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Development of an Interactive Mobile Learning Application with a Problem Based Learning Approach to Support Self-Regulated Learning in Chemistry, Grade X Senior High School

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Abstract: The rapid growth of mobile technology has not been optimally used to support formal chemistry instruction, particularly students' self-regulated learning (SRL). This study developed and evaluated *KimiaKu*, an interactive Android-based mobile learning application applying a Problem Based Learning (PBL) approach to the topic of Electrolyte and Non-Electrolyte Solutions for Grade X Senior High School. Using the 4-D Research and Development model (Define, Design, Develop, and a limited Disseminate stage), the application embeds five PBL phases into 34 interface screens comprising a Material menu, a Virtual Laboratory Simulation, instructional videos, quizzes, and an Activity Log/Reflection feature that records students' planning, monitoring, and self-evaluation. The product was validated by media, language, and content/chemistry experts and tested for practicality with a chemistry teacher and Grade X students, then piloted with a full class of 34 students to gauge learning gains. Results showed very valid media and content (98.75%) and language (94.67%) ratings, and very practical teacher (95.50%) and student (96.17%) responses; a normalized gain of 0.53 (moderate category) indicated a meaningful improvement in learning outcomes after use. These findings position *KimiaKu* as a valid, practical, and promising tool for cultivating self-regulated chemistry learning under the Merdeka Curriculum Phase E.

Keywords: 4-D Model; Chemistry Education; Interactive Media; Mobile Learning; Problem Based Learning (PBL); Self-Regulated Learning

Introduction

The rapid development of digital technology, particularly mobile devices, has profoundly transformed how students access information and construct knowledge, giving rise to mobile learning that allows the learning process to occur flexibly, at any time and in any place (Erfayliana et al., 2022; Ningsih et al., 2023; Prianggi et al., 2022). When designed with appropriate pedagogical approaches, mobile-based learning can create more personalized, flexible, and contextual learning experiences; however, in formal school settings its use remains suboptimal and has yet to be fully integrated with effective learning strategies. This shift reflects a broader transformation in the orientation of education, moving from an emphasis on the transfer of knowledge toward the cultivation of lifelong learning capacity, in which learners are expected to move beyond memorization toward critical thinking, rational decision-making, collaboration, and sustained independent learning (Balangasan et al., 2025; Haidah et al., 2022; Oktarina et al., 2020; Parera et al., 2021), and the locus of the learning process is expected to shift away from teacher-centered instruction toward student-centered learning in which learners actively construct their own understanding (Utomo, 2023).

This condition is particularly relevant in chemistry learning at the senior high school level. Chemistry is characterized by abstract and symbolic content atomic structure, electrical conductivity of solutions, redox

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reactions, and stoichiometry that requires representational thinking connecting macroscopic, microscopic, and symbolic levels; without appropriate visualization and interactive strategies, students are prone to developing misconceptions (Paramansyah et al., 2024). Preliminary observations at SMA Pembangunan Laboratorium UNP found that chemistry learning for Grade X students still relies heavily on teacher-centered methods, with lecture and textbook as the primary approaches, and that students' self-regulated learning indicators were generally 'low' to 'very low': only 23% of students could independently set learning goals, 30% sought additional learning resources, 35% monitored their own comprehension, 28% asked questions when experiencing difficulties, and only 18% engaged in self-reflection after learning (Observation Data, 2024). Daily test results further showed that only 40% of students achieved the Learning Objective Achievement Criteria *(Kriteria Ketercapaian Tujuan Pembelajaran, KKTP)* for the topic of Electrolyte and Non-Electrolyte Solutions, consistent with the evaluation principles of the Merdeka Curriculum, which has replaced the single absolute KKM benchmark with the criterion-referenced KKTP.

