Jurnal Pendidikan Kimia
FKIP Universitas Halu Oleo

p-ISSN : 2503-4480
e-ISSN : 2721-2963

Vol. 11, No. 2, August 2026

DOI: https://doi.org/10.36709/jpkim.v11i2.235

DEVELOPMENT OF A CHEMISTRY-LITERACY-ORIENTED E-MODULE ON BIOBATTERIES FOR PRE-SERVICE CHEMISTRY TEACHERS

Mia Salastri[1], Ida Farida[2], Risa Rahmawati Sunarya[3]*, Sari Sari[4]

[1,2,3,4] Chemistry Education Department, Faculty of Tarbiyah Teacher Training, UIN Sunan Gunung Djati, Bandung, Indonesia

*Corresponding Author: risarahmawatis@uinsgd.ac.id

ARTICLE INFO

Received :
10 July 2026
Revised :
04 August 2026
Accepted :
05 August 2026
Published:
31 August 2026

Keywords:
e-module; chemical literacy; biobattery; design-based research; electrochemistry cell.

Kata Kunci:
e-modul; literasi kimia; design-based research; sel elektrokimia.

ABSTRACT

Abstract: The electrochemical cell is one of the most challenging topics in senior high school chemistry learning. Teaching materials oriented toward chemical literacy are needed to help students connect chemical concepts with real-life situations. This study aimed to produce and evaluate a chemical-literacy-oriented e-module on biobattery fabrication using Design-Based Research (DBR) through three phases: analysis-exploration, design-construction, and evaluation-reflection. The e-module was developed using Articulate 360 with six sequential units integrating the four dimensions of chemical literacy. The product was validated by three experts (Pearson's $r = 0.87$, critical value 0.30) and field-tested with 15 pre-service chemistry teacher students, measured with a 10-item test analyzed via N-Gain and a Wilcoxon signed-rank test. The feasibility test was very feasible (96.31%), and chemical literacy increased significantly overall (N-Gain = 0.77, $p < 0.001$), with the highest gain on content ($g = 0.875$), followed by process ($g = 0.692$), context ($g = 0.600$), and attitude ($g = 0.571$); the latter two were not statistically significant, likely due to a ceiling effect at pretest. This study is limited to a small-scale trial without a control group, so implementation with senior high school students and strengthened process-based activities are recommended for future research.

Abstrak: Sel elektrokimia merupakan salah satu topik paling menantang dalam pembelajaran kimia SMA. Bahan ajar berorientasi literasi kimia sangat dibutuhkan agar peserta didik dapat mengaitkan materi kimia dengan kehidupan nyata. Penelitian ini bertujuan menghasilkan dan mengevaluasi e-modul berorientasi literasi kimia pada materi pembuatan biobaterai menggunakan *Design-Based Research* (DBR) melalui tiga tahap: analisis-eksplorasi, desain-konstruk, dan evaluasi-refleksi. E-modul dikembangkan menggunakan aplikasi Articulate 360 dengan enam unit sekuensial yang mengintegrasikan keempat aspek literasi kimia. Produk divalidasi oleh tiga validator ahli ($r = 0{,}87$, nilai kritis 0,30) dan diuji cobakan kepada 15 mahasiswa calon guru kimia, diukur dengan tes 10 butir yang dianalisis menggunakan rumus N-

p-ISSN : 2503-4480
e-ISSN : 2721-2963
Vol. 11, No. 2, August 2026 DOI: https://doi.org/10.36709/jpkim.v11i2.235

Gain dan uji Wilcoxon signed-rank. Uji kelayakan menunjukkan kategori sangat layak (96,31%), dan literasi kimia meningkat signifikan secara keseluruhan (N-Gain = 0,77, p < 0,001), dengan peningkatan tertinggi pada aspek konten (g = 0,875), diikuti proses (g = 0,692), konteks (g = 0,600), dan sikap (g = 0,571); dua aspek terakhir tidak signifikan secara statistik, diduga karena *ceiling effect* saat *pretest*. Penelitian ini masih terbatas pada uji skala kecil tanpa kelompok kontrol, sehingga implementasi langsung kepada peserta didik SMA serta penguatan aktivitas berbasis proses sains disarankan pada penelitian selanjutnya.

How to Cite:
Salastri, M., Farida, I., Sunarya, R. R., & Sari, S. (2026). Development of a Chemistry-Literacy-Oriented e-Module on Biobatteries for Pre-Service Chemistry Teachers. *Jurnal Pendidikan Kimia FKIP Universitas Halu Oleo*, 11(2), 220–244. https://doi.org/10.36709/jpkim.v11i2.235

INTRODUCTION

The electrochemical cell is a key topic in the chemistry curriculum, as it explains the working principles of batteries, fuel cells, and corrosion processes (Harahap, 2016). Nevertheless, various studies show that this material is difficult for students to understand (Nisa & Fitriza, 2021; Sutantri, 2022). (Sutantri, 2022) concluded from a literature review that students experience difficulty particularly in integrating the three levels of chemical representation—macroscopic, submicroscopic, and symbolic—among which students still poorly understand the relationship between the flow of electric current and electrode reactions and cell potential. In addition, Nisa & Fitriza (2021) found that students often understand electrochemistry merely as a concept disconnected from everyday phenomena. This is presumably because teaching materials and instructional approaches are insufficiently linked to real-life contextual problems, tending instead to be rote and abstract (Raman et al., 2024).

This learning difficulty originates directly from schools, so addressing it strategically also requires strengthening the readiness of the teachers who will soon teach there; pre-service chemistry teachers, who possess adequate content and pedagogical grounding and will shortly undergo teaching practicum (PPL) before entering schools as certified teachers, represent an appropriate entry point for introducing an innovative, literacy-oriented digital teaching tool before it reaches students directly, as pre-service chemistry teachers' technological and pedagogical readiness has

p-ISSN : 2503-4480
e-ISSN : 2721-2963
Vol. 11, No. 2, August 2026 DOI: https://doi.org/10.36709/jpkim.v11i2.235

been shown to develop through structured exposure to digital teaching innovations during their professional preparation (Nugraheni & Srisawasdi, 2025). Equipping pre-service teachers with effective pedagogical tools during this preparation stage, rather than only after they are already in service, has likewise been associated with stronger readiness to adopt innovative, field-relevant teaching practices once they begin their practicum and classroom teaching (Evitasari et al., 2025).

This condition has a direct implication for students' low chemical literacy. Chemical literacy is the ability to understand chemical concepts, analyze scientific evidence, and relate chemistry to real-world problems in an integrated manner (Laila et al., 2022). Afifah & Yusmaita (2019) asserted that chemistry instruction needs to be explicitly designed to optimize the dimensions of literacy—by selecting topics relevant to students' lives, employing inquiry-based strategies, and establishing authentic contexts. Chemical literacy itself encompasses four main domains—context, content, science process, and scientific attitude—which collectively form students' holistic scientific competence (Afifah & Yusmaita, 2019). Integrating these four dimensions into teaching materials is a necessity, so that students not only master theory but are also able to apply and evaluate chemical concepts in real situations.

