the experimental group while the other was the control group (n=28). A class was considered the control group and received the standard biology instruction of

the school with teacher's explanations and classroom discussions and a question and answer session. A different section was grouped as the experimental with inquiry-based learning supported by Nearpod. Each group was taught by the same teacher to ensure uniformity of content coverage and delivery of instruction across the study.

Learning intervention

The experimental class was taught by inquiry- based learning model through Nearpod platform. The activities were developed with the purpose of leading students through key phases of inquiry (problem orientation, questioning, data exploration, explanation, and conclusion drawing). Using interactive slides, quizzes, videos, multimedia visualizations and real-time feedback features, Nearpod facilitated these processes. Some examples of the Nearpod learning packs used in this research are shown in Figure 1. The control class followed the usual biology course of the school, where instruction was mostly oral explanations of the teacher, exercises based on the textbook and laboratory discussions, not involving any interactive digital technology. Both groups learned the same content (human circulatory system) and had equivalent durations of instruction.

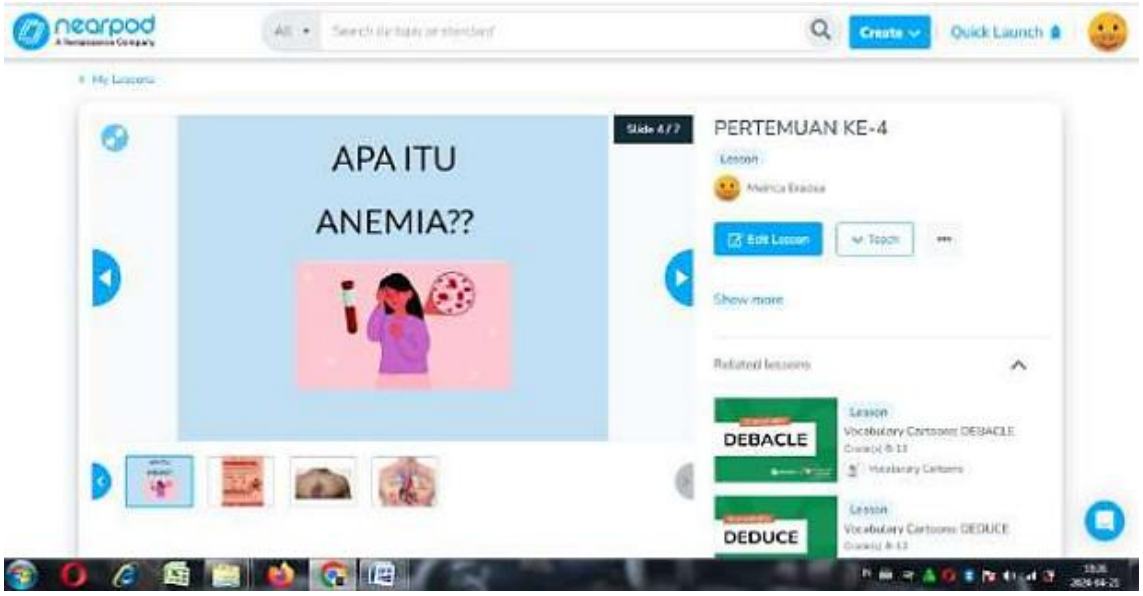

Figure 1 Example of Nearpod-supported inquiry learning materials used in the human circulatory system unit

Table 1 Analytic scoring rubric for essay-based test

Score	Criteria
3	Response is complete, scientifically accurate, well-reasoned, and supported by appropriate evidence or explanation.
2	Response is generally correct but contains minor inaccuracies or incomplete reasoning.
1	Response demonstrates limited understanding, includes major misconceptions, or provides insufficient explanation.
0	Response is incorrect, irrelevant, or left blank.