Problem Based Learning (PBL) is a student-centered approach that uses real-world problems as the starting point for learning, directing students to recognize problems, gather relevant information, evaluate solution alternatives, and reflect on the learning process (Savery, 2021; Yanto, 2019), and integrating PBL with interactive digital platforms has been shown to significantly enhance self-regulated learning compared with conventional expository instruction (Hsu et al., 2023). PBL is theoretically grounded in constructivism, which holds that knowledge is actively built through experience and interaction with the environment rather than passively transmitted (Utomo, 2023), and its implementation typically follows problem orientation, organizing the learning task, individual and group investigation, developing and presenting artifacts, and analyzing and evaluating the problem-solving process (Nurwidodo et al., 2025), a sequence designed to cultivate higher-order thinking skills such as analysis, evaluation, and solution generation (Arviani et al., 2023). These same phases correspond closely to the three cyclical phases of self-regulated learning (SRL) — forethought, performance, and self-reflection (Balazinec et al., 2024; DiBenedetto & Zimmerman, 2010; Greene et al., 2012; Nurjanah & Amalia, 2023) so that problem-based instruction supported by digital platforms has been shown to improve self-regulation more than conventional expository teaching (Mubango & Ngirande, 2024; Putri & Saifuddin, 2024), consistent (Hsu et al., 2023).

As a delivery platform, mobile learning enables instruction to be flexible, personalized, and contextual, allowing learners to access materials at any time and place rather than being confined to the physical classroom (Crompton et al., 2018), and a recent meta-analysis indicates that mobile-device-based instruction positively affects learning outcomes, particularly when paired with active, collaborative pedagogical strategies such as PBL (Garzon et al., 2023). Interactively designed mobile learning media has also been shown to positively affect student engagement and content understanding, especially when its features support active thinking, self-evaluation, and independent investigation (Hwang & Chien, 2022). Even so, a specific gap remains: no prior study appears to have integrated PBL, interactive mobile media, and embedded self-regulated learning measurement (activity logs and reflection features) into a single chemistry application (Puspitasari, 2022; Rosmalawati & Musdalifah, 2025; Venisa & Sofiyanita, 2025), and similar Android-based PBL media developed for other science topics have likewise stopped short of embedding this reflective, log-based SRL instrument directly inside the product itself (Hardika et al., 2024; Nurkhasanah & Rohaeti, 2024).

The novelty of this study therefore lies not simply in producing another PBL-based mobile application, but in embedding a real-time, in-application Activity Log/Reflection feature that operationalizes all three SRL phases — planning, monitoring, and self-evaluation — as part of the learning workflow itself, rather than as a separate paper-based instrument administered after instruction. This matters practically because it lets a chemistry teacher observe how a Grade X student plans, monitors, and reflects on the abstract, symbolic content of electrolyte and non-electrolyte solutions in real time, addressing both the representational difficulty of the topic and the low SRL and KKTP-achievement levels documented in the preliminary observation. This study accordingly develops an interactive mobile learning application using a PBL approach for Grade X chemistry (Electrolyte and Non-Electrolyte Solutions) and evaluates its validity, practicality, and effectiveness, contributing to technology-integrated pedagogy aligned with Merdeka Curriculum Phase E.

Method

This study used a Research and Development (R&D) approach following the 4-D model (Thiagarajan et al., 1974): Define, Design, Develop, and a limited Disseminate stage (Figure 1). The 4-D model was chosen over alternatives such as Borg and Gall, ADDIE, and ASSURE because its four sequential stages provide a systematic yet efficient structure for producing instructional media without the more extensive, cyclical field-testing procedures of Borg and Gall's ten-step model; compared with ADDIE, which targets broader instructional systems design, and ASSURE, which

centers on lesson-level media selection within a single class session, the 4-D model is specifically suited to producing a validated and field-tested standalone learning product. The study was conducted at SMA Pembangunan Laboratorium UNP with Grade X students studying Electrolyte and Non-Electrolyte Solutions under Merdeka Curriculum Phase E.

