pISSN 2685-0761
eISSN 2685-0850

JURNAL INOVASI PEMBELAJARAN KIMIA
(Journal of Innovation in Chemistry Education)
https://jurnal.unimed.ac.id/2012/index.php/jipk
email: Jinovpkim@unimed.ac.id

Recieved : 26 August 2026
Revised : 17 October 2026
Accepted : 28 October 2026
Published : 31 October 2026
Pages : 288 - 298

Development of Chemistry Practical Guide: Integration of PjBL with Augmented Reality Technology in Electrolysis Practical

Ahmad Fauzi Syahputra Yani[1]* and Muhammad Khalil[2]

[1]*Department of Chemistry Education, Universitas Samudra, Langsa, Indonesia*

[2]*Department of Biology Education, Universitas Samudra, Langsa, Indonesia*

Email: ahmadfauzisyahputrayani@unsam.ac.id

Abstract: *This study aims to develop a Chemistry Practical Guide integrating Project-Based Learning (PjBL) and Augmented Reality (AR) for the electrolysis topic to enhance students' conceptual understanding and engagement in chemistry practicum. The research employed a Research and Development (R&D) method using the 4D model (Define, Design, Develop, and Disseminate), conducted up to the Develop stage. The product was validated by three material experts and two media experts, and tested on teachers and students for practicality. The results showed that the guide achieved very high validity scores from material experts (93.8%) and media experts (93.4%). Teacher (90.6%) and student (90.6%) responses also indicated excellent practicality and usability. The integration of PjBL promoted inquiry, collaboration, and critical thinking, while AR technology enhanced visualization of abstract electrochemical processes. The developed guide bridges theoretical understanding and experimental application, serving as an innovative digital-based learning resource for 21st-century chemistry education.*

Keywords: *Chemistry practicum; Project-Based Learning; Augmented Reality; electrolysis; learning innovation*

INTRODUCTION

Practical activities in chemistry learning play a crucial role in connecting theoretical knowledge with real-world applications (Amaliyah et al., 2024; Nainggolan et al., 2019). Through experiments, students can verify scientific principles and develop essential laboratory skills that are fundamental for understanding chemical concepts (Agustian et al., 2022). However, conventional laboratory practices often rely heavily on procedural instruction without emphasizing students' conceptual understanding or problem-solving skills (La Braca & Kalman, 2021). This situation frequently results in passive learning, where students simply follow existing manuals without engaging in higher-order thinking processes. Consequently, abstract concepts such as electrolysis remain difficult for students to comprehend because of limited visualization and contextual representation (Hutahaean et al., 2024; Yani & Oktaviani, 2022).

The demands of the 21st-century learning paradigm, which include critical thinking, creativity, collaboration, communication, and digital literacy, require innovative approaches that integrate technology and student-centered learning models (Rezika & Sugiharti, 2025; Rahmah & Sugiharti, 2024). One promising approach is Project-Based Learning (PjBL), which positions students as active problem solvers and creators of knowledge through real projects that simulate authentic scientific inquiry (Simbolon & Panggabean, 2025; Karan & Brown, 2022). PjBL encourages students to design, conduct, and evaluate experiments collaboratively, thus strengthening their scientific reasoning and creativity in applying chemical principles to solve contextual problems.

The rapid advancement of Augmented Reality (AR) technology provides new opportunities for transforming chemistry learning experiences. AR allows users to visualize invisible molecular processes and chemical reactions interactively, enhancing spatial understanding and motivation (Khalil, 2025; Yamtinah et al., 2023; Mazzuco et al., 2022). Previous studies have demonstrated that AR-based chemistry media significantly improve students' conceptual comprehension and engagement during learning activities (Amirah & Mahartika, 2023; Wulandari et al., 2020). Nevertheless, most existing AR applications focus solely on visualization aspects and are rarely combined with pedagogical models such as PjBL that promote project-oriented inquiry (Yani, 2023).

This condition creates a gap between the potential of AR technology and the need for its pedagogical integration into student-centered learning models. While AR helps in illustrating abstract concepts, it does not inherently promote problem-solving or collaborative learning unless integrated with structured project-based frameworks. Therefore, it is essential to develop an innovative chemistry practical guide that merges the strengths of PjBL and AR, allowing students to not only visualize electrolysis phenomena but also apply conceptual understanding through guided experimental projects.

