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Development of a PjBL-STEM General Chemistry Module Integrated with Electroplating for Redox and Electrolysis

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Abstract: *Redox reactions and electrolysis involve abstract chemical concepts that require teaching materials connecting theoretical explanations with contextual phenomena. However, the integration of electroplating as a central project in PjBL–STEM–based General Chemistry modules on these topics remains underexplored. This study aimed to develop a PjBL–STEM General Chemistry teaching module integrating electroplating and to evaluate its validity and practicality. A research and development (R&D) approach was employed using a modified 4D model comprising three stages: define, design, and develop. Data were collected using subject-matter and media validation forms and a student response questionnaire administered to 30 third-semester Chemistry Education students. Validity was analyzed using Aiken's V, while practicality was expressed as a percentage of student responses. The subject-matter and media validity coefficients were 0.903 and 0.874, respectively, both classified as high. The overall practicality score was 87.50%, classified as very practical. These findings indicate that the developed module meets the validity and practicality criteria and can serve as a supplementary learning resource for redox reactions and electrolysis in General Chemistry.*

Keywords: *PjBL–STEM; General Chemistry; teaching module; electroplating; redox and electrolysis*

INTRODUCTION

Chemistry learning in higher education should enable students to apply chemical concepts to explain phenomena and solve problems in real-world contexts. However, the abstract nature of chemistry, which involves macroscopic, submicroscopic, and symbolic representations, can make some concepts difficult to understand when instruction relies primarily on theoretical explanations (PROKŠA et al., 2018). Teaching materials should therefore combine conceptual explanations with structured activities that help students connect theoretical knowledge with observable phenomena and their applications (Bilek, 2026).

Redox reactions and electrolysis require students to understand electron transfer, oxidation numbers, redox-equation balancing, and processes occurring in electrochemical cells. Previous research has reported difficulties in learning redox and electrochemistry, highlighting the need for contextualized learning resources that connect chemical concepts with observable phenomena (Pratama et al., 2024; Prihastyanti et al., 2020). Electroplating, the electrolytic deposition of a metal coating, provides a relevant context for connecting these concepts

with electrode reactions, metal deposition, electrical variables, and quantitative experimental observations (Asworo, 2023; Péter, 2024). Its integration into project-based learning and Science, Technology, Engineering, and Mathematics (STEM) education can provide a coherent context for applying chemical concepts to a technological process.

Previous studies have developed STEM–PjBL-based learning resources for electrochemistry. Widarti et al. (2020) highlighted the need for video-supported teaching materials on electrolytic cells, while Rokhim et al. (2020) developed flipbook-based materials on redox and electrochemistry supported by instructional videos. Pratama et al. (2024) examined the implementation of STEM–PjBL in redox and electrochemistry learning. Electroplating has also been investigated as a STEM learning context. Sandi (2021) examined STEM-based electroplating instruction in relation to students' conceptual understanding, critical-thinking skills, and collaboration. These studies establish the relevance of STEM–PjBL resources and electroplating activities in chemistry education. However, they do not address the specific development of a structured General Chemistry module that uses copper electroplating as the central project for connecting redox reactions and electrolysis through the stages of Project-Based Learning (PjBL) and the four STEM components.

The needs analysis conducted in this study indicated that the teaching materials used in project-based learning activities did not provide sufficiently clear and systematic guidance. Instructions were often presented as brief bullet points and did not fully explain the steps required for project implementation. Students also reported that laboratory activities helped them connect learning materials with observable phenomena. These findings indicated a need for a learning resource that integrates conceptual explanations, structured project stages, experimental procedures, and contextual applications.