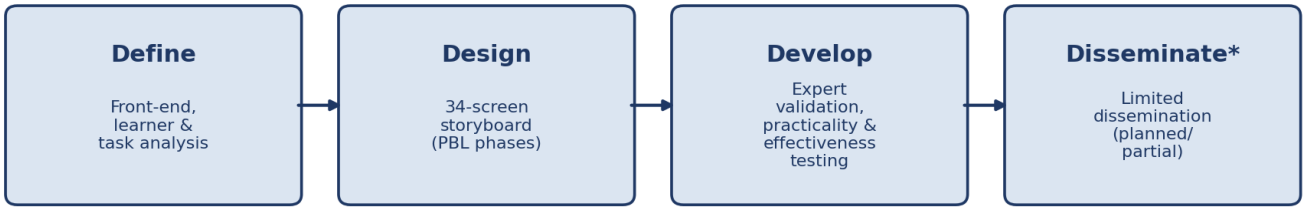


Figure 1. The 4-D Research and Development Procedure Followed in This Study

Define Stage, this stage involved front-end analysis through classroom observations, interviews with the chemistry teacher (Irvan Hidayat, S.Pd.), and a literature review covering curriculum requirements, student characteristics, learning objectives, and existing learning problems, including low self-regulated learning levels and abstract conceptual difficulties in chemistry.

Design Stage, this stage produced a comprehensive storyboard of 34 interface screens mapping the five PBL phases — problem orientation, organizing the learning, individual and group investigation, developing and presenting work, and analyzing and evaluating the problem-solving process — into the application, integrating interactive simulations of electrical conductivity, contextual chemistry problems, formative quizzes, and a self-reflection module.

Develop Stage, the prototype was built as an Android-based mobile application and validated by media, language, and content/chemistry experts from Universitas Negeri Padang; practicality testing then followed with the chemistry teacher and Grade X students, and a classroom pilot examined learning gains before and after use.

Disseminate Stage, dissemination was limited to the trial school for this report; broader implementation in similar school contexts is planned following further product refinement.

Research Subjects, subjects were selected through purposive sampling. Validation involved lecturers from Universitas Negeri Padang assigned by expertise: a media expert who examined interface design, navigation, and the technical implementation of the PBL syntax; a content/chemistry expert who examined alignment of the material with Merdeka Curriculum learning outcomes and the scientific accuracy of ionization representations and conductivity simulations; and a language expert who reviewed communicative clarity and compliance with Indonesian language conventions (PUEBI). Practicality testing involved two chemistry teachers and 12 Grade X students, while the effectiveness pilot (pre-test/post-test) involved the full class of 34 Grade X students at SMA Pembangunan Laboratorium UNP, a grade level chosen because it marks a transitional phase toward more independent learning.

Product Specification, KimiaKu runs on Android devices with a minimum of 2 GB RAM and 128 GB of internal storage and supports animation, simulation, and video; an internet connection is required only for initial download and updates, after which the application can be used offline. Content is aligned with the Phase E learning outcome, by which students analyze solution properties based on electrical conductivity to classify electrolyte and non-electrolyte solutions and design, conduct, and communicate experiments distinguishing the conductivity of different solutions. The main menu integrates Material, a Virtual Laboratory Simulation, instructional Video, Quiz, and an Activity Log/Reflection feature, through which the teacher acts as a facilitator guiding students through each PBL phase both inside and outside class hours.

Instruments used were validation questionnaires for content, media, and language aspects; practicality questionnaires for teacher and student responses; a pre-test and post-test instrument based on Bloom's Revised Taxonomy (C2–C4); and a self-regulated learning questionnaire covering planning, monitoring, strategy control, and self-evaluation. All instruments used a five-point Likert scale. Validity and practicality data were analyzed with the percentage formula $P = (\Sigma x/n) \times 100\%$, where Σx is the total score obtained and n is the maximum possible score, interpreted according to Table 1.

Table 1. Validity and Practicality Interpretation Criteria (Arikunto, 2018)

Percentage (%)	Criteria	Mean score
91–100	Very valid	4.6–5.0
71–90	Valid	4.1–4.5
51–70	Fairly valid	3.6–4.0
31–50	Less valid	3.1–3.5

Percentage (%)	Criteria	Mean score
≤30	Not valid	2.0–3.0

Qualitative data in the form of expert comments and suggestions were compiled thematically and used as the basis for product revision prior to the field trial. Beyond validity and practicality, a self-regulated learning questionnaire was constructed around three operational indicators — planning (setting learning goals, devising strategies, organizing study time), self-monitoring (tracking comprehension, evaluating chosen strategies, identifying difficulties), and self-evaluation (reflecting on outcomes, judging strategy success, formulating improvement plans) — each translated into Likert-scale items and triangulated with in-application activity-log data. Effectiveness was examined through a one-group pre-test/post-test design based on Bloom's Revised Taxonomy (C2–C4), with gains analyzed using the normalized N-Gain statistic.

