

THE EFFECT OF AI-BASED MULTIMEDIA INTEGRATED PROJECT-BASED LEARNING ON STUDENTS' COLLABORATION SKILLS AND CONCEPTUAL UNDERSTANDING IN THE PERIODIC TABLE

Resa Sarita Gerungan¹, Jaslin Ikhsan¹

¹Pendidikan Kimia, Universitas Negeri Yogyakarta, Indonesia

Corresponding Author: resasarita.2024@student.uny.ac.id

Received: 01/04/2026 | Revised : 10/04/2026 | Accepted: 15/05/2026 | Published : 24/05/2026

Abstract

This study aimed to investigate the effect of AI-based multimedia integrated Project-Based Learning (PjBL) on students' collaboration skills and conceptual understanding in learning the Periodic Table. The study employed a quantitative approach using a quasi-experimental method with a non-equivalent control group pretest-posttest design. The participants consisted of 64 tenth-grade students at Universitas Negeri Yogyakarta, divided into an experimental group and a control group, with 32 students in each class. The experimental group was taught using AI-based multimedia integrated PjBL, while the control group received cooperative learning instruction. Data were collected using a collaboration skills questionnaire and a conceptual understanding test. The data were analyzed using MANOVA, Independent Sample t-Test, N-Gain analysis, and Partial Eta Squared effect size analysis with the assistance of SPSS 25. The results showed significant simultaneous differences between the experimental and control groups after treatment, as indicated by the MANOVA test ($p = 0.005 < 0.05$). The Independent Sample t-Test also revealed significant differences in collaboration skills ($p = 0.016$) and conceptual understanding ($p = 0.008$). The N-Gain analysis indicated that the experimental group achieved higher improvement in collaboration skills (0.478) and conceptual understanding (0.393) compared to the control group. Furthermore, the effect size analysis showed medium effects on collaboration skills ($\eta^2 = 0.090$) and conceptual understanding ($\eta^2 = 0.108$). Therefore, AI-based multimedia integrated Project-Based Learning was found to be effective in improving students' collaboration skills and conceptual understanding in chemistry learning, particularly on the Periodic Table topic.

Keywords: *Artificial Intelligence, Multimedia Learning, Project-Based Learning, Collaboration Skills, Conceptual Understanding, Periodic Table*

INTRODUCTION

Education in the 21st century faces major challenges in preparing students for the demands of the digital era and Industry 4.0. The integration of Artificial Intelligence (AI) in education is rapidly growing, with the global market projected to reach \$25.7 billion by 2030 (Holmes et al., 2022). However, UNESCO (2023) reports that around 60% of countries still face difficulties in integrating AI into their educational systems, leading to disparities in educational quality. In Indonesia, only 35% of schools are adequately equipped with digital learning infrastructure (Kemdikbudristek, 2023). In addition, the National Assessment shows that students' collaboration skills and conceptual understanding remain below international standards, with scores of 45.6 and 48.2 respectively. Although policies such as the Ministerial Regulation No. 22 of 2023 have been issued, implementation in classrooms remains limited due to teacher readiness and infrastructure constraints. These conditions highlight the need for innovative learning models that integrate technology while promoting 21st-century skills. Project-Based Learning (PjBL) is widely recognized as an effective student-centered approach that enhances collaboration and problem-solving skills. When combined with AI-based multimedia, PjBL has the potential to provide adaptive learning experiences, real-time feedback, and improved conceptual visualization (Bell, 2010; Holmes et al., 2023). However, the application of Artificial Intelligence (AI) in education is still largely oriented

THE EFFECT OF AI-BASED MULTIMEDIA INTEGRATED PROJECT-BASED LEARNING ON STUDENTS' COLLABORATION SKILLS AND CONCEPTUAL UNDERSTANDING IN THE PERIODIC TABLE