The development of interactive e-modules is regarded as one promising solution to this challenge. Prior research on general chemistry topics has demonstrated the benefits of e-modules for conceptual understanding and learning outcomes, for example through the integration of a scientific-literacy orientation (Raharjo et al., 2017), a trait treatment interaction model (Aswirna et al., 2024), the Flip PDF Professional platform (Seruni et al., 2019), and a problem-solving approach (Sunarya et al., 2024). However, none of these four studies fully integrated a four-dimension chemical literacy framework, and on the specific topic of electrochemistry, available approaches remain limited to a nature-of-science orientation (Suryati et al., 2022) and a conventional scientific approach (Hutabarat et al., 2021), without explicitly mapping content to all four dimensions of chemical literacy.

On other chemistry topics, a chemical-literacy-oriented approach delivered through digital media has proven effective: interactive multimedia on the sublimation topic was found valid ($r = 0.81$) and very feasible (91%) (Sunarya et al., 2026), while an interactive video quiz based

p-ISSN : 2503-4480
e-ISSN : 2721-2963
Vol. 11, No. 2, August 2026 DOI: https://doi.org/10.36709/jpkim.v11i2.235

on problem-based learning improved chemical literacy on the topic of water pollution (Adhwa et al., 2025). Both studies confirm the generalizability of a digital-media-based chemical literacy approach across topics, yet no e-module has explicitly combined a biobattery context with a structured chemical literacy framework on the topic of electrochemistry. This gap underlies the present study: the absence of electrochemistry teaching materials that (a) employ an applicative biobattery context close to students' everyday lives, while simultaneously (b) explicitly mapping the four dimensions of chemical literacy into their structure and learning activities.

The novelty of this study lies in the explicit integration of four elements that have not previously been combined in a single electrochemistry e-module: (1) biobattery content as an applicative context close to students' lives; (2) the Articulate 360 platform, which affords higher interactivity—an interactive E°cell calculator and automatic feedback—compared with e-modules built on Adobe Flash (Raharjo et al., 2017); (3) a sequential learning system in the form of locked navigation that requires mastery of one unit before accessing the next, applying a scaffolding principle relevant to the hierarchical nature of electrochemistry learning difficulties (Sutantri, 2022); and (4) the explicit mapping of the four dimensions of chemical literacy (context, content, process, attitude) onto the unit structure and onto practice questions pitched at cognitive levels C4-C5, unlike Suryati et al. (2022) and Hutabarat et al. (2021), which did not explicitly map a chemical literacy framework across all dimensions. The material development was further grounded in a formal concept analysis of 13 core electrochemistry concept labels (definitions, critical attributes, and superordinate-coordinate-subordinate hierarchies), a procedure not reported in previous electrochemistry e-module research. This combination of four elements constitutes the primary novelty of this study, rather than a mere claim that similar products "remain limited."

Based on the foregoing, this study addresses three research questions: (1) How is a chemical-literacy-oriented e-module on biobattery material developed and what are its results using Articulate 360? (2) How valid and feasible is the e-module according to content experts, media experts, and users? (3) How does pre-service chemistry teachers' chemical literacy improve after using the e-module, and on which aspects is the improvement statistically significant? This study's contribution to chemistry education is to provide preliminary evidence for an electrochemistry e-

p-ISSN : 2503-4480
e-ISSN : 2721-2963
Vol. 11, No. 2, August 2026 DOI: https://doi.org/10.36709/jpkim.v11i2.235

module design that explicitly integrates biobattery content, the Articulate 360 platform, sequential learning, and the four dimensions of chemical literacy at once, together with an example of a more rigorous statistical evaluation procedure (normality testing, nonparametric difference testing, effect size, and ceiling-effect analysis) for the small-scale one-group pretest-posttest designs commonly encountered in teaching-material development research.

METHOD

This study used a Design-Based Research (DBR), or Educational Design Research, approach. DBR is a systematic inquiry into designing, developing, and evaluating educational interventions with the aim of solving complex problems in education while generating widely usable knowledge (McKenney & Reeves, 2018). The research procedure followed the three core DBR stages of (McKenney & Reeves, 2018): (1) Analysis and Exploration; (2) Design and Construction; and (3) Evaluation and Reflection. The activities and outputs of each stage are presented in Table 1.

Table 1. Activities and Outputs of Each Design-Based Research Stage

DBR Stage	Activities	Output
Analysis and Exploration	Literature review and preliminary study on electrochemistry learning difficulties; needs assessment for chemical-literacy-oriented teaching materials; determination of the four chemical literacy aspects as the achievement framework; review of biobattery material	Problem formulation, chemical literacy framework, and scope of biobattery material
Design and Construction	Preparation of a concept-analysis table (13 core concept labels), concept map, flowchart, and storyboard; e-module development in Articulate 360 in .html format; conversion to .apk using Web2APK to enable installation on Android devices (Latip, 2022)	A six-unit e-module draft integrated with the four dimensions of chemical literacy
Evaluation and Reflection	Validation testing by three expert validators; product revision based on validator input; feasibility testing and limited trial with 15 pre-service chemistry teacher students; learning evaluation through pretest-posttest	A validated final e-module, feasibility data, and chemical literacy improvement data

p-ISSN : 2503-4480
e-ISSN : 2721-2963
Vol. 11, No. 2, August 2026 *DOI: https://doi.org/10.36709/jpkim.v11i2.235*

This study was carried out through a single design-evaluate-revise cycle (not an iterative multi-cycle process), with product revision conducted once based on validator input before the limited trial was administered; consequently, no re-testing with the validators or second evaluation cycle was carried out after revision. This single-cycle limitation is discussed further in the Conclusion. From this process, one generalizable design principle was formulated: hierarchical electrochemistry material should be presented through a locked sequential-navigation system that requires mastery of a prerequisite concept before students may access a more complex concept.

Validation testing was conducted by three expert validators selected based on the alignment between their area of expertise and the aspect being assessed, comprising two content experts who reviewed every aspect of the e-module's content, including the accuracy of the electrochemistry concepts, the depth of the material, and its alignment with chemical literacy indicators, as well as one media expert who reviewed the media and appearance aspects, including navigation functionality, visual quality, and product interactivity. This three-validator composition was considered adequate because it covers two main domains of expertise relevant to the product being developed, namely content expertise and instructional-media/technical expertise, so that the validation process assessed not only scientific accuracy but also the quality of presentation and the product's overall technical usability. The validation instrument was a five-point Likert questionnaire (5 = very good, 4 = good, 3 = fairly good, 2 = poor, 1 = very poor) covering four aspects: e-module appearance, presentation, language, and content. Validation data were analyzed using the Pearson product-moment correlation coefficient (r), compared against a critical value of $r = 0.30$; an instrument or aspect was declared valid if $r > 0.30$ (Sugiyono, 2017).