Instruments and data collection

The data was gathered through an essay-based examination intended to assess two result variables: critical thinking abilities and cognitive learning outcomes. The instrument included ten essay questions, of which five questions reflected on critical thinking (analysis, evaluation and reasoning) and five questions on cognitive learning outcomes according to the revised Bloom's taxonomy. The questions for the test have been evaluated by experts in biology education and measurement to determine the content validity and readability. Results from the expert review process were that all items were rated as valid and acceptable to assess the constructs of interest. Some modifications to wording and item clarity were made prior to the pilot testing to enhance readability. Pilot testing was conducted before the actual implementation in order to assess validity and understandability of items.

An analytic scoring rubric was used to rate student answers. Each question was rated on a 4-point scale (0-3), where 0 represents a wrong or irrelevant answer, 1 a minimal response containing significant misconceptions, 2 a somewhat right response with sufficient reasoning and 3 a full and scientifically correct answer with suitable explanations. To ensure a fair scoring, the rubric was uniformly used for all answers. Synopsis of the grading rubric can be found

in Table 1. Pretests were conducted to assess students' prior knowledge and critical thinking before the treatment and posttests were carried out following the treatment to evaluate the learning improvement.

Data analysis

The data were analyzed using one-way ANCOVA to investigate the effect of the instructional model on students' critical thinking skills and cognitive learning outcomes with the control of pretest score as covariate. For each ANCOVA, the posttest score as the dependent variable, the instructional group (experimental or control) was used as the fixed factor, and the corresponding pretest score was used as a covariate. This analysis was applied to reduce the variability at baseline between the groups and to enable better estimation of the treatment effect. Prior to the ANCOVAs, normality and homogeneity of variances were tested by using the Kolmogorov–Smirnov and the Levene tests, respectively. Analyses were conducted using IBM SPSS Statistics version 26.0. The level of significance was set at 0.05. To evaluate the magnitudes of instruction effects, partial η^2 effect sizes were also reported.

C. Results and discussion

The results of this study demonstrate that Nearpod-assisted inquiry learning had a significant effect on students' critical thinking skills and cognitive learning outcomes in senior high school biology. Before performing the hypothesis tests, descriptive statistics were reviewed to confirm the comparability of the intervention and control groups.

Descriptive statistics of students' learning outcomes

Table 2 presents the descriptive statistics of students' critical thinking skills and cognitive learning outcomes in both groups. The baseline average scores suggest that the students from the experimental and the control groups had comparable starting levels of knowledge and skills, and that differences in the posttest scores could be attributed to the instructional intervention, rather than to initial differences.

Table 2 Descriptive statistics of students' critical thinking skills and cognitive learning outcomes

Variable	Group	N	Pretest (M ± SD)	Posttest (M ± SD)
Critical thinking skills	Experimental	28	49.18 ± 8.54	68.36 ± 9.21
	Control	28	50.07 ± 8.12	63.14 ± 8.87
Cognitive learning outcomes	Experimental	28	61.43 ± 7.96	82.54 ± 8.15
	Control	28	63.21 ± 8.24	72.18 ± 8.73

Table 3 ANCOVA results for students' critical thinking skills

Source	Sum of squares	df	Mean Square	F	p	Partial η^2
Pretest	0.096	1	0.096	0.001	.979	.000
Learning model	549.861	1	549.861	4.106	.048*	.072
Error	7097.297	53	133.911	–	–	–

As shown in Table 2, both groups experienced learning gains; however, the experimental group demonstrated a greater increase in both critical thinking skills and cognitive learning outcomes. This finding suggests that embedding inquiry-based learning in an interactive digital environment was more pedagogically effective than traditional teaching methods.

Effect of Nearpod-assisted inquiry learning on critical thinking skills

To examine the statistical significance of these differences, an analysis of covariance was conducted while controlling for pretest scores. The ANCOVA results for students' critical thinking skills are presented in Table 3.