Resa Sarita Gerungan and Jaslin Ikhsan

toward individualized learning and adaptive systems, while its integration into collaborative pedagogical approaches such as Project-Based Learning (PjBL) remains limited (Rienties et al., 2020; Zawacki-Richter et al., 2019). Collaboration skills refer to students' ability to work effectively in groups, while conceptual understanding refers to the ability to comprehend and apply scientific concepts meaningfully. Despite their importance, Indonesian students still demonstrate low performance in these areas, partly due to limited collaborative learning practices in classrooms. Previous studies indicate that the use of Artificial Intelligence in learning environments has a positive effect on student engagement through interactive learning systems, adaptive feedback, and personalized learning experiences (Wang & Guo, 2025). In chemistry education, particularly the periodic table topic, students often experience difficulties in understanding abstract concepts and periodic trends (Zawacki-Richter et al., 2019). This topic requires visualization and conceptual integration, which can be supported by AI-based multimedia and PjBL approaches. However, existing literature shows that AI and PjBL are still studied separately, and their integration remains limited. Bibliometric analysis (2018–2024) confirms that AI, PjBL, and chemistry education form distinct research clusters, indicating a clear research gap. Therefore, this study proposes an AI-based multimedia integrated Project-Based Learning model to enhance students' collaboration skills and conceptual understanding in the periodic table topic. The novelty lies in integrating AI not only as a learning support tool but also as a facilitator of collaborative learning within PjBL.

METHOD

Research Design

This study employed a quantitative approach using a quasi-Experiment method with a non-equivalent control group pretest–posttest design. Two groups were involved in the study: an Experiment group taught using AI-based multimedia integrated Project-Based Learning (PjBL) and a control group taught using a cooperative learning model. Both groups received a pretest before the treatment and a posttest after the learning intervention. The research design is presented in Table 1.

Table 1. Research Design

Group	Pretest	Treatment	Posttest
Experiment	O ₁	X	O ₂
Control	O ₃	–	O ₄

Description:

O₁ = Pretest of the Experiment group

O₂ = Posttest of the Experiment group

O₃ = Pretest of the control group

O₄ = Posttest of the control group

X = AI-based multimedia integrated Project-Based Learning (PjBL)

Participants and Research Setting

The study was conducted from August to October 2025 during the first semester of the 2025/2026 academic year at SMAS Kristen 1 Tomohon. The population consisted of all tenth-grade students at the school. Two classes were selected using simple random sampling. Class X-7, consisting of 32 students, was assigned as the Experiment group, while class X-8, consisting of 32 students, served as the control group.

Learning Procedure

The implementation of AI-based multimedia integrated PjBL in the Experiment class followed six stages adapted from the Project-Based Learning framework.

THE EFFECT OF AI-BASED MULTIMEDIA INTEGRATED PROJECT-BASED LEARNING ON STUDENTS' COLLABORATION SKILLS AND CONCEPTUAL UNDERSTANDING IN THE PERIODIC TABLE

Resa Sarita Gerungan and Jaslin Ikhsan

Table 2. Learning Stages of AI-Based Multimedia Integrated Project-Based Learning (PjBL)

Learning Stage	Description of Activities
Project Identification	Students were introduced to essential questions related to the Periodic Table topic, such as understanding the properties and applications of chemical elements in daily life. AI tools were used to assist group formation and topic distribution.
Project Planning	Students collaboratively designed project plans, divided responsibilities among group members, created activity timelines, and selected digital tools such as ChatGPT, Canva, and Google Slides to support project completion.
Activity Exploration	Students explored information related to chemical elements using AI-assisted resources and scientific references. Group discussions were conducted to validate findings and organize project materials.
Production	Students developed project products in the form of digital presentations, educational videos, podcasts, or interactive multimedia related to Periodic Table concepts.
Exchange of Results	Each group presented their project results in front of the class. Students discussed similarities and differences among chemical elements and provided peer feedback during classroom discussions.
Evaluation	Evaluation was conducted based on content accuracy, creativity, presentation quality, collaboration skills, and student participation. Reflection activities were also carried out to evaluate students' learning experiences and the role of AI during project completion.