The limited trial involved 15 sixth-semester Chemistry Education students at UIN Sunan Gunung Djati Bandung as pre-service chemistry teachers. Participants were selected using purposive sampling with the following criteria: (a) had completed the Electrochemistry course, and (b) had completed the Instructional Media course, so that they possessed both content and pedagogical grounding to evaluate the e-module from two perspectives at once. It should be emphasized that this e-module was designed for senior high school students as its end users, whereas the limited trial at this stage targeted pre-service chemistry teachers. This

p-ISSN : 2503-4480
e-ISSN : 2721-2963
Vol. 11, No. 2, August 2026 DOI: https://doi.org/10.36709/jpkim.v11i2.235

choice of subjects was based on considerations of practicality for a small-scale study and on pre-service teachers' capacity to critically evaluate the product's pedagogical quality; however, the implication is that generalizing the learning outcomes (N-Gain) to senior high school students as the primary target must be done cautiously and requires direct testing in future research.

Participants were given an oral explanation of the study's purpose and voluntarily agreed to participate, as confirmed by their signature on the feasibility questionnaire sheet. The study was conducted during the current even-semester academic year; the sequence of activities from validation testing through the limited trial spanned three weeks.

The feasibility test used a Likert-scale questionnaire covering four aspects (content, language, media, and appearance) completed by 15 participants. Learning evaluation was conducted through a pretest and posttest using 10 chemical-literacy-oriented multiple-choice items (total score 100), covering four aspects: context (items 4, 9), content (items 2, 3, 8), process (items 5, 6, 10), and attitude (items 1, 7). Before being used for the main measurement, the 15 participants' pretest responses were analyzed to obtain item characteristics, including the difficulty index (proportion of correct answers), the discrimination index (the difference in the proportion of correct answers between the upper 27% and lower 27% groups based on total score), and test reliability using the Kuder-Richardson-20 (KR-20) formula, which is appropriate for dichotomous correct-incorrect data (Handayani & Iba, 2020).

Pretest-posttest data were analyzed through several stages. First, descriptive statistics (mean, standard deviation, minimum-maximum) were calculated for pretest, posttest, and N-Gain scores, both overall and per chemical literacy aspect. Second, learning improvement was calculated using the normalized N-Gain formula at the class-average level [g = (mean posttest − mean pretest) / (ideal maximum score − mean pretest)], with categories of high ($g \geq 0.70$), moderate ($0.30 \leq g < 0.70$), and low ($g < 0.30$). Third, a Shapiro-Wilk normality test was applied to the difference scores (posttest − pretest), as it is appropriate for small sample sizes (Mishra et al., 2019). Fourth, because the difference-score data were not normally distributed (explained in the Results section), a Wilcoxon signed-rank test (nonparametric) was used as a substitute for the paired-sample t-test, at a significance level of $\alpha = 0.05$. Fifth, effect size was calculated

p-ISSN : 2503-4480
e-ISSN : 2721-2963
Vol. 11, No. 2, August 2026 DOI: https://doi.org/10.36709/jpkim.v11i2.235

using the rank-biserial correlation (r) to complement the p value, following general interpretation guidelines: small ($r \approx 0.10–0.29$), moderate ($r \approx 0.30–0.49$), and large ($r \geq 0.50$) (Kraft, 2020). Sixth, the distribution of individual N-Gain categories (high/moderate/low, plus an "already at maximum" category for participants whose pretest score equaled the ideal score) was reported to reveal inter-individual variation rather than only the class average. Seventh, the possibility of a ceiling effect was analyzed by calculating the proportion of participants who had already reached the instrument's maximum score at pretest for each chemical literacy aspect, following the approach described by Staus et al. (2021).

This study used a one-group pretest-posttest design without a control group or random assignment. This design allows for measuring score changes within the same group, but does not permit causal claims that improvement was solely attributable to the e-module, because internal-validity threats such as history, maturation, and testing effects could not be controlled (Bierer et al., 2025). Accordingly, all findings of learning improvement in this study are reported as preliminary evidence, not as evidence of the e-module's causal effectiveness.

RESULT AND DISCUSSION

The results of this study were obtained from the validation questionnaires completed by three expert validators, the feasibility questionnaire, and the limited trial involving 15 Chemistry Education students.

Study of E-Module Material Development

The chemical-literacy-oriented biobattery e-module was developed using the Articulate 360 application and can be accessed on Android devices as well as other digital devices. Development began with the preparation of a concept-analysis table containing 13 core electrochemistry concept labels—including the voltaic cell, redox reactions, oxidation, reduction, anode, cathode, electrolyte, biobattery, organic acid, and biobattery performance factors—followed by the preparation of a concept map, flowchart, and detailed storyboard for each scene and slide. The flowchart's purpose was to lay out the e-module's flow from beginning to end. The storyboard-making process was then carried out to obtain an initial picture of the appearance and description associated with the flowchart. The e-module flowchart is presented in Figure 1.

p-ISSN : 2503-4480
e-ISSN : 2721-2963
Vol. 11, No. 2, August 2026
DOI: https://doi.org/10.36709/jpkim.v11i2.235