The results of ANCOVA for students' critical thinking skills after controlling for their pretest scores are shown in Table 3. The pretest covariate did not significantly predict the critical thinking performance at posttest, $F(1, 53) = 0.001$, $p = .979$, suggesting that the baseline differences did not account for much of the variability in the posttest scores. In contrast, the learning model had a significant effects on students' critical thinking skills, $F(1, 53) = 4.106$, $p = .048$, partial $\eta^2 = .072$. It means that these students who engaged in Nearpod-facilitated inquiry based learning performed significantly different in posttest critical thinking than those taught in traditional way after adjusting for the pretest results. The magnitude of the effect was medium and it suggests that the instructional intervention had a significant influence on students' critical thinking development.

While the result for critical thinking was significant, the effect size was medium (partial $\eta^2 = .072$). One reason that could explain this is the relatively short intervention period because critical thinking skills tend to require long-term and repetitive inquiry experiences to develop deeply. In addition, the relatively small sample size may have underestimated the magnitude of the differences between groups. Longitudinal studies with larger samples can confirm whether technology-supported inquiry learning is

effective in enhancing critical thinking skills in students.

Theoretical Implications From a theoretical perspective, the finding is in line with a large body of literature that argued that inquiry-based learning facilitates higher-order thinking through actively involving students in posing questions, analyzing, evaluating, and reasoning with evidence (e.g., Pedaste et al., 2015; Hmelo-Silver & DeSimone, 2013). Also, in line with the recent secondary science education study, structured inquiry tasks (using scaffolding) help students to think critically in a significant way (Chusni et al., 2022; Anderson & Krathwohl, 2001).

The integration of Nearpod appears to strengthen this effect by functioning as a pedagogical scaffold. Inquiry learning can pose cognitive challenges when students lack sufficient guidance or engagement tools (Kirschner et al., 2006). Interactive online platforms like Nearpod mitigate the aforementioned issues by displaying abstract ideas, organizing stages of questioning, and delivering real-time formative assessments. Recent studies have indicated that inquiry learning supported by technology results in greater improvements in analytical thinking than inquiry learning without technology support (Hinostroza et al., 2024; Akuma & Callaghan, 2018).

Effect of Nearpod-assisted inquiry learning on cognitive learning outcomes

The impact of the instructional model on students' cognitive learning outcomes was also examined using ANCOVA, as shown in Table 4.

Table 4 ANCOVA results for students' cognitive learning outcomes

Source	Sum of squares	df	Mean square	F	p	Partial η^2
Pretest	641.076	1	641.076	6.884	.011*	.115
Learning model	2018.517	1	2018.517	21.675	< .001*	.290
Error	4935.602	53	93.125	–	–	–

Table 4 displays the results of the ANCOVA for students' cognitive learning outcomes, controlling for the pretest scores. 3.3.2 The pretest covariate The pretest covariate had a significant effect on posttest cognitive learning outcomes, $F(1, 53) = 6.884$, $p = .011$, partial $\eta^2 = .115$, which means that students' prior knowledge explained some of the variance on their posttest performance. More notably, the learning model was significantly associated with the learning outcomes in cognitive learning, $F(1, 53) = 21.675$, $p < .001$, partial $\eta^2 = .290$. This result revealed that after adjusting for differences between pretest scores, students who engaged in Nearpod-facilitated inquiry-based learning obtained significantly greater cognitive learning outcomes as compared to those taught by the school's traditional instructional method. The magnitude of the effect was large, indicating substantial educational value of the instructional intervention on students cognitive achievement.

These results align with the work of Michael (2006), Cooper et al. (2018) that suggestion inquiry learning as active larning enhances cognitive outcomes by involving learners in searching, interpreting and integrating scientific data. Inquiry-based teaching promotes active knowledge construction by students, which is positively associated with students' conceptual understanding and long-term retention in biology education (Freeman et al., 2014; Theobald et al., 2020).