Result and Discussion

Define Stage Results

The define stage revealed four main findings: students' self-regulated learning was categorically low, with the lowest indicator being self-reflection (18%); the KKTP achievement rate on Electrolyte and Non-Electrolyte Solutions was only 40% (mean score 68); students experienced conceptual difficulties in understanding ionization processes and relating theory to real-world phenomena; and mobile phones were owned by nearly all students but were not optimally used as learning tools. These findings align with Darling-Hammond et al. (2020), who emphasize that teacher-centered instruction limits the development of students' critical thinking and learning autonomy.

Table 2. Initial Observation Data on Students' Self-Regulated Learning

Self-regulated learning indicator	Percentage (%)	Category
Setting learning goals independently	23.00	Low
Seeking additional learning resources	30.00	Low
Monitoring comprehension during learning	35.00	Low
Asking questions when facing difficulties	28.00	Low
Self-reflection after learning	18.00	Very low

Source: Chemistry teacher, Grade X, SMA Pembangunan Laboratorium UNP

Design Stage Results

The design stage produced a 34-screen storyboard for *KimiaKu*, structuring content flow according to the five PBL phases. Each phase was operationalized into a specific interface feature: the Problem Orientation phase presents contextual chemistry scenarios related to electrolyte phenomena in everyday life; the Organizing phase provides structured learning objectives and resource navigation; the Investigation phase includes interactive simulations of electrical conductivity experiments and ionization animations; the Developing and Presenting phase features collaborative task submission tools; and the Evaluating phase integrates formative quizzes and the guided self-reflection module. This design is consistent with (Mayer, 2014) Cognitive Theory of Multimedia Learning, which emphasizes dual-channel processing through text, visual, and interactive elements to reduce cognitive overload. Table 3 maps each menu feature to its corresponding PBL phase alongside the minimum device requirements (Android OS 5.0 or later, 2 GB RAM, 128 GB storage).

Table 3. *KimiaKu* Menu Features Mapped to PBL Syntax Phases

Menu feature	Function/description	PBL syntax phase
Material	Presents conceptual explanation of electrolyte/non-electrolyte solutions	Problem orientation; organizing the learning
Virtual laboratory simulation	Lets students manipulate solutions and observe electrical conductivity interactively	Individual and group investigation
Video	Demonstrates PBL steps from problem identification to reflection	Problem orientation; investigation
Quiz	Provides interactive items evaluating conceptual understanding	Developing and presenting work
Activity log/reflection	Records the learning process and self-evaluation	Analyzing and evaluating the problem-solving process

Develop Stage Results: Validity, Practicality, and Effectiveness

Validation instruments were constructed for three expert categories. Content/chemistry validation covered curriculum alignment with Merdeka Curriculum Phase E, accuracy of chemistry concept presentation, appropriateness of PBL phase integration, relevance of contextual problems, and scientific

correctness of ionization and conductivity representations. Media validation covered interface design quality, navigation structure, interactive element functionality, and visual consistency. Language validation assessed communicative clarity, vocabulary appropriateness for Grade X, compliance with Indonesian language conventions (PUEBI), and coherence between narrative text and media elements. Practicality instruments covered usability, time efficiency, appeal, and support for self-regulated learning. As documentation of the resulting product, Figure 2 shows the *KimiaKu* application interface as it appears when run on an Android smartphone. Table 4 presents the resulting validity and practicality scores.