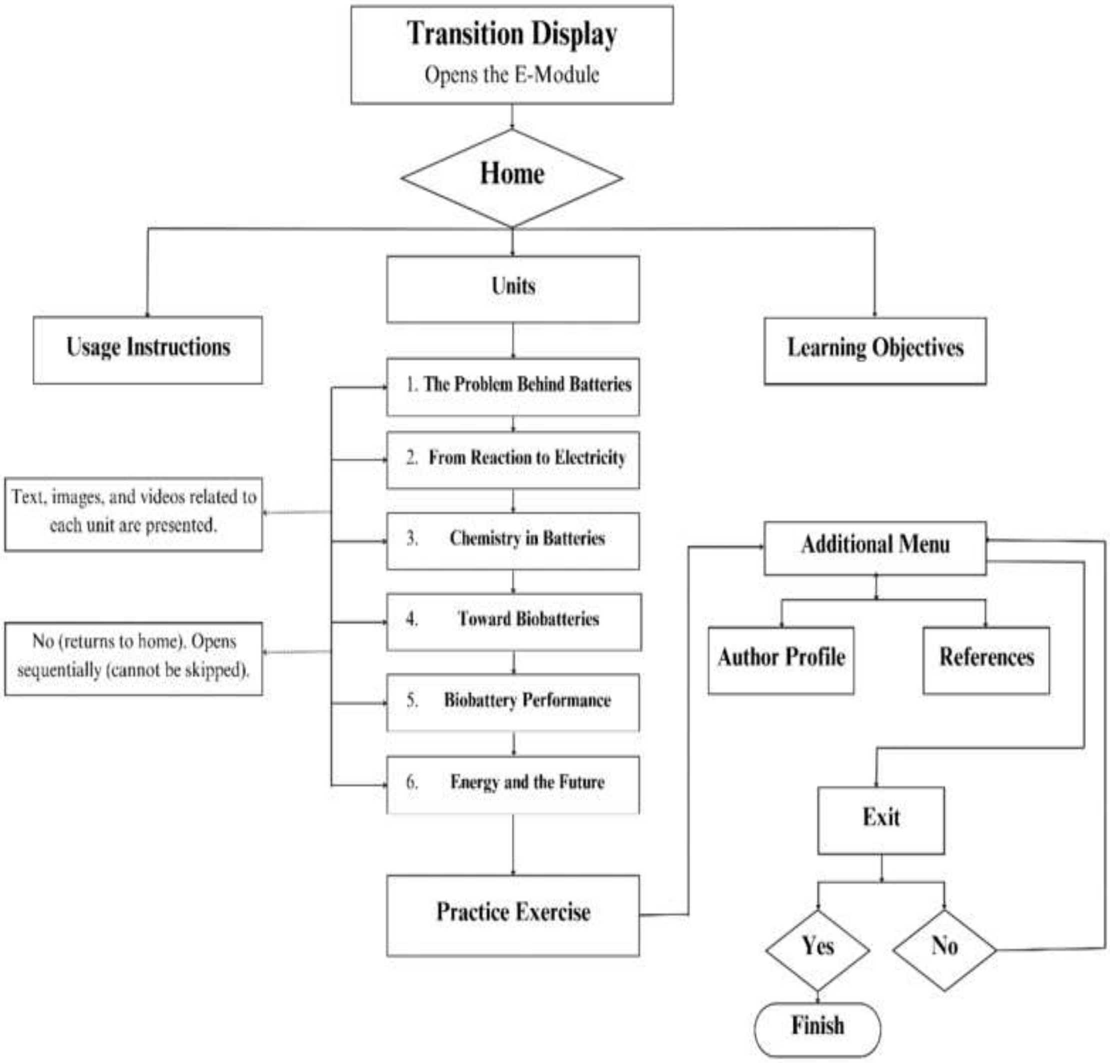

Figure 1. Flowchart of the Chemical Literacy-Oriented E-Module on Biobattery Fabrication

The e-module contains six units arranged sequentially and can only be accessed in order to ensure learning completeness: (1) The Problem Behind Batteries, presenting the context of the environmental impact of conventional batteries and the urgency of biobatteries for students; (2) From Reactions to Electricity, discussing the history of the voltaic cell, redox reactions, and the components of a voltaic cell; (3) Chemistry in Batteries, which reviews organic acids as electrolytes and features an interactive E^0-cell calculator; (4) Toward Biobatteries, which compares variations in electrolytes, electrodes, and series-parallel circuits; (5) Biobattery Performance, analyzing factors that influence biobattery performance; and

p-ISSN : 2503-4480
e-ISSN : 2721-2963
Vol. 11, No. 2, August 2026
DOI: https://doi.org/10.36709/jpkim.v11i2.235

(6) Energy and the Future, linking biobatteries to the SDGs and the global context of renewable energy.

The chemical literacy framework is integrated into the e-module through three main dimensions: (1) Visualization, in the form of phenomenon videos, voltaic cell diagrams, voltage-time graphs, and infographics; (2) Operational chemical literacy indicators for each aspect; and (3) The four aspects of chemical literacy (context, content, process, attitude) as the framework for learning achievement.

These six units are arranged in a graded sequence and can only be accessed in order, so that students cannot move on to the next unit before completing the previous one. This arrangement follows the principle of learning-content sequencing, in which mastery of one concept becomes a prerequisite for understanding more complex concepts at the next stage (Broman et al., 2018; Diantari et al., 2018). The sequence of units in this e-module is designed to help students build understanding gradually, starting from an introduction to the context of energy problems through to the application of concepts in biobattery design. The development details of each unit are described in points (a) through (f) below.

Before accessing the units, users are first directed through the home page and the unit list page as the e-module's initial navigation, as shown in Figure 2 and Figure 3.

Figure 2. Home page of the e-module

p-ISSN : 2503-4480
e-ISSN : 2721-2963
Vol. 11, No. 2, August 2026 *DOI: https://doi.org/10.36709/jpkim.v11i2.235*

Figure 3. Page of the e-module content

(a) The first unit, The Problem Behind Batteries, falls under the context aspect. This unit directs students to analyze the relevance of biobatteries as a solution to the problems of using conventional batteries in daily life, covering alternative energy issues and an initial introduction to biobatteries. Its presentation includes a phenomenon video on everyday battery use, along with trigger questions and initial reflection to build students' awareness of the topic to be studied. The contextual understanding gained at this stage becomes the foundation for students to learn the chemical reactions behind how batteries work in the following unit, as shown in Figure 4.

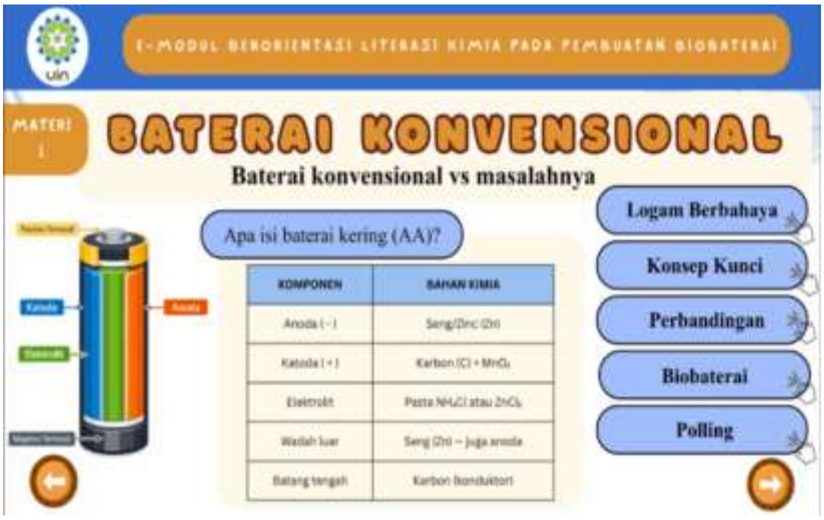

Figure 4. Page of "The Problem Behind Batteries"

Jurnal Pendidikan Kimia
FKIP Universitas Halu Oleo

p-ISSN : 2503-4480
e-ISSN : 2721-2963

Vol. 11, No. 2, August 2026 DOI: https://doi.org/10.36709/jpkim.v11i2.235

(b) The second unit, From Reactions to Electricity, falls under the content aspect and focuses on the concepts of oxidation and reduction reactions as the operating principle of the voltaic cell. Students practice analyzing the components of the voltaic cell and identifying natural materials with the potential to be used as biobatteries, accompanied by explanations of the cell components and electron flow. The understanding of redox reactions built at this stage becomes a prerequisite for understanding its more specific application in the next unit, as shown in Figure 5.