Nearpod also promotes cognitive engagement through interactive elements, such as quizzes that are integrated, multimedia visualizations, and real-time feedback. On the other hand, research studies on interactive digital learning environments indicate that these attributes positively impact students' motivation, level of engagement and academic achievement (Bond et al., 2021; Schindler et al., 2017). In the context of biology learning, it is worth noting that multimedia-supported inquiry activities can be quite efficient in developing students' understanding of complicated and abstract phenomena, such as physiological systems (Mulet et al., 2019; Mayer, 2020).

Integrated pedagogical implications

Collectively, the results shown in Tables 1–3 indicate that NQO best supported inquiry-based learning over that of the regular school class materials with regard to critical thinking and the learning of cognitive contents. This result is in line with the findings of previous works stating that the use of digital technologies in inquiry-based learning contexts has potential to develop students' higher-order thinking skills as well as academic performance. Among others, Akuoko et al. (2025) found that technology-supported inquiry-based learning activities foster scientific reasoning and conceptual comprehension of students, and Arifin et al. (2025) found that digitally-mediated inquiry learning significantly enhanced critical thinking and learning achievement. In the same manner, de Jong et al. (2021) summarized digital inquiry science as positive challenging students to think actively and construct meanings, the result of which is better learning out comes. The present findings contribute to this line of research by providing evidence for the efficacy of Nearpod-facilitated inquiry learning in high school biology, in particular in a rural educational setting. From a theoretical standpoint, these findings are consistent with constructivist perspectives of learning which posit students achieve deeper understanding when they are active producers of knowledge through inquiry, interaction, and reflection.

The interactive elements of Nearpod might have additionally contributed to this by allowing students to visualize biological processes, obtain immediate feedback, and become more involved in crafting questions. Thus, it seems that combining inquiry-based instruction with interactive digital technology serves as an effective approach for fostering higher-level thinking and academic achievement in the field of biology teaching.

This result can be explained by the constructivist theory of learning. Piaget (1970) believed that learners actively construct knowledge through exploration and interaction with their environment, while Vygotsky (1978) emphasized the role of social interaction in cognitive development. It is possible that the interactive features of Nearpod such as quizzes in real time, collaborative discussions, and multimedia resources, may have facilitated this skill development as they prompted students to interact more closely with biological ideas and to share among themselves. Comparable results are found by prior research indicating that technology-supported inquiry learning enhances learner engagement, critical thinking and conceptual understanding (Akuma & Callaghan, 2018; de Jong et al., 2021; Arifin et al., 2025).

The implications of our study can be considered also by other models of technology integration, for example, the TPACK model in which the assumption of technological, pedagogical, and content knowledge application to teaching analysis is highlighted (Mishra & Koehler, 2006). Inquiry learning with Nearpod shows how digital technology can be authentically merged with inquiry pedagogy and biology subject matter to produce interactive, student-focused sessions. In this connection, technology is not simply used as a tool for presentation, but as a cognitive tool that mediates scientific inquiry, conceptual learning, and social learning.

This study demonstrates processing the three TPACK domains together. CK (content knowledge) was the biology topic of the human circulatory system. PK (pedagogical knowledge) was demonstrated by using inquiry (students question, investigate, and reason with evidence) to teach. Technological knowledge was exemplified in Nearpod's tools, including interactive quizzes, multimedia visualizations, group activities, and immediate feedback. The synergy of these three domains allowed technology to serve pedagogical objectives and, at the same time, help students learn complicated biological concepts.

Moreover, the findings are in line with the argument that technology-enhanced inquiry learning has the potential to enhance students' motivation and engagement, as digital environments can immediately respond to their work, offer visual learning experiences, and engage them in interactive learning. Biology education can particularly benefit from these learning conditions because it is a science in which many abstract ideas are visualized and actively investigated to foster meaningful learning.