The novelty of this research lies in the integration of Project-Based Learning with Augmented Reality technology within the electrolysis practicum context, creating a hybrid instructional tool that bridges conceptual visualization and experimental inquiry. Unlike previous studies that focused only on AR-based learning media, this study emphasizes the development of a practical guide that simultaneously fosters understanding, motivation, and student collaboration through project-oriented experimentation.

This study aims to develop and validate a chemistry practical guide that integrates Project-Based Learning and Augmented Reality technology for the electrolysis experiment topic. Specifically, it seeks to (1) determine the validity and feasibility of the developed guide based on expert assessment, (2) analyze teachers' responses regarding its practicality, and (3) evaluate students' perceptions of its effectiveness in supporting meaningful and engaging chemistry learning.

LITERATURE REVIEW

Chemistry Practicum and Conceptual Understanding

Chemistry practicum is a vital component of science education that enables students to connect theoretical concepts with empirical experiences. Through hands-on laboratory activities, learners can develop scientific reasoning, manipulative skills, and conceptual understanding (Sinaga et al., 2021). However, several studies have reported that students often engage in practicum activities in a procedural manner, following step-by-step instructions without meaningful reflection or conceptual analysis (Yani & Oktaviani, 2022). This traditional approach limits students' opportunities to think critically, solve problems, and internalize chemical concepts. In particular, electrolysis

is recognized as one of the most challenging topics because it involves abstract microscopic processes such as ion migration, electrode reactions, and oxidation-reduction mechanisms that are not easily observed (Amirah & Mahartika, 2023). Therefore, the development of innovative practicum materials that emphasize inquiry, visualization, and active learning is essential for improving students' comprehension of electrochemical concepts.

Project-Based Learning (PjBL) in Chemistry Education

Project-Based Learning (PjBL) is an instructional model that encourages students to construct knowledge through authentic projects related to real-life problems (Silma et al., 2024). PjBL engages students in designing experiments, collecting data, interpreting results, and presenting findings collaboratively (Hermawan & Syarifuddin, 2022). Research has shown that PjBL fosters higher-order thinking skills such as analysis, synthesis, and evaluation while simultaneously improving students' creativity and scientific communication (Nasution & Setyaningrum, 2024; Loyens et al., 2023). The model's constructivist nature also supports student autonomy and motivation, making it suitable for practical-based science learning (Mishra, 2023). Despite these advantages, effective implementation of PjBL requires adequate resources and well-designed instructional materials that guide students through each phase of project development. Therefore, integrating PjBL into chemistry practicum requires structured guidance that supports inquiry and collaborative learning.

Augmented Reality (AR) in Chemistry Learning

Augmented Reality (AR) overlays virtual elements such as 3D models or animations onto real-world objects, enabling users to interact with complex scientific phenomena in immersive ways. In chemistry education, AR has been proven to enhance students' visualization of molecular structures, reaction mechanisms, and laboratory procedures (Fadhilah & Nasution, 2025; Yamtinah et al., 2023). AR-based media provide multimodal learning experiences that promote spatial reasoning and increase engagement (Mazzuco et al., 2022). For example, interactive AR simulations have been shown to significantly improve students' understanding of abstract concepts and reduce misconceptions (Wulandari et al., 2020). However, most AR applications in chemistry primarily serve as visualization tools rather than integrated learning environments that promote inquiry and collaboration (Amirah & Mahartika, 2023). Hence, AR needs to be embedded within pedagogical frameworks such as PjBL to achieve deeper learning outcomes.

Integration of PjBL and AR for Chemistry Practicum Innovation

Combining PjBL and AR represents a promising innovation in chemistry education. The PjBL framework provides the pedagogical foundation for inquiry-based learning, while AR enhances visualization and interactivity (Yani, 2023). This integration allows students to design experimental projects supported by real-time augmented representations of chemical systems, bridging the gap between theoretical understanding and experimental application. Prior studies have explored similar integrations in various scientific disciplines, reporting positive impacts on student engagement, motivation, and conceptual mastery (Yamtinah et al., 2023). Few studies have specifically developed chemistry practicum guides that combine these two elements, particularly within the context of electrolysis experiments.

This study thus contributes to the literature by developing a PjBL-based chemistry practical guide integrated with AR technology designed to enhance students' understanding and engagement in electrolysis experiments. The integration not only supports visualization of abstract electrochemical processes but also encourages project-based inquiry, teamwork, and creativity, key competencies of 21st-century learners.