Figure 5. Page of "From Reactions to Electricity"

(c) The third unit, Chemistry in Batteries, remains under the content aspect and emphasizes the application of redox reaction concepts to the operating mechanism of biobatteries, using natural materials such as fruits or vegetables as electrolytes. At this stage, students identify the factors that influence biobattery performance. Understanding of these factors is further deepened in the fourth unit, which focuses on the process aspect, as shown in Figure 6.

Figure 6. Page of "Chemistry in Batteries"

p-ISSN : 2503-4480
e-ISSN : 2721-2963
Vol. 11, No. 2, August 2026
DOI: https://doi.org/10.36709/jpkim.v11i2.235

(d) The fourth unit, Toward Biobatteries, enters the process aspect. Students compare various natural materials as electrolytes based on pH and voltage data, variations in anode-cathode arrangement, and series-parallel circuits, then determine the most effective material with reasoning supported by observational data. The data-analysis skills developed at this stage provide the foundation for comparing biobattery performance more comprehensively in the next unit, as shown in Figure 7.

Figure 7. Page of "Toward Biobatteries"

(e) The fifth unit, Biobattery Performance, continues the process aspect by analyzing comparative data on biobattery performance measurements based on the type of electrolyte used, supported by an infographic on biobattery performance factors and a voltage-time graph. After understanding the technical achievements of biobatteries from a scientific standpoint, students are guided to reflect on the meaning and benefits of biobattery development in the final unit, as shown in Figure 8.

Figure 8. Page of "Biobattery Performance"

p-ISSN : 2503-4480
e-ISSN : 2721-2963
Vol. 11, No. 2, August 2026
DOI: https://doi.org/10.36709/jpkim.v11i2.235

(f) The sixth unit, Energy and the Future, falls under the attitude aspect. This unit invites students to adopt a positive attitude toward opportunities for alternative energy development and to reflect on future energy limitations, presented through a video on alternative energy developments, an infographic on biobattery applications, and reflective statements as the closing of the learning sequence, as shown in Figure 9.

Figure 9. Page of "Energy and the Future"

The e-module is also equipped with interactive features in the form of information pop-ups (key concepts, key facts), embedded instructional videos, an interactive E°cell calculator, and adaptive practice questions pitched at cognitive levels C4 (analyzing) and C5 (evaluating) with automatic feedback; users who answer correctly receive positive confirmation, while those who answer incorrectly receive an explanatory discussion.

The multimodal presentation applied is in line with the cognitive theory of multimedia learning, which states that the simultaneous combination of text, images, and video enhances conceptual understanding and retention more effectively than single-mode presentation (Laila et al., 2022; Mayer, 2014). The sequential learning system is also relevant to the principle of scaffolding in learning, in which understanding of prerequisite concepts is built before moving on to more complex concepts, a principle that is essential for addressing students' hierarchical difficulties in learning electrochemistry (Sutantri, 2022).

p-ISSN : 2503-4480
e-ISSN : 2721-2963
Vol. 11, No. 2, August 2026
DOI: https://doi.org/10.36709/jpkim.v11i2.235

Validation Test Results

The e-module was validated by three expert validators on four aspects: appearance, presentation, language, and content. Data were analyzed using the Pearson product-moment correlation coefficient (r), compared against a critical value of r = 0.30; an aspect was declared valid if the resulting r_{value} exceeded this critical value. The validation test results are presented in Table 2.

Table 2. E-Module Validation Test Results by Three Expert Validators

No	Statement	$R_{observed}$	$R_{critical}$	Result	Interpretation
1	e-Module Display Aspect	0.88	0.30	Valid	High
2	Presentation Aspects	0.88	0.30	Valid	High
3	Linguistic Aspects	0.85	0.30	Valid	High
4	Content Aspects	0.88	0.30	Valid	High
	Average	**0.87**	**0.30**	**Valid**	**High**

The r_{value} on every aspect exceeded the critical value of 0.30, so the e-module was declared valid on all four assessed aspects. The content aspect obtained the highest score (r = 0.88), indicating that the validators considered the accuracy of the electrochemistry concepts and their alignment with chemical literacy indicators to be good. Indicators covering conceptual accuracy, appropriateness of difficulty level for students, the relevance of biobatteries to everyday life, clarity of the four chemical literacy aspects, and the capacity to promote critical thinking were all rated valid with a high interpretation. This finding indicates that the e-module has met the criteria of a valid teaching material according to experts, both in terms of content substance and the technical quality of its media.

Based on validator input, two main revisions were made before the e-module was field-tested: (1) strengthening the visual aesthetic aspect (color contrast, layout of interactive elements) to make it more comfortable for users to access, and (2) raising the cognitive level of the practice questions to analyzing (C4) and evaluating (C5), because the question stimuli in the initial draft were judged not to trigger higher-order thinking processes. This revision is consistent with the principle that chemical-literacy-oriented questions need to require students to analyze data or phenomena, rather than merely recall facts (Laila et al., 2022).

The validity score obtained (r = 0.87) is consistent with the findings of Sunarya et al. (2026) on interactive multimedia for the sublimation topic

p-ISSN : 2503-4480
e-ISSN : 2721-2963
Vol. 11, No. 2, August 2026 *DOI: https://doi.org/10.36709/jpkim.v11i2.235*

(r = 0.81) and is higher than that of an e-module oriented toward the Trait Treatment Interaction model (Aswirna et al., 2024). The consistency of the "high" category across several chemistry media development studies suggests that designs grounded in concept analysis and an explicit literacy framework tend to produce products with good content validity according to expert assessment, although this cross-study comparison should be interpreted cautiously, as the instruments and rating scales used in each study are not identical.

Results of the Limited Trial Test

The limited trial test involved 15 sixth-semester Chemistry Education students at UIN Sunan Gunung Djati Bandung as prospective chemistry teachers. As future educators who will teach chemistry, they were able to evaluate the e-module from two perspectives simultaneously: the user's perspective as learners of biobattery material, and the pedagogical perspective in assessing the quality of the instructional materials.

a. Feasibility Test

The feasibility test was conducted by 15 pre-service chemistry teacher respondents using a Likert-scale questionnaire covering four aspects. The feasibility test results are presented in Table 3.