Instruments and Data Collection

Two instruments were used in this study:

1. Collaboration Skills Questionnaire

Collaboration skills were measured using an observation sheet and questionnaire adapted from Greenstein (2014). The instrument consisted of 24 statements covering indicators such as productive work, active contribution, communication, responsibility, conflict resolution, and teamwork.

2. Conceptual Understanding Test

Students' conceptual understanding of the Periodic Table topic was measured using a 20-item multiple-choice test administered as a pretest and posttest. The test covered periodic trends, electron configuration, element classification, and properties of elements.

Validity and Reliability

The instruments were validated through expert judgment involving two validators who evaluated content, construction, and language aspects. Empirical validity was analyzed using Pearson Product Moment correlation with the assistance of IBM SPSS Statistics 25. Items were considered valid when the correlation coefficient exceeded the r-table value and the significance value was less than 0.05. Instrument reliability was analyzed using Cronbach's Alpha, with a minimum acceptable value of 0.70.

Data Analysis

Data analysis was performed using *Multivariate Analysis of Variance* (MANOVA) to examine the simultaneous effect of AI-based multimedia integrated Project-Based Learning (PjBL) on students' collaboration skills and conceptual understanding. Before MANOVA testing, assumption tests including normality, homogeneity, linearity, and multicollinearity were conducted using SPSS 25. The hypotheses were tested at a significance level of 0.05. If the significance value was less than 0.05, the null hypothesis was rejected, indicating significant differences between the Experiment and control groups.

THE EFFECT OF AI-BASED MULTIMEDIA INTEGRATED PROJECT-BASED LEARNING ON STUDENTS' COLLABORATION SKILLS AND CONCEPTUAL UNDERSTANDING IN THE PERIODIC TABLE

Resa Sarita Gerungan and Jaslin Ikhsan

To measure students' learning improvement, the normalized gain (N-Gain) score was calculated using the following formula:

$$N - GAIN = \frac{S_{post} - S_{pre}}{S_{max} - S_{pre}}$$

The N-Gain criteria are presented in Table 3.

Table 3. N-Gain Criteria

N-Gain Score	Category
$g > 0.7$	High
$0.3 \leq g \leq 0.7$	Medium
$g < 0.3$	Low

Furthermore, the effectiveness of the treatment was analyzed using *partial eta squared* (η^2) to determine the effect size of the intervention. The interpretation of effect size is presented in Table 4.

Table 4. Effect Size Criteria

Partial Eta Squared (η^2)	Percentage	Category
$0.01 < \eta^2 \leq 0.06$	1% – 6%	Low
$0.06 < \eta^2 \leq 0.14$	6% – 14%	Medium
$\eta^2 > 0.14$	> 14%	High

RESULT AND DISCUSSION

Instrument Validity and Reliability

Before conducting the hypothesis testing, the research instruments were tested for validity and reliability. The conceptual understanding test consisted of 20 multiple-choice items. Empirical validity testing was conducted using Pearson Product-Moment correlation analysis with the assistance of IBM SPSS Statistics 25. The results showed that all items had correlation coefficients higher than the r-table value (0.361) and significance values lower than 0.05, indicating that all items were valid and suitable for use in the study.

Table 5. Results of Conceptual Understanding Test Validity

Item	r-count	p-value	Interpretation
B1	0.471	0.009	Valid
B2	0.382	0.037	Valid
B3	0.478	0.008	Valid
B4	0.443	0.014	Valid
B5	0.412	0.024	Valid
B6	0.438	0.016	Valid
B7	0.666	0.000	Valid
B8	0.426	0.019	Valid
B9	0.447	0.013	Valid
B10	0.665	0.000	Valid
B11	0.448	0.013	Valid
B12	0.626	0.000	Valid

THE EFFECT OF AI-BASED MULTIMEDIA INTEGRATED PROJECT-BASED LEARNING ON STUDENTS' COLLABORATION SKILLS AND CONCEPTUAL UNDERSTANDING IN THE PERIODIC TABLE