Contemporary international literature suggests that digital learning environments can contribute to provide inclusive and quality learning in different educational contexts, including in rural and underdeveloped areas (Hennessy et al., 2022; OECD, 2021). This is in line with earlier studies which show that technology supported inquiry learning has the potential to foster students' critical thinking and academic performance. Among others, Akuma and Callaghan (2018) showed that technology-based inquiry activities facilitated scientific reasoning and conceptual understanding, whereas de Jong et al. (2021) revealed that digital IBL-scaffolds increased learners' participation and knowledge building in science education. On the other hand, a systematic review and meta-analysis by Arifin et al. (2025) showed positive and significant impact of inquiry-based learning on students' critical thinking skill in science subjects. The current study builds on these research by showing that inquiry-based learning, facilitated through Nearpod, can be effectively employed in a high school biology class in a rural Indonesian environment. Hence, these findings suggest that interactive digital environments combined with inquiry-based pedagogy may lead to meaningful learning and promising learning outcomes inclusive in low-end-of-the-scale education contexts.

Nevertheless, the adoption of the Nearpod-enabled inquiry learning is likely to pose some challenges, especially in the schools where technology is not very much accessible. Poor internet connection, lack of digital devices, inadequate technological infrastructure, and disparities in teachers' digital skills may also impair the level to which technology is integrated into classroom instruction. In addition, (digital) inquiry learning might be challenging for students to get used to, especially when they have little prior experience with technology-enhanced learning environments. Thus, its success hinges on the support of the institution, the professional development of the teacher, the provision of the necessary infrastructure and the development of suitable didactic material which takes into account the specific educational context in which it will be applied. Blended and/or simplified forms of technology use in resource limited schools may offer a more pragmatic solution to preserving the benefits of enquiry-based digital learning while negating some of the technological challenges.

It is conceivable that the novelty of interacting with a digital platform may have contributed to some of the positive responses from students, especially since students' exposure in the past to TEL environments was limited. Further long-term studies are required to confirm whether the benefits

observed are maintained upon the waning of the novelty effect.

D. Conclusion

This research revealed that Nearpod-supported inquiry-based learning had a positive impact on the students' critical thinking skills and conceptual knowledge of biology. These results demonstrate the feasibility of the inquiry pedagogy framework complemented by interactive digital technology to foster essential 21st-century educational competencies such as critical thinking, problem solving, and dynamic knowledge construction. Nearpod enables to overcome some of the common limitations of traditional teacher-led instruction by offering real-time feedback, multimedia visualization, and student interaction. Hence, the application of digital inquiry-based learning may be a beneficial approach for biology educators and institutions to enhance students' engagement and understanding of the content by making the learning process student-focused and more meaningful in the long run. These are especially important for rural and under-resourced schools, where well-constructed digital inquiry learning could assist in transcending the limitations of traditional instruction and at the same time support students in making sense of biology. Hence, it is recommended for the upcoming studies to include broader and heterogeneous samples, to investigate for long-term learning effects, and to consider investigating the application of Nearpod-based inquiry learning in different biology content and across various educational levels. Qualitative or mixed-method inquiries are recommended to advance understanding of students' and teachers' experiences in technology-mediated inquiry learning.

E. Acknowledgement

The authors wish to thank the Biology teacher and the students of the partner senior high school for their cooperation and enthusiastic participation in the study. The authors also express their gratitude to the Faculty of Education, Universitas Jember, for providing institutional support during this study. The authors also thank the academic colleagues who were instrumental in providing critical feedback during the instrument validation process.

F. References

Abdullah, M. I., Inayati, D., & Karyawati, N. N. (2022). Nearpod use as a learning platform to improve student learning motivation in an elementary school. *Journal of Education and Learning (EduLearn), 16*(1), 121–129. DOI: https://doi.org/10.11591/edulearn.v16i1.20421

Akuma, F. V., & Callaghan, R. (2018). Teaching practices linked to the implementation of inquiry-based practical work in certain science classrooms. *Journal of Research in Science Teaching*, *56*(1), 64-90. DOI: https://doi.org/10.1002/tea.21469