METHODS

Research Design

This study employed a Research and Development (R&D) design using the 4D model developed by Thiagarajan, Semmel, and Semmel, which consists of four main stages: Define, Design, Develop, and Disseminate (Figure 1) (Thiagarajan, 1974). However, this research was conducted only up to the Develop stage due to its focus on creating and validating the chemistry practical guide. The goal of this study was to develop a Project-Based Learning (PjBL) integrated with Augmented Reality (AR) practical guide for electrolysis and evaluate its validity, practicality, and feasibility based on expert and user assessments.

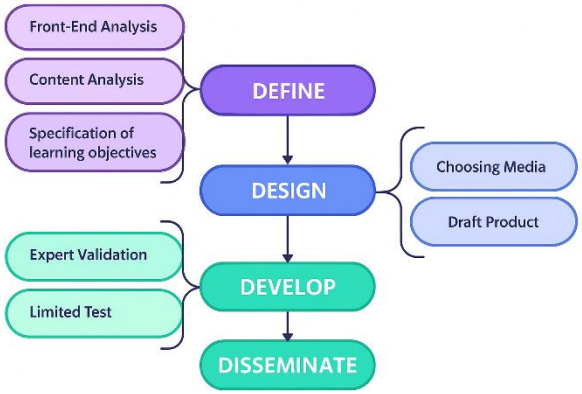


Figure 1. 4D Development Model

Define Stage

The Define stage aimed to identify the fundamental needs and constraints in current chemistry practicum activities. Several analyses were conducted:

- Curriculum and Competency Analysis: The relevant learning objectives and core competencies (Cognitive: C3–C4 level) for the electrolysis topic were identified from the Indonesian high school chemistry curriculum.
- Learner and Context Analysis: Surveys and interviews with chemistry teachers and students revealed that most learners experienced difficulty understanding the electrolysis process due to its abstract nature and limited visualization in conventional lab manuals.
- Concept and Task Analysis: The key concepts to be included in the guide, electrolyte types, electrode reactions, ion migration, and product identification, were analyzed to align with the inquiry process in the PjBL model.

Design Stage

At the Design stage, a blueprint of the PjBL-AR Chemistry Practical Guide was created. The structure of the guide was developed following the five main syntax stages of PjBL: (1) project orientation, (2) planning and design, (3) project implementation, (4) presentation and analysis, and (5) reflection and evaluation (Yulhendri et al., 2023).

- The printed guidebook was designed to include project tasks, experimental steps, reflection questions, and integrated AR components.
- The AR components were developed using Blender 3D software for model creation and Unity integrated with Vuforia SDK for AR application development (Vidal-Balea et al, 2021; Kurt & İnce, 2020).
- Each section contained QR codes or markers that allowed users to access 3D visualizations of electrolysis apparatus, ion movements, and electrode reactions using smartphones.
- A draft version of the guide was reviewed by chemistry education experts before proceeding to product development.

Develop Stage

The Develop stage involved creating and validating the practical guide, followed by user response testing. Product validation was carried out by three experts in chemistry education (content) and two media design experts using structured rubrics.

- Material Expert Validation: Focused on content accuracy, curriculum alignment, clarity of learning objectives, integration of PjBL syntax, and appropriateness of AR features.

- Media Expert Validation: Assessed layout consistency, visual design, readability, interactivity, and ease of navigation.

  Both expert groups provided quantitative ratings and qualitative feedback, which were used to refine the product iteratively.

After validation, the revised version of the guide was tested in a limited implementation involving two chemistry teachers and sixteen high school students in Langsa, Indonesia. The teachers and students completed questionnaires evaluating the guide's practicality, clarity, attractiveness, and usefulness. Data were collected through observation and response forms after participants used the guide in a simulated electrolysis experiment.

Instruments

Four types of instruments were used according to each development phase:

1. Need Analysis Questionnaire, to identify initial learning difficulties and media requirements.
2. Expert Validation Rubric, consisting of 18 indicators for material validity and 19 for media validity, using a 4-point Likert scale (1 = poor, 4 = excellent).
3. Teacher Response Questionnaire, containing 8 statements evaluating practicality and pedagogical relevance.
4. Student Response Questionnaire, consisting of 8 items assessing comprehension, motivation, and interactivity.