Resa Sarita Gerungan and Jaslin Ikhsan

Item	r-count	p-value	Interpretation
B13	0.411	0.024	Valid
B14	0.537	0.002	Valid
B15	0.381	0.038	Valid
B16	0.458	0.011	Valid
B17	0.545	0.002	Valid
B18	0.366	0.046	Valid
B19	0.447	0.013	Valid
B20	0.381	0.038	Valid

The reliability analysis was performed using Cronbach’s Alpha. The results demonstrated that the collaboration skills questionnaire had a Cronbach’s alpha of 0.975, while the conceptual understanding test had a Cronbach's alpha of 0.817. Both values exceeded the minimum reliability criterion of 0.70, indicating that the instruments were reliable and consistent for measuring the research variables.

Table 6. Reliability Test Results

Instrument	Number of Items	Cronbach’s Alpha	Interpretation
Collaboration Skills Questionnaire	24	0.975	Highly Reliable
Conceptual Understanding Test	20	0.817	Reliable

These findings indicate that the instruments used in this study were appropriate for collecting valid and consistent data. According to Hair et al. (2019), Cronbach’s Alpha values above 0.70 indicate good internal consistency in educational research instruments.

Assumption Testing

Before conducting MANOVA analysis, assumption tests including normality and homogeneity tests were performed.

Table 7. Multivariate Normality Test Results

Group	Data	Correlation Coefficient
Experiment	Pretest	0.98
	Posttest	0.974
Control	Pretest	0.960
	Posttest	0.991

The results indicated strong correlation coefficients in all datasets, suggesting that the data were normally distributed multivariately.

THE EFFECT OF AI-BASED MULTIMEDIA INTEGRATED PROJECT-BASED LEARNING ON STUDENTS' COLLABORATION SKILLS AND CONCEPTUAL UNDERSTANDING IN THE PERIODIC TABLE

Resa Sarita Gerungan and Jaslin Ikhsan

Table 8. Univariate Normality Test Results

Variable	Data	Experimental (p-value)	Control (p-value)	Interpretation
Collaboration Skills	Pretest	0.857	0.056	Normal
	Posttest	0.238	0.908	Normal
Conceptual Understanding	Pretest	0.48	0.617	Normal
	Posttest	0.286	0.322	Normal

All p-values were greater than 0.05, indicating that the data were normally distributed.

Table 9. Homogeneity Test Results

Data	Box's M	F	p-value	Interpretation
Pretest	3.378	1.087	0.353	Homogeneous
Posttest	4.48	1.441	0.229	Homogeneous

The Box's M test results showed p-values greater than 0.05, indicating homogeneous covariance matrices between the groups. Therefore, the assumptions required for MANOVA analysis were fulfilled.

Multivariate Hypothesis Testing

The multivariate hypothesis testing using Hotelling's Trace was conducted to determine whether there were simultaneous differences in collaboration skills and conceptual understanding between the experimental and control groups.

Table 10. Multivariate Test Results

Data	Statistical Test	F	P-value
Pretest	Hotelling's Trace	0.583	0.561
Posttest	Hotelling's Trace	5.806	0.005

The pretest results showed no significant difference between the experimental and control groups ($p > 0.05$), indicating that both groups had equivalent initial abilities before treatment. However, the posttest results showed a significance value of 0.005 ($p < 0.05$), indicating significant simultaneous differences between the two groups after the implementation of AI-based multimedia integrated Project-Based Learning (PjBL). These findings demonstrate that AI-based multimedia integrated Project-Based Learning (PjBL) positively influenced students' collaboration skills and conceptual understanding simultaneously. Project-based learning encourages students to actively engage in collaborative problem-solving activities, discussion, and knowledge construction through authentic learning experiences. Technology-supported PjBL environments also provide opportunities for students to improve communication, teamwork, and higher-order thinking skills during project completion processes (Aifan, 2022; Zhang & Hwang, 2022). Furthermore, the integration of AI-assisted and multimedia-supported learning environments enables students to access adaptive learning

THE EFFECT OF AI-BASED MULTIMEDIA INTEGRATED PROJECT-BASED LEARNING ON STUDENTS' COLLABORATION SKILLS AND CONCEPTUAL UNDERSTANDING IN THE PERIODIC TABLE

Resa Sarita Gerungan and Jaslin Ikhsan

resources, receive immediate feedback, and explore concepts more interactively, which contributes positively to conceptual understanding and student engagement in learning activities.