Table 3. Feasibility test Results (n=15)

No.	Evaluation Aspect	Percentage (%)	Remarks
1	Content Aspect	96.88	Very Feasible
2	Language Aspects	95.55	Very Feasible
3	Media Aspects	97.06	Very Feasible
4	Appearance Aspects	95.73	Very Feasible
	Average	**96.31**	**Very Feasible**

The mean feasibility percentage of the e-module was 96.31%, falling into the Very Feasible category (90-100%). The media aspect obtained the highest percentage (97.06%), reflecting that pre-service chemistry teachers judged the e-module to be very easy to use on Android devices, with functional navigation and an attractive appearance. The content aspect (96.88%) indicated that the biobattery content was perceived as relevant to students' real-life context and explicitly oriented toward the four chemical literacy aspects. The appearance aspect (95.73%) and language aspect (95.55%) likewise fell into the Very Feasible category.

p-ISSN : 2503-4480
e-ISSN : 2721-2963
Vol. 11, No. 2, August 2026
DOI: https://doi.org/10.36709/jpkim.v11i2.235

The high feasibility percentage across all aspects is consistent with the findings of Sunarya et al. (2026) and Adhwa et al. (2025), who likewise reported very high feasibility levels for chemistry instructional media with an applicative context. This result indicates that, according to pre-service chemistry teachers' assessment, the e-module was judged feasible in terms of content, language, media, and appearance. However, because this e-module was designed for senior high school students whereas the feasibility assessment above came from pre-service teachers, this feasibility conclusion cannot yet be generalized directly to the product's primary target users without further testing with senior high school students.

b. Learning Evaluation Results

Learning evaluation was conducted using a pretest and posttest with 10 chemical-literacy-oriented multiple-choice items. Before the pretest-posttest data were analyzed further, item characteristics were analyzed from the 15 pretest responses. The item analysis results are presented in Table 4.

Table 4. Difficulty Index and Discrimination Index of Chemical Literacy Test Items (n=15)

Item	Aspect	Difficulty Index (p)	Category	Discrimination Index (D)	Category
1	Attitude	0.800	Easy	0.750	Excellent
2	Content	0.667	Moderate	0.250	Fair
3	Content	0.800	Easy	0.250	Fair
4	Context	0.733	Easy	0.750	Excellent
5	Process	0.667	Moderate	0.000	Poor
6	Process	0.800	Easy	0.250	Fair
7	Attitude	0.733	Easy	0.250	Fair
8	Content	0.467	Moderate	1.000	Excellent
9	Context	0.600	Moderate	0.500	Good
10	Process	0.667	Moderate	0.250	Fair

Based on Table 4, the test instrument's reliability, calculated using the Kuder-Richardson-20 (KR-20) formula, was 0.58, which falls into the moderate reliability category (Handayani & Iba, 2020). Nine of the ten items had a discrimination index in the fair-to-excellent category, but item 5 (process aspect) had a discrimination index of 0.000 (poor category),

p-ISSN : 2503-4480
e-ISSN : 2721-2963
Vol. 11, No. 2, August 2026 *DOI: https://doi.org/10.36709/jpkim.v11i2.235*

meaning this item was unable to distinguish between high- and low-ability participants at pretest. This finding is an important note: the chemical literacy test instrument in this study, particularly for the process aspect and some other aspects represented by only 2-3 items, still has psychometric limitations that need to be improved in future research, for example by revising or replacing item 5 and increasing the number of items per aspect.

Descriptive statistics, normality-test results, and the overall pretest-posttest difference test are presented in Table 5.

Table 5. Descriptive Statistics and Overall Pretest-Posttest Difference Test for Chemical Literacy (n=15)

Statistic	Pretest (%)	Posttest (%)
Mean	69.33	91.33
SD	20.52	9.15
Minimum	10	80
Maximum	90	100

Class-level N-Gain: 0.77 (High category) Shapiro-Wilk normality test (posttest-pretest difference score): $W = 0.700$; $p = 0.00025$ (< 0.05) → data not normally distributed Wilcoxon signed-rank test: $p = 0.00056$ (< 0.05) → statistically significant improvement Effect size (rank-biserial r): $r = 1.000$ (large category)

Because the difference-score data were not normally distributed (Shapiro-Wilk $p < 0.05$), the difference test used was the Wilcoxon signed-rank test rather than the paired-sample t-test. The test results show that the overall improvement in chemical literacy was statistically significant ($p < 0.001$) with a large effect size. Nevertheless, this overall average picture may mask variation at the level of individual chemical literacy aspects, so an aspect-level analysis was needed and is presented in Table 6.

Table 6. N-Gain, Difference Test, and Effect Size by Chemical Literacy Aspect (n=15)

Aspect	Pretest (%)	Posttest (%)	Class N-Gain	Cate gory	p (Wilcoxon)	Signifi cant?	Effect size (r)	% Already at Maximu m at Pretest
Context	66.67	86.67	0.600	Mode rate	0.063	No	1.000	53.3% (8/15)

p-ISSN : 2503-4480
e-ISSN : 2721-2963
Vol. 11, No. 2, August 2026
DOI: https://doi.org/10.36709/jpkim.v11i2.235

Content	64.44	95.56	0.875	High	0.002	Yes	1.000	20.0% (3/15)
Process	71.11	91.11	0.692	Mode rate	0.008	Yes	0.808	26.7% (4/15)
Attitude	76.67	90.00	0.571	Mode rate	0.102	No	0.667	60.0% (9/15)

To complement the class-average picture, the distribution of N-Gain categories at the individual level (rather than the average) is presented in Table 7, in response to the need to examine variation among participants rather than only the group average.

Table 7. Distribution of Individual N-Gain Categories by Chemical Literacy Aspect (n=15)

Aspect	High	Moderate	Low (including negative)	Already at Maximum at Pretest
Overall	8	7	0	0
Context	3	1	3	8
Content	10	1	1	3
Process	9	1	1*	4
Attitude	4	1	1*	9

**One participant in the process aspect and one participant in the attitude aspect experienced a score decrease (negative N-Gain) from pretest to posttest.*

Tables 6 and 7 show a far more nuanced picture than the overall average in Table 5. On the content aspect, every indicator (high N-Gain, significance p = 0.002, large effect size) shows a consistent and strong improvement. The process aspect also shows a significant improvement (p = 0.008), although one participant experienced a score decrease. In contrast, on the context and attitude aspects, the Wilcoxon signed-rank test did not show a statistically significant difference (p = 0.063 and p = 0.102, respectively), even though the class-average N-Gain fell into the moderate category. This lack of significance is consistent with the finding in Table 6 that 53.3% of participants on the context aspect and 60.0% of participants on the attitude aspect had already reached the instrument's maximum score at pretest, so that, mathematically, no room for improvement was available for the majority of participants on these two aspects—a ceiling effect (Staus et al., 2021). In other words, the relatively low N-Gain on the context and attitude aspects is most likely not caused by a weakness of the e-module in facilitating these two aspects, but rather by

p-ISSN : 2503-4480
e-ISSN : 2721-2963
Vol. 11, No. 2, August 2026 DOI: https://doi.org/10.36709/jpkim.v11i2.235

the instrument's limitation in detecting improvement among participants whose initial ability was already high.