Data Analysis

Quantitative data from the validation rubrics and response questionnaires were analyzed using descriptive statistics to determine the percentage of validity and practicality. The formula used was:

$$\text{Percentage Score} = \frac{Total\ obtained\ score}{Maximum\ possible\ score} \times 100\%$$

Scores above 85% were categorized as *very valid* or *very practical* (Sugiyono, 2025). Meanwhile, qualitative data from expert comments and participant feedback were analyzed thematically to refine the final version of the product.

RESULT AND DISCUSSION

The development of the Chemistry Practical Guide integrating Project-Based Learning (PjBL) and Augmented Reality (AR) for the electrolysis topic was completed through the *Define*, *Design*, and *Develop* stages of the 4D model (Figure 2 & 3). The developed guidebook combines project-based inquiry with interactive AR visualizations to enhance students' conceptual understanding and engagement. The results include product validation by experts, and responses from teachers and students as potential users.



Figure 2. Cover of the Augmented Reality-based Electrolysis Practical Guide



Figure 3. Interface design of the Augmented Reality-based Electrolysis Practical Guide

Validation of the Practical Guide

a. Material Expert Validation

Material experts assessed the accuracy, completeness, and pedagogical quality of the content. The validation focused on five aspects: curriculum alignment, conceptual accuracy, depth of material, integration of PjBL, and integration of AR technology.

The average score of material validation was 93.8%, categorized as "very valid". This indicates that the developed practical guide accurately represents electrolysis concepts, aligns with curriculum competencies, and effectively integrates PjBL and AR components. The experts highlighted that AR visualization successfully clarified abstract concepts such as electron flow and electrode reactions, while the PjBL structure strengthened scientific reasoning and collaboration.

Table 1. Result of Material Expert Validation

Aspect	Percentage (%)	Category
Curriculum and content relevance	94.0	Very valid
Concept accuracy and scientific correctness	94.7	Very valid
Depth and scope of materials	91.7	Very valid
Integration of Project-Based Learning	93.3	Very valid
Integration of Augmented Reality	94.0	Very valid
Usefulness and meaningfulness for students	92.0	Very valid
Average	**93.8**	**Very valid**

b. Media Expert Validation

Table 2. Result of Media Expert Validation

Aspect	Percentage (%)	Category
Visual design and layout	93.0	Very valid
Readability and language clarity	91.5	Very valid
Illustration and AR quality	95.0	Very valid
Consistency and navigation	94.0	Very valid
Interactivity and practicality	93.5	Very valid

Aspect	Percentage (%)	Category
Average	**93.4**	**Very valid**

Media experts evaluated the design, interactivity, readability, and functionality of the AR elements. The total mean score was 93.4%, classified as "very valid." The design layout was deemed attractive and consistent with the learning context of high school students. Experts also reported that the AR application (developed with Blender 3D and Unity) worked seamlessly and provided intuitive access through QR codes embedded in the guide.

Teacher Response toward Practical Guide

The teacher response questionnaire focused on the feasibility and pedagogical practicality of the developed product. Two chemistry teachers from Langsa city participated in the limited trial.

Table 3. Teacher Response toward the Developed Practical Guide

Aspect	Percentage (%)	Category
Content alignment with curriculum	95.0	Very good
Support for Project-Based Learning	87.5	Good
AR usefulness in understanding electrolysis	87.5	Good
Clarity of instructions and procedures	87.5	Good
Attractiveness of guide design	87.5	Good
Encouragement of student activeness	100.0	Excellent
Time suitability for classroom implementation	75.0	Fair
Potential as a reference for school learning	95.0	Very good
Average	**90.6**	**Very good**

The average percentage of teacher responses was 90.6%, indicating excellent practicality. Teachers agreed that the integration of PjBL promoted inquiry-oriented instruction and that AR features enhanced students' interest and conceptual clarity. They also noted that the guide could serve as a reliable instructional reference for classroom-based or independent laboratory activities.

Student Response toward Practical Guide

A limited-scale trial was conducted with 16 high school students. The response questionnaire included aspects of comprehension, motivation, attractiveness, and interactivity.

The average score obtained from students was 90.6%, categorized as "very positive." Students expressed that the PjBL structure encouraged them to participate actively, while the AR components helped them visualize ion migration and electrode reactions effectively. The combination of real and virtual learning environments also increased their enjoyment and engagement in chemistry practicals.