Univariate Hypothesis Testing

Independent Sample t-Test analysis was conducted to determine the effect of the treatment on each dependent variable separately.

Table 11. Independent Sample t-Test Results

Variable	t-count	t-table	p-value	Interpretation
Collaboration Skills	2.47	1.998	0.016	Significant
Conceptual Understanding	2.745	1.998	0.008	Significant

The results indicated significant differences between the experimental and control groups in both collaboration skills and conceptual understanding. Students in the experimental group demonstrated better collaboration skills than students in the control group. During project activities, students actively collaborated in planning projects, discussing ideas, dividing responsibilities, and presenting project outcomes. The use of AI-assisted multimedia also facilitated communication and information sharing among group members. This finding is consistent with Kokotsaki et al. (2016) who emphasized that collaborative project-based learning environments improve teamwork, communication, and shared problem-solving skills. In addition, Rienties et al. (2020) explained that AI-supported collaborative learning environments encourage more interactive and student-centered learning experiences.

Similarly, conceptual understanding in the experimental group was significantly higher than in the control group. The use of AI tools such as ChatGPT and multimedia applications enabled students to access interactive explanations, visualize abstract chemistry concepts, and receive immediate feedback during project development. This process helped students construct deeper conceptual understanding regarding periodic trends, electron configurations, and chemical element properties. These findings align with Wang & Guo (2025), who found that AI-assisted learning environments improve students' engagement and conceptual comprehension through adaptive and personalized learning experiences. Moreover, Zawacki-Richter et al. (2019) stated that AI integration in education supports deeper understanding by facilitating interactive learning and access to diverse learning resources.

N-Gain Analysis

Table 12. N-Gain Results of Collaboration Skills

Group	N-Gain Score	Category	Percentage	Interpretation
Experimental	0.478	Medium	47.78%	Less Effective
Control	0.384	Medium	38.40%	Ineffective

The experimental group obtained a higher N-Gain score than the control group, indicating that AI-based multimedia-integrated PjBL was more effective at improving students' collaboration skills. Although both groups were categorized within the medium category, the experimental group demonstrated better quantitative improvement.

THE EFFECT OF AI-BASED MULTIMEDIA INTEGRATED PROJECT-BASED LEARNING ON STUDENTS' COLLABORATION SKILLS AND CONCEPTUAL UNDERSTANDING IN THE PERIODIC TABLE

Resa Sarita Gerungan and Jaslin Ikhsan

Table 13. N-Gain Results of Conceptual Understanding

Group	N-Gain Score	Category	Percentage	Interpretation
Experimental	0.393	Medium	39.33%	Ineffective
Control	0.196	Low	19.62%	Ineffective

The N-Gain analysis for conceptual understanding showed that the experimental group achieved a medium improvement category, while the control group remained in the low category. These findings indicate that AI-based multimedia integrated PjBL was more effective in enhancing conceptual understanding compared to conventional learning. The integration of AI into project-based learning enabled students to explore chemistry concepts more independently and interactively. AI-assisted multimedia provided meaningful visualization and contextual learning experiences, particularly for abstract chemistry topics such as the Periodic Table. Recent studies have shown that AI-supported learning environments contribute positively to personalized learning, adaptive feedback, and student-centered instruction, thereby improving students' conceptual understanding and learning outcomes (Chen et al., 2020; Zhai et al., 2021). Furthermore, multimedia-assisted AI learning tools help students visualize abstract scientific concepts more effectively and increase engagement during the learning process (Hwang & Tu, 2021). Overall, the findings of this study confirm that AI-based multimedia integrated Project-Based Learning is an effective instructional approach for improving students' collaboration skills and conceptual understanding in chemistry learning. The integration of AI creates more interactive, collaborative, and meaningful learning experiences that support the development of 21st-century competencies.