Two participants with negative N-Gain were also found, one each on the process and attitude aspects. The score decrease in these cases cannot be explained with certainty from the available data, but may be attributable to factors such as answering errors, fatigue during the posttest, or an ambiguous item (particularly item 5, which was identified as having a poor discrimination index in Table 4); this finding is reported transparently as part of the learning evaluation, rather than being hidden behind the group average.

Based on the entire analysis above, it can be concluded that the e-module shows strong preliminary evidence of improving chemical literacy on the content and process aspects, but has not yet been statistically proven effective on the context and attitude aspects in this trial—largely due to a measurement limitation (ceiling effect) rather than solely a weakness of the product. The claim that the e-module is "equally effective for all users" is not supported by the data and therefore cannot be sustained; the findings of this study are more appropriately interpreted as preliminary evidence of the e-module's potential, given that a one-group design without a control group does not permit causal claims of effectiveness (Bierer et al., 2025).

This finding also needs to be interpreted in light of subject appropriateness: the trial was conducted with sixth-semester pre-service chemistry teachers who already possessed a foundation in electrochemistry concepts, not with the senior high school students who are the e-module's primary target. The relatively high pretest scores on some aspects (context and attitude) likely reflect participants' prior knowledge as advanced-level students, and this ceiling-effect pattern may not appear, or may appear in a different pattern, if the e-module were tested directly with the senior high school students who are its intended users. Further testing with senior high school students using a control-group design is therefore strongly recommended before an effectiveness claim for the product can be made convincingly.

p-ISSN : 2503-4480
e-ISSN : 2721-2963
Vol. 11, No. 2, August 2026 DOI: https://doi.org/10.36709/jpkim.v11i2.235

CONCLUSION

This study produced a chemical-literacy-oriented e-module on biobattery material, developed through a single Design-Based Research cycle (analysis-exploration, design-construction, evaluation-reflection) using Articulate 360, comprising six units with locked sequential navigation that map electrochemistry content onto the four dimensions of chemical literacy. The e-module was declared valid by three expert validators on all aspects (mean r = 0.87) and very feasible according to the assessment of 15 pre-service chemistry teacher students (mean 96.31%). The learning evaluation showed a statistically significant improvement in chemical literacy at the overall level (class N-Gain = 0.77, $p < 0.001$) as well as specifically on the content and process aspects, whereas on the context and attitude aspects the improvement was not statistically significant, mainly because most participants had already reached scores near the instrument's maximum at pretest (a ceiling effect).

This study has a number of limitations that warrant attention both in interpreting the results and in future research. First, the trial involved a small sample (n = 15) without a control group and without random assignment, precluding causal claims about the e-module's effectiveness. Second, the participants were sixth-semester pre-service chemistry teachers rather than the senior high school students who are the product's primary target users; generalizing the results to students requires direct testing. Third, the chemical literacy test instrument used (10 items) had moderate reliability (KR-20 = 0.58) and one item with a poor discrimination index, along with a still-limited number of items per aspect (2-3 items), making aspect-level measurement less precise. Fourth, product development went through only a single design-evaluate-revise cycle without post-revision re-testing. In practical terms, this e-module can be used as an alternative contextual electrochemistry teaching material at the higher-education level, as well as a promising prototype for further development for students. Future research is recommended to implement the e-module directly with students using a control-group or quasi-experimental design, to strengthen the test instrument (particularly for the context and attitude aspects so that they are not constrained by a ceiling effect, and to revise or replace items with low discrimination indices), and to carry out additional DBR cycles to further validate the resulting design principle.

p-ISSN : 2503-4480
e-ISSN : 2721-2963
Vol. 11, No. 2, August 2026 DOI: https://doi.org/10.36709/jpkim.v11i2.235

ACKNOWLEDGMENT

The researchers express their sincere appreciation to UIN Sunan Gunung Djati Bandung, the validators, students, and peer reviewers for their support and valuable contributions to this study.

REFERENCES

Adhwa, J. B., Sunarya, R. R., Sari, S., Farida, I., & Izzulhaq, B. D. (2025). The Use of Problem Based Interactive Video Quizzes to Improve Students' Chemical Literacy on the Topic of Water Pollution. *Jurnal IPA & Pembelajaran IPA*, *9*(2), 650–665. https://doi.org/10.24815/jipi.v9i2.46249

Afifah, S., & Yusmaita, E. (2019). Perancangan Assesmen Literasi Kimia Pada Materi Termokimia Kelas XI SMA/MA. *Edukimia*, *1*(3), 79–83. https://doi.org/10.24036/ekj.v1.i3.a60

Aswirna, P., Wardani, T., Asrar, A., Fahmi, R., & Fahmi, D. M. (2024). Designing a Thermochemistry E-Module Based on the Trait Treatment Interaction Educational Model for Madrasah Aliyah Students. *JTK (Jurnal Tadris Kimiya)*, *9*(1), 102–112. https://doi.org/10.15575/jtk.v9i1.30924

Bierer, S. B., Beck Dallaghan, G., Borges, N. J., Brondfield, S., Fung, C. C., Huggett, K. N., Teal, C. R., Thammasitboon, S., & Colbert, C. Y. (2025). Moving Beyond Simplistic Research Design in Health Professions Education: What a One-Group Pretest-Posttest Design Will Not Prove. *MedEdPORTAL, 21, Article 11527*. https://doi.org/10.15766/mep_2374-8265.11527

Broman, K., Bernholt, S., & Parchmann, I. (2018). Using model-based scaffolds to support students solving context-based chemistry problems. *International Journal of Science Education*, *40*(10), 1176–1197. https://doi.org/10.1080/09500693.2018.1470350

Diantari, L. P. E., Damayanthi, L. P. E., Sugihartini, N. S., & Wirawan, I. M. A. (2018). Pengembangan E-Modul Berbasis Mastery Learning Untuk Mata Pelajaran KKPI Kelas XI. *Jurnal Nasional Pendidikan Teknik Informatika (JANAPATI)*, *7*(1), 33. https://doi.org/10.23887/janapati.v7i1.12166

p-ISSN : 2503-4480
e-ISSN : 2721-2963
Vol. 11, No. 2, August 2026 *DOI: https://doi.org/10.36709/jpkim.v11i2.235*