Table 4. Recapitulation of Validity and Practicality Results

Type of assessment	Respondent(s)	Percentage (%)	Category
Media validation	1 media validator	98.75	Very valid
Language validation	1 language validator	94.67	Very valid
Content/chemistry validation	1 content validator	98.75	Very valid
Teacher practicality	2 chemistry teachers	95.50	Very practical
Student practicality	12 Grade X students	96.17	Very practical

Source: expert validation and practicality questionnaires, 2026

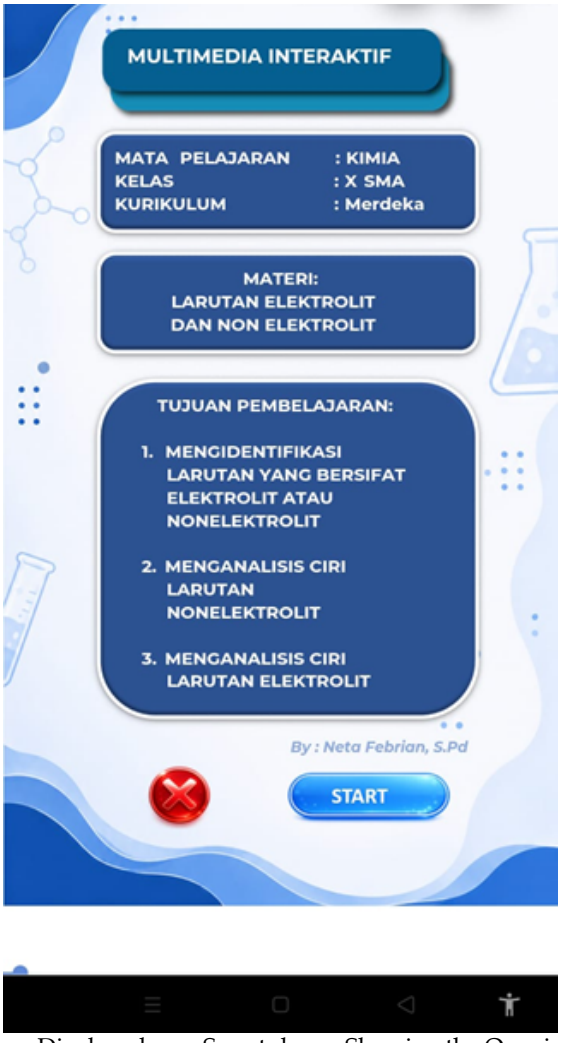


Figure 2. *KimiaKu* Application Interface Displayed on a Smartphone, Showing the Opening Menu for the Electrolyte and Non-Electrolyte Solutions Material

Beyond validity and practicality, a classroom pilot with the full class of 34 Grade X students examined effectiveness through a pre-test/post-test design. The mean pre-test score was 48.76 and the mean post-test score was 76.47, yielding a normalized gain of 0.53 (moderate category); individually, 29 students (85.3%)

fell into the moderate N-Gain category and 5 students (14.7%) into the high category, with no student showing a decline. This pattern indicates a meaningful improvement in learning outcomes after using *KimiaKu* and provides preliminary evidence — alongside the validity and practicality results above — that the application is not only well designed but also effective in supporting learning of Electrolyte and Non-Electrolyte Solutions.

Discussion

These results address a gap identified in prior literature: the absence of an integrated system combining PBL, interactive mobile learning, and embedded self-regulated learning measurement within a single chemistry application (Puspitasari, 2022; Rosmalawati & Musdalifah, 2025). Unlike related Android-based PBL media developed for other science topics (Hardika et al., 2024; Syamsudin et al., 2022) or PBL-based electronic worksheets for chemistry (Nurkhasanah & Rohaeti, 2024), *KimiaKu* embeds the self-reflection module as a real-time, in-application feature rather than an external paper instrument, enabling continuous rather than end-of-unit formative data on students' metacognitive processes. This aligns with Zimmerman's framework (Panadero, 2022; Sinkkonen & Tapani, 2024), which identifies self-monitoring and self-evaluation as the most critical components of the self-regulated learning cycle, and is consistent with meta-analytic evidence that mobile-device-based instruction yields stronger learning outcomes when paired with active pedagogical strategies rather than used as a passive content-delivery channel (Garzon et al., 2023; Salirawati & Wiyarsi, 2012).