Effect Size Analysis

To determine the magnitude of the effect of AI-based multimedia integrated Project-Based Learning (PjBL) on students' collaboration skills and conceptual understanding, effect size analysis was conducted using Partial Eta Squared (η^2). The results are presented in Table 14.

Table 14. Effect Size Results

Variable	Sig.	Partial Eta Squared (η^2)	Category
Collaboration Skills	0.016	0.09	Medium
Conceptual Understanding	0.008	0.108	Medium

The effect size analysis showed that AI-based multimedia integrated Project-Based Learning (PjBL) had a medium effect on both collaboration skills and conceptual understanding. The Partial Eta Squared value for collaboration skills was 0.090, indicating that the treatment contributed approximately 9.0% to the improvement of students' collaboration skills. Meanwhile, the Partial Eta Squared value for conceptual understanding was 0.108, indicating that the treatment contributed approximately 10.8% to students' conceptual understanding improvement. These findings suggest that the integration of AI-based multimedia within Project-Based Learning provides a meaningful contribution to improving students' learning outcomes. The medium effect size indicates that the learning intervention not only produced statistically significant differences but also had practical educational significance. The use of AI-assisted multimedia encouraged students to interact more actively during collaborative activities and facilitated better visualization of abstract chemistry concepts related to the Periodic Table. This finding is in line with previous studies in chemistry education conducted by Indonesian researchers, which reported that Project-Based Learning and multimedia-supported instruction significantly improve students' collaboration skills, engagement, and conceptual understanding in chemistry learning contexts (Kholid et al., 2024; Winartiasih et al., 2023).

THE EFFECT OF AI-BASED MULTIMEDIA INTEGRATED PROJECT-BASED LEARNING ON STUDENTS' COLLABORATION SKILLS AND CONCEPTUAL UNDERSTANDING IN THE PERIODIC TABLE

Resa Sarita Gerungan and Jaslin Ikhsan

The higher effect size obtained in conceptual understanding compared to collaboration skills indicates that AI-supported multimedia was particularly effective in helping students comprehend chemistry concepts through interactive visualization, adaptive feedback, and independent exploration of learning materials. AI-assisted learning environments provide students with opportunities to access learning resources more flexibly and support active knowledge construction processes during project activities. Previous studies in Indonesian chemistry education also revealed that multimedia-integrated PjBL environments can improve higher-order thinking skills, scientific skills, and conceptual mastery through interactive and student-centered learning experiences (Kholid et al., 2024). Therefore, the integration of AI-based multimedia into Project-Based Learning can be considered an effective and innovative approach to support meaningful chemistry learning and the development of students' 21st-century competencies.

CONCLUSION

Based on the results of the study, it can be concluded that AI-based multimedia integrated Project-Based Learning (PjBL) significantly improved students' collaboration skills and conceptual understanding in learning the Periodic Table. The multivariate analysis demonstrated significant simultaneous differences between the experimental and control groups after the implementation of the learning model. In addition, the univariate analysis confirmed that students who learned through AI-based multimedia integrated PjBL achieved better collaboration skills and higher conceptual understanding than those who learned through conventional cooperative learning.

The N-Gain analysis further indicated that the experimental group experienced greater improvement in both variables compared to the control group. Moreover, the effect size analysis revealed that the intervention had a medium practical effect on collaboration skills and conceptual understanding. These findings suggest that the integration of AI-assisted multimedia within Project-Based Learning creates more interactive, collaborative, and meaningful learning experiences that support the development of students' 21st-century competencies. Therefore, AI-based multimedia integrated Project-Based Learning can be considered an innovative and effective instructional approach for chemistry education, especially in facilitating students' understanding of abstract concepts and enhancing collaborative learning skills. Future studies are recommended to explore the implementation of AI-integrated PjBL in different science topics, educational levels, and broader learning contexts to strengthen its effectiveness and applicability in education.