Evitasari, A. D., Wilujeng, I., Tohani, E., Trisnani, N., & Hermansyah, A. K. (2025). Prospective elementary teachers' pedagogical understanding in science: a qualitative study from Indonesia. *Cogent Education*, *12*(1). https://doi.org/10.1080/2331186X.2025.2556621

Handayani, S. L., & Iba, K. (2020). Karakteristik Tes Keterampilan Proses Sains: Validitas, Reliabilitas, Tingkat Kesukaran dan Daya Pembeda Soal. *Publikasi Pendidikan*, *10*(2), 100. https://doi.org/10.26858/publikan.v10i2.13051

Harahap, M. R. (2016). Sel Elektrokimia: Karakteristik dan Aplikasi. *CIRCUIT: Jurnal Ilmiah Pendidikan Teknik Elektro*, *2*(1). https://doi.org/10.22373/crc.v2i1.764

Hutabarat, P. M., Sanova, A., & Syamsurizal, S. (2021). Modul Elektronik Berbasis Pendekatan Saintifik pada Materi Ikatan Kimia. *Orbital: Jurnal Pendidikan Kimia*, *5*(2), 178–187. https://doi.org/10.19109/ojpk.v5i2.9471

Kraft, M. A. (2020). Interpreting Effect Sizes of Education Interventions. *Educational Researcher*, *49*(4), 241–253. https://doi.org/10.3102/0013189X20912798

Laila, E., Sudarmin, S., Prasetya, A. T., & Sumarni, W. (2022). Studi Literatur: Penggunaan Jenis Media Pembelajaran untuk Meningkatkan Kemampuan Literasi Kimia Siswa. *EDUKATIF : JURNAL ILMU PENDIDIKAN*, *4*(3), 4982–4993. https://doi.org/10.31004/edukatif.v4i3.2907

Latip, A. (2022). Penerapan Model Addie dalam Pengembangan Multimedia Pembelajaran Berbasis Literasi Sains. *DIKSAINS : Jurnal Ilmiah Pendidikan Sains*, *2*(2), 102–108. https://doi.org/10.33369/diksains.2.2.102-108

Mayer, R. E. (2014). Cognitive Theory of Multimedia Learning. In *The Cambridge Handbook of Multimedia Learning* (pp. 43–71). Cambridge University Press. https://doi.org/10.1017/CBO9781139547369.005

McKenney, S., & Reeves, T. C. (2018). *Conducting Educational Design Research*. Routledge. https://doi.org/10.4324/9781315105642

Mishra, P., Pandey, C., Singh, U., Gupta, A., Sahu, C., & Keshri, A. (2019). Descriptive statistics and normality tests for statistical data. *Annals of Cardiac Anaesthesia*, *22*(1), 67-72. https://doi.org/10.4103/aca.ACA_157_18

p-ISSN : 2503-4480
e-ISSN : 2721-2963
Vol. 11, No. 2, August 2026 *DOI: https://doi.org/10.36709/jpkim.v11i2.235*

Nisa, N. A., & Fitriza, Z. (2021). Identifikasi Mikonsepsi Siswa Menengah Atas (SMA) Pada Pembelajaran Kimia Materi Redoks dan Elektrokimia : Studi Literatur. *EDUKATIF : JURNAL ILMU PENDIDIKAN*, *3*(4), 1191–1198. https://doi.org/10.31004/edukatif.v3i4.516

Nugraheni, A. R. E., & Srisawasdi, N. (2025). Development of pre-service chemistry teachers' knowledge of technological integration in inquiry-based learning to promote chemistry core competencies. *Chemistry Education Research and Practice*, *26*(2), 398–419. https://doi.org/10.1039/D4RP00160E

Raharjo, Moh. W. C., Suryati, S., & Khery, Y. (2017). Pengembangan E-Modul Interaktif Menggunakan Adobe Flash Pada Materi Ikatan Kimia untuk Mendorong Literasi Sains Siswa. *Hydrogen: Jurnal Kependidikan Kimia*, *5*(1), 8. https://doi.org/10.33394/hjkk.v5i1.102

Raman, Y., Surif, J., & Ibrahim, N. H. (2024). Alternative Framework in Electrochemistry among Secondary Schools Students in Johor, Malaysia. *International Journal of Interactive Mobile Technologies (IJIM)*, *18*(05), 148–157. https://doi.org/10.3991/ijim.v18i05.47931

Seruni, R., Munawaoh, S., Kurniadewi, F., & Nurjayadi, M. (2019). Pengembangan Modul Elektronik (E-Module) Biokimia pada Materi Metabolisme Lipid Menggunakan Flip PDF Professional. *JTK (Jurnal Tadris Kimiya)*, *4*(1), 48–56. https://doi.org/10.15575/jtk.v4i1.4672

Staus, N. L., O'Connell, K., & Storksdieck, M. (2021). Addressing the Ceiling Effect when Assessing STEM Out-Of-School Time Experiences. *Frontiers in Education*, *6, Article 690431*. https://doi.org/10.3389/feduc.2021.690431

Sugiyono. (2017). *Metode penelitian pendidikan: Pendekatan kuantitatif, kualitatif, dan R&D*. Alfabeta.

Sunarya, R. R., Hijriansyah, R., & Aisyah, R. (2024). Implementation of Problem Solving-Based Electron Configuration E-Modules to Improve Student Learning Outcomes. *Jurnal Pendidikan Kimia Indonesia*, *8*(1), 11–20. https://doi.org/10.23887/jpki.v8i1.70029

Sunarya, R. R., Setiani, D., & Farida, I. (2026). Validity and Feasibility of Interactive Multimedia on Sublimation Topics Oriented toward Chemical Literacy. *International Journal of Learning Media on Natural Science (IJLENS)*, *3*(1), 21–31. https://doi.org/10.60005/ijlens.v3i1.157

p-ISSN : 2503-4480
e-ISSN : 2721-2963
Vol. 11, No. 2, August 2026 DOI: https://doi.org/10.36709/jpkim.v11i2.235

Suryati, S., Surningsih, S., & Mashami, R. A. (2022). Pengembangan E-Modul Interaktif Reaksi Redoks Dan Elektrokimia Berbasis Nature Of Science Untuk Penumbuhan Literasi Sains Siswa. *Reflection Journal*, *2*(1), 26–33. https://doi.org/10.36312/rj.v2i1.847

Sutantri, N. (2022). Studi literatur: Kesulitan siswa pada pembelajaran kimia SMA topik sel volta. *Jurnal Kajian Pendidikan IPA*, *2*(1), 111–116. https://doi.org/10.52434/jkpi.v2i1.1624