Theoretically, the correspondence between the five PBL phases and the three-phase SRL cycle — forethought, performance, and self-reflection (Nurjanah & Amalia, 2023; Prihantoro et al., 2025; Winne, 2018) explains why an application structured around PBL syntax is well positioned to cultivate self-regulated learning: the problem orientation and organizing phases parallel forethought, in which learners set goals and plan strategies; the investigation and developing/presenting phases parallel performance, involving monitoring and strategy execution; and the analyzing/evaluating phase parallels self-reflection. This is consistent with evidence that problem-based instruction supported by digital platforms enhances self-regulation more effectively than conventional expository teaching (Eggers et al., 2021; Putri & Saifuddin, 2024; Rasheed et al., 2021; Shurygin et al., 2024; Sucipto, 2017) and with systematic-review evidence that PBL supports learners' self-regulation across subject areas (Arani, 2025; Guo et al., 2024; JaleniauskienĖ, 2016; Orhan, 2025; Wilder, 2015).

The moderate N-Gain (0.53) should be interpreted alongside the validity and practicality findings rather than in isolation: a highly valid and practical product that produces only a moderate learning gain suggests that instructional quality and usability are necessary but not sufficient conditions for large effect sizes, and that gains may also depend on implementation time, teacher facilitation quality, and students' prior familiarity with mobile-assisted PBL — factors this study's single-class, one-group pilot was not designed to disentangle. From a pedagogical standpoint (Joy, 2018; Nurenberg & Tuller, 2023; Sugihandika et al., 2026), the framework carries practical implications for chemistry teachers under the Merdeka Curriculum: because *KimiaKu* positions the teacher as a facilitator rather than the primary source of information, its adoption requires a shift from delivering lectures toward guiding investigation, posing probing questions during problem orientation, and reviewing students' reflection logs to identify learners who may need additional scaffolding (Amelia & Abtokhi, 2023; Azzaroiha et al., 2025; Ernawati et al., 2022, 2023; Hendrayana & Mutaqin, 2025; Pan & Liu, 2022; Sari et al., 2024).

As a single-group pilot without a comparison class, this study cannot yet attribute the observed gain solely to *KimiaKu* rather than to general instructional attention, and the practicality sample (12 students) and effectiveness sample (34 students) drew on the same cohort at different points, which limits generalizability beyond this school context. Future research is encouraged to use a control-group design to isolate the application's effect, to examine transferability to other abstract chemistry topics such as redox reactions or acid–base equilibrium, and to compare *KimiaKu*'s impact on self-regulated learning against non-PBL interactive media within the same student population.

Conclusion

This study developed and empirically evaluated *KimiaKu,* an interactive Android-based mobile learning application using a Problem Based Learning approach for Electrolyte and Non-Electrolyte Solutions in Grade X Senior High School, guided by the 4-D model and beginning with a Define stage that documented low self-regulated learning (18–35%) and low KKTP achievement (40%) as the primary learning problems; the Design stage produced a 34-screen storyboard integrating five PBL phases into concrete features, including interactive simulations, contextual problems, formative quizzes, and a self-reflection module; and the Develop stage showed the product to be very valid in media, language, and content/chemistry aspects (94.67–98.75%), very practical according to teachers and students (95.50–96.17%), and effective in a classroom pilot, with a moderate normalized learning gain of 0.53. Together

these results indicate that embedding a real-time reflective log within a PBL-structured mobile application is a valid, practical, and promising strategy for cultivating self-regulated chemistry learning under Merdeka Curriculum Phase E, and future research is recommended to test *KimiaKu* with a control-group design, extend it to other abstract chemistry topics, and pursue broader dissemination across school contexts.

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Author Contributions
Conceptualization, N.F. and F.Y.; methodology, N.F. and F.Y.; investigation, N.F.; data curation, N.F.; writing—original draft preparation, N.F. and N.H.; writing—review and editing, A.H. and F.Y.; supervision, N.H. and F.Y.; project administration, A.H. and N.F.; funding acquisition, not applicable. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest
The authors declare no conflict of interest.

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