Previous research has demonstrated the development of project-based and STEM-integrated chemistry learning resources for various topics. Sinaga & Sagala (2021) developed a project-based module on thermochemistry, while Purba & Sembiring (2023) developed a project-based module on chemical equilibrium. Other studies reported PjBL–STEM or STEM-integrated resources for buffer solutions (Aulya et al., 2021), solubility and solubility products (Makuasa et al., 2024), chemical equilibrium (Gurusinga et al., 2024; Ibrahim & Sutiani, 2025), and electrolyte and nonelectrolyte solutions (Ma'sumah & Mitarlis, 2021). Although these studies demonstrate the application of project-based and STEM-integrated approaches across chemistry topics, the integration of copper electroplating as the central project in a General Chemistry module connecting redox reactions and electrolysis remains comparatively underexplored. The present study addresses this gap by developing a PjBL–STEM General Chemistry module that integrates the electroplating experiment into a structured project.

The module was designed to connect the four STEM components within a single project. Science is represented by the principles of redox reactions and electrolysis; Technology by the electroplating process and digital learning media; Engineering by the design and assembly of the electroplating system; and Mathematics by measurement and experimental data processing. These components are incorporated into structured project activities intended to guide students through the application of chemical concepts to an observable technological process.

Accordingly, this study aimed to develop a PjBL–STEM General Chemistry module integrating an electroplating experiment into redox reactions and electrolysis and to evaluate its validity based on subject-matter and media expert assessments and its practicality based on student responses. The study addressed the

following research questions: (1) How valid is the developed module according to subject-matter and media experts? and (2) How practical is the developed module based on student responses?

LITERATURE REVIEW

Research and Development (R&D)

Research and development (R&D) is a systematic approach to developing or validating educational products (Sugiyono, 2014). Its stages generally include needs analysis, product design, expert validation, trials, and revision (Sugiyono, 2014). In educational research, R&D has been used to develop instructional materials, including teaching materials, student worksheets, and assessment instruments (Efendi et al., 2022). Previous studies have also applied this approach to chemistry teaching materials and laboratory modules, assessing their validity and practicality (Pratiwi et al., 2020; Anggraini et al., 2019). These studies provide a methodological basis for developing and evaluating the module in the present study.

4D Model

The 4D model developed by Thiagarajan et al. (1974) comprises four stages: define, design, develop, and disseminate. These stages involve analyzing learning needs and objectives, designing the product, validating and revising it, and distributing it to intended users (Zamsiswaya et al., 2024). The model has been applied in chemistry education, including the development of a digital flipbook module on chemical bonding (Simbolon & Panggabean, 2025). In this study, the model was modified to include only the define, design, and develop stages because the research focused on module development and the evaluation of its validity and practicality.

Teaching Module

A teaching module is a structured learning resource that organizes content and activities according to learning objectives and student characteristics (Astuti et al., 2024). In chemistry education, modules can help connect abstract concepts with observable phenomena. Electrochemistry requires students to relate macroscopic observations to microscopic processes and symbolic representations. Integrating conceptual explanations with contextualized activities can support these connections (Triayuni et al., 2023). This consideration informed the development of a module linking redox reactions and electrolysis with a copper electroplating project.

Project-Based Learning (PjBL)

Project-Based Learning (PjBL) engages students in investigating problems through structured projects, commonly involving question formulation, project planning, scheduling, progress monitoring, product assessment, and reflection (Jannah et al., 2023). In chemistry education, PjBL can connect theoretical concepts with practical applications. Damanik et al. (2024) examined a PjBL-assisted e-module on electrolyte and nonelectrolyte solutions, while Hanif et al. (2024) described PjBL–STEM activities involving problem identification, product design, experimentation, data analysis, presentation, and reflection. These stages informed the organization of the present module, which guides students through project planning, electroplating activities, data processing, analysis, and presentation.

Science, Technology, Engineering, and Mathematics (STEM) Approach

STEM integrates Science, Technology, Engineering, and Mathematics through connected, contextualized learning experiences to address real-world problems (Kelley & Knowles, 2016; Halawa et al., 2024). In chemistry education, this approach links chemical principles with technological applications, system design, and quantitative analysis. Asih et al. (2020) developed a PjBL-based, STEM-integrated module on voltaic cells, while Sari et al. (2026) developed STEM–PBL-based thermochemistry materials and evaluated their validity and practicality. These studies demonstrate the relevance of STEM integration in chemistry

teaching materials. In the present module, Science involves redox reactions and electrolysis, Technology involves the electroplating apparatus and digital media, Engineering involves designing and assembling the system, and Mathematics involves measurement and experimental data analysis.