Akuoko, E. A., Fulmer, G. W., Hand, B., Suh, J., & Gardner, G. (2025). Characterizing inquiry-based science classroom learning environments—Generative or replicative—Using teachers' epistemic orientations: A qualitative study. *Frontiers in Education, 10*, 1508207. DOI: https://doi.org/10.3389/feduc.2025.1508207

Alarcon, D. A. U., Talavera-Mendoza, F., Rucano Paucar, F. H., Cayani Caceres, K. S., & Machaca Viza, R. (2023). Science and inquiry-based teaching and learning: A systematic review. *Frontiers in Education, 8,* 1170487. DOI: https://doi.org/10.3389/feduc.2023.1170487

Anderson, L. W., & Krathwohl, D. R. (2001). *A taxonomy for learning, teaching, and assessing: A revision of Bloom's taxonomy of educational objectives*. Longman. Retrieved from https://www.pearson.com

Anjani, D., Suciati, S., & Maridi, M. (2017, August). The effectiveness of inquiry-based learning module to improve the cognitive learning outcomes. In *1st Annual International Conference on Mathematics, Science, and Education (ICoMSE 2017)*, (pp. 166-171). Atlantis Press. DOI: https://doi.org/10.2991/icomse-17.2018.28

Bond, M., Bedenlier, S., Marín, V. I., & Händel, M. (2021). Emergency remote teaching in higher education: Mapping the first global online semester. *International Journal of Educational Technology in Higher Education*, *18*(50), 1–24. DOI: https://doi.org/10.1186/s41239-021-00282-x

Chusni, M. M., Saputro, S., Suranto., & Rahardjo, S. B. (2022). Enhancing critical thinking skills of junior high school students through discovery-based multiple representations learning model. *International Journal of Instruction, 15*(1), 927-944. DOI: https://doi.org/10.29333/iji.2022.15153a

Cooper, K. M., Ashley, M., & Brownell, S. E. (2018). Breaking down barriers: A bridge program helps first-year biology students connect with faculty. *Journal of College Science Teaching*, *47*(4), 60–66. DOI: https://doi.org/10.2505/4/jcst18_047_04_60

de Jong, T., Gillet, D., Rodríguez-Triana, M. J., Hovardas, T., Dikke, D., Doran, R., Dziabenko, O., Koslowsky, J., Korventausta, M., Law, E., Pedaste, M., Tasiopoulou, E., Vidal, G., & Zacharia, Z. C. (2021). Understanding teacher design practices for digital inquiry-based science learning: The case of Go-Lab. *Educational Technology Research and Development, 69*(2), 417–444. DOI: https://doi.org/10.1007/s11423-020-09904-z

Ellianawati, E., Sipayung, E. S. P. S., Subali, B., Linuwih, S., & Simbulas, L. J. (2025). Effectiveness of Nearpod-based interactive learning media in enhancing students' scientific literacy and numeracy in renewable energy topic. *Jurnal*

Pendidikan MIPA, *26*(1), 367-380. DOI: https://doi.org/10.23960/jpmipa.v26i1.pp367-380

Freeman, S., Eddy, S. L., McDonough, M., Smith, M. K., Okoroafor, N., Jordt, H., & Wenderoth, M. P. (2014). Active learning increases student performance in science, engineering, and mathematics. *Proceedings of the National Academy of Sciences*, *111*(23), 8410–8415. DOI: https://doi.org/10.1073/pnas.1319030111

Harahap, H. S., & Nurlina, A. H. (2021). Pengaruh model pembelajaran guided inquiry dan modified free inquiry terhadap kemampuan berpikir kritis siswa pada materi pencemaran lingkungan di SMA Negeri 1 Kotapinang. *Bio-Lectura: Jurnal Pendidikan Biologi*, *8*(2), 119–129. DOI: https://doi.org/10.31849/bl.v8i2.7690