REFERENCES

- Aifan, H. (2022). Implementing a project-based collaborative learning approach using PowerPoint to improve students' 21st-century skills. *E-Learning and Digital Media*, 19(3), 258–273. <https://doi.org/10.1177/20427530211030642>
- Bell, S. (2010). Project-Based Learning for the 21st Century: Skills for the Future. *The Clearing House*, 83, 39–43. <https://doi.org/10.1080/00098650903505415>
- Chen, L., Chen, P., & Lin, Z. (2020). Artificial Intelligence in Education: A Review. *IEEE Access*, 8, 75264–75278. <https://doi.org/10.1109/ACCESS.2020.2988510>
- Holmes, W., Bialik, M., & Fadel, C. (2023). *Artificial intelligence in education* (pp. 621–653). <https://doi.org/10.58863/20.500.12424/4276068>
- Hwang, G.-J., & Tu, Y.-F. (2021). Roles and Research Trends of Artificial Intelligence in Mathematics Education: A Bibliometric Mapping Analysis and Systematic Review. *Mathematics*, 9(6). <https://doi.org/10.3390/math9060584>
- Kemdikbudristek. (2023). *Asesmen Nasional 2022: Laporan Hasil. Kementerian Pendidikan, Kebudayaan, Riset, dan Teknologi Republik Indonesia*.
- Kholid, I., Haris, M., & Hasibuan, E. (2024). The development of a project-based multimedia and its effectiveness in improving students' higher order thinking skills about chemistry bonding concept. *Jurnal Pendidikan Kimia (JPKIM)*, 16(3), 230–237.
- Kokotsaki, D., Menzies, V., & Wiggins, A. (2016). Project-based learning: A review of the literature. *Improving Schools*, 19(3), 267–277. <https://doi.org/10.1177/1365480216659733>
- Rienties, B., Köhler Simonsen, H., & Herodotou, C. (2020). Defining the Boundaries Between Artificial Intelligence in Education, Computer-Supported Collaborative Learning, Educational Data Mining, and Learning Analytics: A Need for Coherence. *Frontiers in Education*, 5. <https://doi.org/10.3389/educ.2020.00128>
- Wang, K., & Guo, Z. (2025). Can Learners' Use of GenAI Enhance Learning Engagement?—A Meta-Analysis. *Education Sciences*, 15(12). <https://doi.org/10.3390/educsci15121578>

THE EFFECT OF AI-BASED MULTIMEDIA INTEGRATED PROJECT-BASED LEARNING ON STUDENTS' COLLABORATION SKILLS AND CONCEPTUAL UNDERSTANDING IN THE PERIODIC TABLE

Resa Sarita Gerungan and Jaslin Ikhsan

- Winartiasih, Novita, D., & Ulum, B. (2023). Penerapan project based learning dengan strategi teaching at the right level untuk meningkatkan keterampilan kolaborasi dan komunikasi peserta didik pada materi hukum dasar kimia. *Journal of Chemical Education*, 12(3), 244–251.
- Zawacki-Richter, O., Marín, V. I., Bond, M., & Gouverneur, F. (2019). Systematic review of research on artificial intelligence applications in higher education – where are the educators? *International Journal of Educational Technology in Higher Education*, 16(1), 39. <https://doi.org/10.1186/s41239-019-0171-0>
- Zhai, X., Chu, X., Chai, C. S., Jong, M. S. Y., Istenic, A., Spector, M., Liu, J.-B., Yuan, J., & Li, Y. (2021). A Review of Artificial Intelligence (AI) in Education from 2010 to 2020. *Complexity*, 2021(1), 8812542. <https://doi.org/https://doi.org/10.1155/2021/8812542>
- Zhang, D., & Hwang, G.-J. (2022). Effects of Interaction between Peer Assessment and Problem-Solving Tendencies on Students' Learning Achievements and Collaboration in Mobile Technology-Supported Project-Based Learning. *Journal of Educational Computing Research*, 61(2), 208–234. <https://doi.org/https://doi.org/10.1177/07356331221094250>