Redox and Electrolysis

Redox reactions involve electron transfer and form the basis of electrochemical processes. Their study includes determining oxidation numbers and identifying oxidation and reduction through electron loss or gain (Ali et al., 2024; Yuen et al., 2024). Electrolysis uses electrical energy to drive a nonspontaneous chemical reaction. In electroplating, metal ions in an electrolyte are reduced at the cathode, forming a metal coating on the object's surface (Fahmi & Zamrudy, 2021). In copper electroplating, Cu^{2+} ions gain electrons at the cathode to form metallic copper, while oxidation occurs at the anode (Asworo, 2023). These principles provide the scientific foundation for integrating copper electroplating as a project connecting redox reactions and electrolysis in the developed module.

METHODS

Research Design

This study employed a Research and Development (R&D) approach to develop a General Chemistry teaching module integrating Project-Based Learning (PjBL), Science, Technology, Engineering, and Mathematics (STEM), and an electroplating experiment for redox reactions and electrolysis. The development procedure adapted the Four-D model proposed by Thiagarajan et al. (1974), which consists of four stages: define, design, develop, and disseminate. In this study, the development process was limited to the define, design, and develop stages, while the disseminate stage was not conducted.

Development Procedure

The development procedure consisted of three stages. In the define stage, an analysis was conducted of instructional needs, student characteristics, curriculum requirements, redox reactions and electrolysis content, and the need for teaching materials integrating project-based activities and experiments. In the design stage, the module structure, learning objectives, instructional content, PjBL–STEM activities, activity worksheets, experimental procedures, and evaluation instruments were designed.

The develop stage involved preparing the initial module, conducting expert validation, revising the product based on validator feedback, and assessing the module's practicality. At this stage, an electroplating experiment was also conducted to develop the experimental procedure, documentation, video, and supporting data to be incorporated into the module. The electroplating experiment used an iron nail as the cathode and copper as the anode in a 0.3 M $CuSO_4$ solution, with an electrode separation of 5 cm. The electric current was maintained at a constant 1200 mA, while the voltage and plating duration were varied across 7.5, 9, and 12 V and 30, 45, and 60 minutes, respectively. Before plating, the iron nail was cleaned with 70% alcohol for approximately 15 minutes and then subjected to pickling in 15% H_2SO_4 for 10–15 seconds. The nail was subsequently rinsed with distilled water, dried, and weighed. After electroplating, the nail was rinsed, dried, and weighed again. The resulting procedures, documentation, and supporting data were then incorporated into the teaching module. The electroplating activity was conducted as part of the module development process and was not intended to evaluate instructional effectiveness.

Validators and Participants

Product validation was conducted by three validators: one lecturer in chemistry or science and two Chemistry Education lecturers who taught General Chemistry. All three validators assessed the content and

media aspects of the developed module using the corresponding validation instruments.

The practicality assessment involved 30 third-semester students enrolled in a Chemistry Education program. The class was selected because the students had previously studied redox reactions and electrolysis in a General Chemistry course and therefore possessed relevant prior knowledge. All students in the selected class participated as respondents using total population sampling (census sampling).

The practicality assessment was conducted in a single session lasting 150 minutes, equivalent to three semester credit units (SKS). The students reviewed the developed module, including its instructional content, PjBL–STEM activities, electroplating activity, and evaluation components, and subsequently completed a student response questionnaire. The students did not perform the electroplating experiment during the practicality assessment.

Data Collection Techniques

Validity data were collected using subject-matter and media expert validation forms completed by the three validators. Each validator assigned a score to every indicator and provided written comments or suggestions to inform product revisions. Practicality data were collected through a student response questionnaire administered after the students had reviewed the developed module. Documentation of the electroplating experiment, including photographs, videos, experimental procedures, and supporting observational results, was used as supplementary data during module development.