Table 4. Student Response toward the Developed Practical Guide

Indicator	Percentage (%)	Category
Ease of understanding content	89.0	Very positive
Interest in Project-Based Learning approach	91.0	Very positive
Usefulness of AR for concept visualization	94.0	Very positive
Clarity of practical steps and instructions	88.0	Positive
Attractiveness of the guide	91.0	Very positive
Motivation to learn chemistry	90.0	Very positive
Activeness during practicum	88.0	Positive
Appropriateness of allocated time	87.0	Positive
Average	**90.6**	**Very positive**

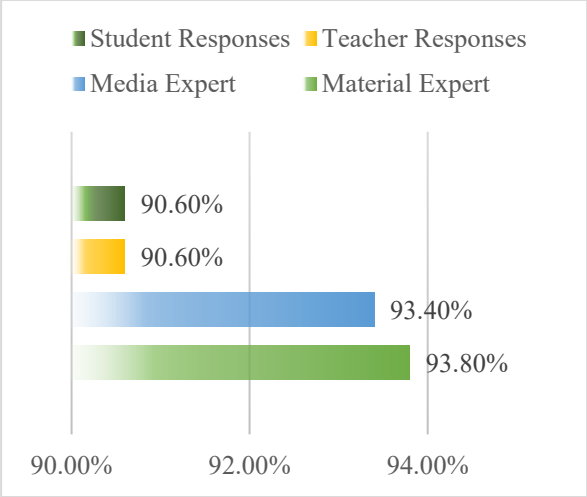


Figure 4. Average Percentage of Validation and Responses of Practical Guide

DISCUSSION

The results demonstrate that the developed PjBL-AR Chemistry Practical Guide is valid, practical, and feasible for supporting electrolysis learning. The high validity scores (≥93%) from material and media experts confirm that the guide's content and interface meet pedagogical and technological standards. These findings are consistent with Yamtinah et al. (2023), who reported that AR-based chemistry learning media enhance conceptual understanding through multimodal visualization.

The integration of Project-Based Learning provided an authentic learning framework that promotes scientific inquiry, collaboration, and reflection, skills aligned with 21st-century competencies (Retno et al., 2025; Eswaran, 2024; Williamson, 2023). Meanwhile, the Augmented Reality elements acted as cognitive scaffolds that help students visualize invisible electrochemical processes, supporting constructivist learning principles. This aligns with the findings of Wulandari et al. (2020), who emphasized the role of AR in improving students' creative thinking and engagement.

Teacher responses indicate that the guide has strong pedagogical relevance and can bridge the gap between theory and practice. Similarly, student feedback suggests that integrating AR into project-based learning creates an engaging, interactive environment that improves motivation and conceptual retention. These findings correspond to previous works showing that blended approaches combining AR and inquiry-based learning improve students' learning outcomes (Mazzuco et al., 2022; Amirah & Mahartika, 2023).

The novel contribution of this research lies in developing a comprehensive practical guide that not only visualizes abstract concepts but also integrates structured project tasks within the AR-enhanced practicum context. This dual integration represents a pedagogical and technological advancement in chemistry education, particularly in electrochemical learning materials.

CONCLUSION

The developed Chemistry Practical Guide integrating Project-Based Learning (PjBL) and Augmented Reality (AR) on electrolysis was proven valid and practical, with expert validation scores exceeding 93% and user responses >90%. The integration of PjBL fostered critical thinking and collaboration, while AR enhanced visualization of abstract electrochemical processes. This innovation bridges theoretical understanding and experimental inquiry, offering an engaging alternative for chemistry practicum. Further research should examine its implementation on a larger scale to evaluate long-term learning impacts.

ACKNOWLEDGEMENT

The authors would like to express their sincere gratitude to Universitas Samudra for providing financial support for this research through the Institute for Research and Community Service (LPPM) under the Assistant Lecturer Research Scheme with grant number 3/UN54.6/PT.01.03/2025. The authors also thank all teachers and students who participated in this study for their valuable contributions and cooperation during the research process.