Hennessy, S., D'Angelo, S., McIntyre, N., Koomar, S., Kreimeia, A., Cao, L., Brugha, M., & Zubairi, A. (2022). Technology use for teacher professional development in low- and middle-income countries: A systematic review. *Computers and Education Open, 3,* 100080. DOI: https://doi.org/10.1016/j.caeo.2022.100080

Hinostroza, J. E., Armstrong-Gallegos, S., & Villafaena, M. (2024). Roles of digital technologies in the implementation of inquiry-based learning (IBL): A systematic literature review. *Social Sciences & Humanities Open, 9*, 100874. DOI: https://doi.org/10.1016/j.ssaho.2024.100874

Hmelo-Silver, C. E., & DeSimone, C. (2013). Problem-based learning: An instructional model of collaborative learning. In C. E. Hmelo-Silver, C. A. Chinn, C. K. K. Chan, & A. O'Donnell (Eds.), The international handbook of collaborative learning. (pp. 370–386). Routledge.

Kirschner, P. A., Sweller, J., & Clark, R. E. (2006). Why minimal guidance during instruction does not work: An analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry-based teaching. *Educational Psychologist, 41*(2), 75–86. DOI: https://doi.org/10.1207/s15326985ep4102_1

Mayer, R. E. (2020). *Multimedia learning* (3rd ed.). Cambridge University Press. DOI: https://doi.org/10.1017/9781316941355

Michael, J. (2006). Where's the evidence that active learning works? *Advances in Physiology Education, 30*(4), 159–167. DOI: https://doi.org/10.1152/advan.00053.2006

Mishra, P., & Koehler, M. J. (2006). Technological pedagogical content knowledge: A framework for teacher knowledge. *Teachers College Record, 108*(6), 1017–1054. DOI: https://doi.org/10.1111/j.1467-9620.2006.00684.x

Mulet, J., van de Leemput, C., & Amadieu, F. (2019). A critical literature review of perceptions of tablets for learning in primary and secondary schools. *Educational Psychology Review, 31*(3), 631–662. DOI: https://doi.org/10.1007/s10648-019-09478-0

OECD. (2019). *PISA 2018 results: What students know and can do*. OECD Publishing. DOI: https://doi.org/10.1787/5f07c754-en

OECD. (2021). *Education at a glance 2021*. OECD Publishing. DOI: https://doi.org/10.1787/b35a14e5-en

Pedaste, M., Mäeots, M., Siiman, L. A., de Jong, T., van Riesen, S. A. N., Kamp, E. T., Manoli, C. C., Zacharia, Z. C., & Tsourlidaki, E. (2015). Phases of inquiry-based learning: Definitions and the inquiry cycle. *Educational Research Review*, *14*, 47–61. DOI: https://doi.org/10.1016/j.edurev.2015.02.003

Petersen, M. R. (2022). Strategies to scaffold students' inquiry learning in science. *Science Education International, 33*(3), 267–275. DOI: https://doi.org/10.33828/sei.v33.i3.1

Piaget, J. (1970). *Science of education and the psychology of the child.* Orion Press.

Schindler, L. A., Burkholder, G. J., Morad, O. A., & Marsh, C. (2017). Computer-based technology and student engagement: A critical review of the literature. *International Journal of Educational Technology in Higher Education, 14,* 25. DOI: https://doi.org/10.1186/s41239-017-0063-0

Soomro, R. B., Soomro, A., & Memon, I. (2025). *Inquiry-based science teaching and its impact on critical thinking and problem-solving skills: A meta-analysis of STEM education* [Preprint]. Research Square. DOI: https://doi.org/10.21203/rs.3.rs-6365963/v1

Theobald, E. J., Hill, M. J., Tran, E., Agrawal, S., Arroyo, E. N., Behling, S., Freeman, S. (2020). Active learning narrows achievement gaps. *Proceedings of the National Academy of Sciences*, *117*(12), 6476–6483. DOI: https://doi.org/10.1073/pnas.1916903117

Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes*. Harvard University Press. Retrieved from https://www.jstor.org/stable/j.ctvjf9vz4