Research Instruments

Three instruments were used in this study: a subject-matter expert validation form, a media expert validation form, and a student response questionnaire. The subject-matter validation form consisted of 16 items covering four aspects: content appropriateness, accuracy and clarity of the material, presentation quality, and language appropriateness. The media validation form consisted of 15 items covering three aspects: visual design and layout, readability and navigation, and instructional media presentation. Both validation forms used a four-point Likert scale (1–4).

The student response questionnaire consisted of 20 items covering five aspects: interest and motivation, readability and ease of understanding, presentation appeal and quality, PjBL–STEM integration, and experimental activities and module benefits. The questionnaire used a five-point Likert scale (1–5).

Data Analysis Techniques

a. Validity Analysis

The validity of the developed module was analyzed using Aiken's V coefficient, calculated using Equation (1) (Tajuddin et al., 2025):

$$V = \frac{\sum s}{n(c-1)} \qquad (1)$$

where V is the validity coefficient, r is the score assigned by a validator, l_0 is the lowest score on the rating scale, n is the number of validators, and c is the number of rating categories. The value of s is calculated as $s = r - l_0$. In this study, the validation involved three validators ($n = 3$), the lowest rating was 1 ($l_0 = 1$), and the validation scale consisted of four categories ($c = 4$).

For each aspect, the scores assigned by each validator to the items belonging to that aspect were summed to obtain an aspect-level total score for each validator. The Aiken's V coefficient for each aspect was calculated using the item-level ratings for the corresponding aspect. The overall Aiken's V coefficient was calculated using the ratings for all items in the validation instrument.

The resulting Aiken's V coefficients were interpreted according to the criteria presented in Table 1.

Table 1. Categories of Aiken's V validity coefficients

Aiken's V coefficient	Category
$V \geq 0.80$	High
$0.70 \leq V < 0.80$	Moderate
$V < 0.70$	Poor

(Tajuddin et al., 2025)

b. Practicality Analysis

The practicality of the developed module was analyzed descriptively based on the student response questionnaire. The questionnaire used a five-point Likert scale ranging from 1 to 5. The practicality percentage was calculated using Equation (2) (Arman et al., 2019):

$$P = \frac{f}{N} \, x \, 100\% \qquad (2)$$

where P is the practicality percentage, f is the total score obtained, and N is the maximum possible score. The practicality results were interpreted using the criteria in Table 2.

Table 2. Practicality categories

Percentage	Criteria
$80\% < x \leq 100\%$	Very practical
$60\% < x \leq 80\%$	Practical
$40\% < x \leq 60\%$	Practical enough
$20\% < x \leq 40\%$	Less practical
$0\% < x \leq 20\%$	Very less practical

(Arman et al., 2019)

All validity and practicality calculations were performed using Microsoft Excel.

RESULT AND DISCUSSION

Define Stage

The define stage identified instructional needs related to redox reactions and electrolysis. The needs analysis indicated that existing teaching materials did not provide sufficiently systematic guidance for project implementation. Accordingly, the module was designed around copper electroplating on iron nails to connect redox and electrolysis concepts with observable electrode reactions and technological applications. Previous studies have also used metal-plating activities as a context for chemistry learning (Purwanti et al., 2023; Asworo, 2023).

Design Stage

The module was organized into learning objectives, conceptual explanations, project planning, experimental procedures, data analysis, reflection, exercises, and evaluation. Its electroplating project integrated all four STEM components: Science through redox and electrolysis concepts; Technology through the power supply and digital media; Engineering through system design and assembly; and Mathematics through measurement and data analysis. This integrated design is consistent with previous chemistry teaching materials developed around electrolytic cells (Widarti et al., 2020) and chemical equilibrium (Ibrahim & Sutiani, 2025).

Develop Stage

The develop stage resulted in a PjBL–STEM General Chemistry teaching module integrating an electroplating experiment to contextualize redox reactions and electrolysis. The experiment used an iron nail as the cathode and copper as the anode, with a power supply providing electrical energy. Figure 1 documents the experimental setup, plating process, and the iron nail before and after copper plating.