REFERENCES

Agustian, H. Y., Finne, L. T., Jørgensen, J. T., Pedersen, M. I., Christiansen, F. V., Gammelgaard, B., & Nielsen, J. A. (2022). Learning outcomes of university chemistry teaching in laboratories: A systematic review of empirical literature. *Review of Education*, *10*(2), e3360. https://doi.org/10.1002/rev3.3360

Amaliyah, N. I., Aznam, N., & Dewi, S. S. (2024). Analysis of Students' Scientific Attitude Through Experience Practicum Activities in Chemistry Learning. *Jurnal Penelitian Pendidikan IPA*, *10*(1), 19-27. https://doi.org/10.29303/jppipa.v10i1.6068

Amirah, G., & Mahartika, I. (2023). Penuntun Praktikum Termokimia berbasis Augmented Reality: Kajian Efektivitas Media. *Journal of Natural Sciences Learning*, *2*(2), 83-89. https://jom.uin-suska.ac.id/index.php/JNSL/article/view/477

Eswaran, U. (2024). Project-based learning: Fostering collaboration, creativity, and critical thinking. In *Enhancing education with intelligent systems and data-driven instruction* (pp. 23-43). IGI Global Scientific Publishing. https://doi.org/10.4018/979-8-3693-2169-0.ch002

Fadhilah, N. F. & Nasution, H. A. (2025). Development of Chemistry E-Modules Based on Augmented Reality Technology on Hydrocarbon Material. *Jurnal Inovasi Pembelajaran Kimia*, *7*(1), 123-133. https://doi.org/10.24114/jipk.v7i1.67921

Hermawan, A., & Syarifuddin, Y. (2022). Kajian Teoretik Penerapan Project Based Learning dalam Praktikum Ilmu Pengetahuan Alam. *SEARCH: Science Education Research Journal*, *1*(1), 42-47. http://e-jurnal.iainsorong.ac.id/index.php/jaser/article/view/1239

Hutahaean, E., Pardiana, P., & Hadiyati, Y. (2024). Identify Students' misconceptions on electrolysis using two-tier diagnostic test. *Journal of Research in Environmental and Science Education*, *1*(1), 1-11. https://doi.org/10.70232/bvc08237

Karan, E., & Brown, L. (2022). Enhancing Student's Problem-Solving Skills through Project-Based Learning. *Journal of Problem Based Learning in Higher Education*, *10*(1), 74-87. https://eric.ed.gov/?id=EJ1361504

Khalil, M. (2025). Pengembangan AR Book Bioinformatika: Visualisasi In Silico Potensi Tanaman Herbal Lokal. *Jurnal Jeumpa*, *12*(1), 57-68. https://doi.org/10.33059/jj.v12i1.11629

Kurt, G., & İnce, G. (2020). ARgent: A web based augmented reality framework for dynamic content generation. *Avrupa Bilim ve Teknoloji Dergisi*, 244-257. https://doi.org/10.31590/ejosat.779946

La Braca, F., & Kalman, C. S. (2021). Comparison of labatorials and traditional labs: The impacts of instructional scaffolding on the student experience and conceptual understanding. *Physical Review Physics Education Research*, *17*(1), 010131. https://doi.org/10.1103/PhysRevPhysEducRes.17.010131

Loyens, S. M., Van Meerten, J. E., Schaap, L., & Wijnia, L. (2023). Situating higher-order, critical, and critical-analytic thinking in problem-and project-based learning environments: A systematic review. *Educational Psychology Review*, *35*(2), 39.

https://doi.org/10.1007/s10648-023-09757-x

Mazzuco, A., Krassmann, A. L., Reategui, E., & Gomes, R. S. (2022). A systematic review of augmented reality in chemistry education. *Review of Education*, *10*(1), e3325. https://doi.org/10.1002/rev3.3325

Mishra, N. R. (2023). Constructivist approach to learning: An analysis of pedagogical models of social constructivist learning theory. *Journal of research and development*, *6*(01), 22-29. https://doi.org/10.3126/jrdn.v6i01.55227

Nainggolan, B., Hutabarat, W., & Gultom, L. (2019). Pengembangan Penuntun Praktikum Kimia Inovatif Terintegrasi Pembelajaran Berbasis Proyek dan Karakter Pada Materi Koloid. *Jurnal Inovasi Pembelajaran Kimia*, *1*(2), 50-57. https://doi.org/10.24114/jipk.v1i2.14760

Nasution, S. L. S., & Setyaningrum, W. (2024). Enhancing higher-order thinking and conceptual understanding through STEM-PjBL: A comprehensive assessment of its impact on education. *Indonesian Journal of Educational Research and Review*, *7*(3), 656-666. https://doi.org/10.23887/ijerr.v7i3.81285

Rahmah, A. & Sugiharti, G. (2024). Application of STEM-based LKPD on Reaction Rate Material to Improve Students' Critical Thinking Ability. *Jurnal Inovasi Pembelajaran Kimia*, *5*(2), 141-147. https://doi.org/10.24114/jipk.v5i2.55215