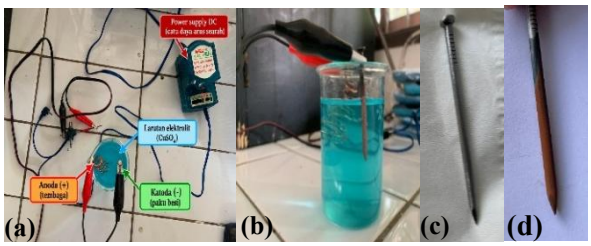


Figure 1. Electroplating experiment: (a) experimental setup, (b) plating process, (c) iron nail before plating, and (d) iron nail after copper plating

Photographs and video documentation were incorporated into the module to illustrate the experimental procedure and observable electrochemical processes. The use of videos in chemistry learning and laboratory activities has also been discussed by Rachmawati et al.

(2025) and Schmidt-mccormack et al. (2017). These materials served as instructional resources rather than evidence of learning effectiveness.

Figure 2 presents selected components of the developed module, illustrating the organization of its instructional materials and project activities.

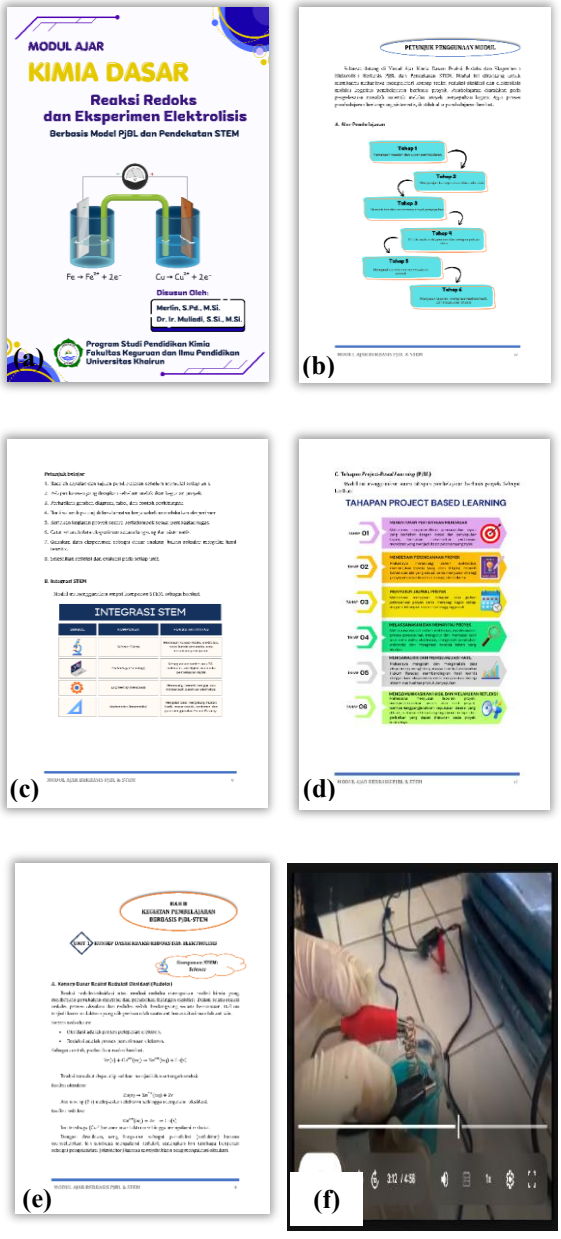


Figure 2. Selected components of the developed module: (a) cover, (b) learning instructions, (c) STEM integration, (d) PjBL stages, (e) redox learning materials, and (f) electroplating video

a. Validity Assessment

The developed module was evaluated by three validators for subject-matter and media validity using a four-point rating scale. The data were analyzed using Aiken's V. Expert assessment is an important step in evaluating the content appropriateness and presentation quality of teaching materials before user trials (Rahma & Azhar, 2021; Cahyani et al., 2024).

Subject-matter validity covered four aspects: content appropriateness, accuracy and clarity, presentation quality, and language appropriateness. The results are presented in Table 3.