Retno, R. S., Purnomo, P., Hidayat, A., & Mashfufah, A. (2025). Conceptual framework design for STEM-integrated project-based learning (PjBL-STEM) for elementary schools. *Asian Education and Development Studies*, *14*(3), 579-604. https://doi.org/10.1108/AEDS-08-2024-0188

Rezika, R. & Sugiharti, G. (2025). Development of Chemistry Learning Module Based on Discovery Learning on the Periodic Properties of Elements *Jurnal Inovasi Pembelajaran Kimia*, *7*(1), 144-153. https://doi.org/10.24114/jipk.v7i1.67941

Silma, N., Maulida, I., Wulan, A. P., Merawati, J., & Hasan, M. K. (2024). A comprehensive review of Project-Based Learning (PBL): Unravelling its aims, methodologies, and implications. *Journal of Education, Social & Communication Studies*, *1*(1), 10-19. https://ojs.ptmjb.com/index.php/JESCS/article/view/3

Simbolon, N. R. L. & Panggabean, F. T. M. (2025). Development of a PjBL-Based Digital Flipbook Module on Chemical Bonding for Grace XI Students. *Jurnal Inovasi Pembelajaran Kimia*, *7*(1), 38-46. https://doi.org/10.24114/jipk.v7i1.67531

Sinaga, M., Silaban, R., & Jahro, I. S. (2021, March). Development of chemistry practicum guidelines with the support of STEM (science, technology, engineering, and mathematics) integrating character education. In *Journal of Physics: Conference Series* (Vol. 1811, No. 1, p. 012058). IOP Publishing. https://doi.org/10.1088/1742-6596/1811/1/012058

Sugiyono. (2025). *Statistika untuk penelitian (Edisi Revisi).* Alfabeta, Bandung.

Thiagarajan., S. et al. (1974). *Instructional Development for Training Teachers of Exceptional Children: A Source Book*.

Minnesota: University of Minnesota. https://files.eric.ed.gov/fulltext/ED090725.pdf

Vidal-Balea, A., Blanco-Novoa, Ó., Fraga-Lamas, P., & Fernández-Caramés, T. M. (2021). Developing the next generation of augmented reality games for pediatric healthcare: An open-source collaborative framework based on ARCore for implementing teaching, training and monitoring applications. *Sensors*, *21*(5), 1865. https://doi.org/10.3390/s21051865

Williamson, E. (2023). The effectiveness of project-based learning in developing critical thinking skills among high school students. *European Journal of Education*, *1*(1), 1-11. https://forthworthjournals.org/journals/index.php/EJE/article/view/26

Wulandari, R., Widodo, A., & Rochintaniawati, D. (2020). Penggunaan aplikasi augmented reality untuk memfasilitasi penguasaan konsep dan keterampilan berpikir kreatif peserta didik. *Jurnal Pendidikan Biologi Universitas Negeri Malang*, *11*(2), 59-69. https://doi.org/10.17977/um052v11i2p59-69

Yamtinah, S., VH, E. S., Saputro, S., Ariani, S. R. D., Shidiq, A. S., Sari, D. R., & Ilyasa, D. G. (2023). Augmented reality learning media based on tetrahedral chemical representation: How effective in learning process?. *Eurasia Journal of Mathematics, Science and Technology Education*, *19*(8), em2313. https://doi.org/10.29333/ejmste/13436

Yani, A. F. S. (2023). Analisis Kebutuhan Bahan Ajar Interaktif Berbasis Augmented Reality (AR) Pada Topik Elektrolisis. *KATALIS: Jurnal Penelitian Kimia dan Pendidikan Kimia*, *6*(2), 75-81. https://doi.org/10.33059/katalis.v6i2.9006

Yani, A. F. S., & Oktaviani, C. (2022). Praktikum Kimia SMA Kelas XI pada Materi Asam Basa Sesuai Model Discovery dan Project Based Learning. *KATALIS: Jurnal Penelitian Kimia Dan Pendidikan Kimia*, *5*(1), 17-24. https://doi.org/10.33059/katalis.v5i1.5367

Yulhendri, Y., Prima Sakti, M. R., Sofya, R., Ritonga, M., Alisha, W. P., Sudjatmoko, A., & Susanti, N. (2023). Strategies for project based learning during the pandemic: The benefits of reflective learning approach. *Sage Open*, *13*(4), 21582440231217885. https://doi.org/10.1177/21582440231217885