Table 3. Aiken's V Results for Subject-Matter Validation of the PjBL–STEM General Chemistry Module

Aspect	No. of Items	V_1	V_2	V_3	Aiken's V	Category
Content appropriateness	4	15	14	16	0.917	High
Accuracy and clarity of the material	4	14	14	14	0.833	High
Presentation quality	4	15	14	16	0.917	High
Language appropriateness	4	16	15	15	0.944	High
Average	16				0.903	High

Content appropriateness obtained an Aiken's V value of 0.917 (high), reflecting the alignment of the material with the Course Learning Outcomes (CPMK) and sub-course learning outcomes (Sub-CPMK), STEM integration, redox and electrolysis concepts, and supporting examples. The electroplating project provided a context for applying these concepts, consistent with the importance of content appropriateness in teaching material evaluation (Mubarok et al., 2024).

Accuracy and clarity obtained the lowest subject-matter value (0.833), although it remained in the high-validity category. This aspect covered conceptual accuracy, terminology, explanations, reaction equations,

calculations, and content depth. The result highlights the need to ensure clear connections between observable phenomena, particle-level processes, and symbolic representations in explaining electrode reactions and electroplating equations. This consideration is consistent with Sukmawati, (2019), who discussed macroscopic, microscopic, and symbolic representations in electrochemistry learning.

Presentation quality also obtained a high value (0.917), reflecting the alignment of PjBL stages, STEM components, content sequence, exercises, and evaluation with the learning objectives. The module organized activities from project planning and electroplating to data processing and presentation Sakina et al., (2025) similarly emphasized the importance of integrating chemical representations in presenting voltaic cell content.

Language appropriateness received the highest subject-matter value (0.944). The assessment covered grammar, spelling, instructional clarity, communicative language, and readability for students. This result indicates that language was the most favorably assessed subject-matter aspect, consistent with the role of language appropriateness in teaching material evaluation (Marisa et al., 2025).

Media validity covered visual design and layout, readability and navigation, and instructional media presentation. The results are shown in Table 4.

Table 4. Aiken's V Results for Media Validation of the PjBL-STEM General Chemistry Module

Aspect	No. of Items	V_1	V_2	V_3	Aiken's V	Category
Visual design and layout	5	19	18	18	0.889	High
Readability and navigation	5	19	18	20	0.933	High
Instructional media presentation	5	17	17	17	0.800	High
Average	15				0.874	High

Visual design and layout obtained an Aiken's V value of 0.889 (high), based on the cover, text and image layout, color and contrast, illustration placement, and tables and diagrams. This result indicates that the visual components met the validators' criteria. The relevance of visual elements and their connection to textual explanations are important considerations in teaching material design (Ge & Lai, 2021; Goes et al., 2009)

Readability and navigation received the highest media validity value (0.933). The assessment covered typography, contents and numbering, section differentiation, the sequence of project activities, and the readability of chemical symbols, terminology, units, and equations. The module's organization was designed to help students locate information and follow the learning sequence, consistent with the inclusion of readability and navigation in media validity assessment by Harahap & Nasution (2022).

Instructional media presentation obtained the lowest media value (0.800), although it remained in the high-validity category. The assessment covered the alignment of illustrations with chemical concepts, clarity of activity visuals and instructions, design consistency, and presentation of PjBL stages. This result identifies visual representation and its alignment with explanatory content as areas for further refinement, consistent with Afifah et al. (2023), who emphasized connections between images, text, and accurate chemical representations in redox learning materials.

Based on the subject-matter and media validation results, a comparison of the mean Aiken's V values is presented in Figure 3.

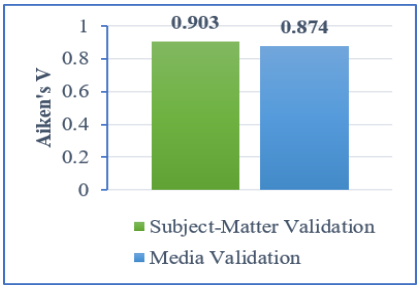


Figure 3. Comparison of the mean Aiken's V values for subject-matter and media validation

The mean Aiken's V values were 0.903 for subject-matter validity and 0.874 for media validity; both were classified as high. These results indicate that the module met the validity criteria based on expert assessments, although instructional media presentation remains an area for refinement. This finding is consistent with Suwadarma et al., (2020), who reported that STEM–PjBL–based chemistry instructional materials met validity criteria.

b. Practicality Assessment

Module practicality was assessed through student responses, as practicality concerns the ease with which users can use a product (Utama & Zulyusri, 2022). Following expert validation and revision, 30 third-semester Chemistry Education students reviewed the module and completed a 20-item questionnaire covering five aspects. The results are presented in Table 5.

Table 5. Practicality Assessment Results for the PjBL-STEM General Chemistry Module

Aspect	No. of Items	Practicality (%)	Category
Interest and motivation	4	86.17	Very practical
Readability and ease of understanding	4	87.67	Very practical
Presentation appeal and quality	4	89.17	Very practical
PjBL-STEM integration	4	87.50	Very practical
Experimental activities and module benefits	4	87.00	Very practical
Overall average	20	87.50	Very practical

Interest and motivation obtained a practicality percentage of 86.17%, classified as very practical. Student responses reflected their perceptions of the module's appeal and their motivation to explore the material. The electroplating project connected redox reactions and electrolysis with practical applications, consistent with Wijnia et al. (2024), who reported a positive relationship between project-based learning and student motivation. However, the present study assessed student perceptions rather than changes in motivation.

Readability and ease of understanding obtained 87.67%, indicating favorable responses to the clarity of language, chemical terminology, explanations, and activity instructions. The importance of textual explanations in supporting understanding of chemistry content has also been discussed by Meyer & Pietzner (2022).

Presentation appeal and quality received the highest percentage (89.17%). This aspect covered visual design, images, tables, layout, and content organization. The result indicates favorable student responses to the module's presentation, consistent with the importance of connecting visual elements with textual explanations in chemistry teaching materials (Dickmann et al., 2019).

PjBL-STEM integration obtained 87.50%, reflecting student responses to the clarity of project stages, integration of STEM components, and connections between chemical concepts and everyday applications. The project connected redox and electrolysis concepts with the use of a power supply, electroplating system design, and experimental data analysis. This approach reflects the integration of science, technology, engineering, and mathematics described by Kelley & Knowles (2016).

Experimental activities and module benefits obtained 87.00%. Student responses addressed the clarity of experimental procedures, data-processing guidance, connections between redox and electrolysis, and the module's usefulness as a learning resource. These components are relevant to electrolysis learning, which connects electrode processes with chemical concepts and reaction equations (Pradani et al., 2020).

Overall, the module obtained a practicality percentage of 87.50%, classified

as very practical. All five aspects received this classification, with presentation appeal and quality scoring highest (89.17%) and interest and motivation lowest (86.17%). These results indicate favorable student responses to the module. A similar practicality classification was reported for a STEM–PjBL–based chemistry e-module by Ibrahim & Sutiani (2025).

Research Limitations

This study was limited to the define, design, and develop stages of the modified 4D model; the disseminate stage and broader implementation were not conducted. The evaluation focused on validity based on expert assessments and practicality based on student responses. Learning outcomes were not measured through pretest–posttest assessments or other instruments; therefore, the module's effectiveness cannot yet be established. Future research should examine its effectiveness and implementation in broader learning contexts.

CONCLUSION

This study developed a PjBL–STEM General Chemistry teaching module integrating an electroplating experiment for redox reactions and electrolysis through the define, design, and develop stages. The module combines chemical concepts, project activities, experimental observations, data processing, and instructional videos. Expert validation yielded Aiken's V coefficients of 0.903 for subject matter and 0.874 for media, both classified as high validity. The practicality assessment yielded 87.50%, classified as very practical, based on student responses. These findings indicate that the module meets the assessed validity and practicality criteria and can serve as a supplementary learning resource for redox reactions and electrolysis in a General Chemistry course. However, its effectiveness in improving learning outcomes remains to be established through further research.

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