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DEVELOPMENT OF A PROBLEM BASED LEARNING E-MODULE TO ENHANCE STUDENTS' SCIENTIFIC LITERACY IN REACTION RATE LEARNING

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ABSTRAK

Rendahnya literasi sains peserta didik dalam topik laju reaksi menjadi salah satu tantangan dalam pembelajaran kimia, yang disebabkan oleh keterbatasan bahan ajar yang mampu mengaitkan konsep dengan permasalahan kontekstual serta kurang mendorong partisipasi aktif peserta didik dalam pembelajaran. Oleh karena itu, diperlukan inovasi bahan ajar yang dapat memfasilitasi pembelajaran bermakna melalui pendekatan yang berpusat pada peserta didik. Penelitian ini bertujuan untuk mengembangkan e-modul berbasis *Problem Based Learning* (PBL) dan menganalisis kevalidan, kepraktisan, dan keefektifannya dalam meningkatkan literasi sains peserta didik pada materi laju reaksi. Penelitian ini menerapkan pendekatan metode *Research and Development* (R&D) dengan model ADDIE. Kevalidan produk diperoleh dari penilaian oleh ahli materi dan ahli media, kepraktisan diperoleh melalui kuesioner respon peserta didik, sedangkan efektivitas e-modul diperoleh berdasarkan hasil pretest dan posttest literasi sains. Hasil validasi ahli materi terhadap produk menghasilkan skor 87.78%, sedangkan validasi ahli media mencapai 92.73%, yang tergolong dalam kategori sangat valid. Respon peserta didik memperoleh skor 93.1% pada kelompok kecil dan 92.1% pada kelompok besar yang tergolong dalam kategori sangat baik. E-modul juga efektif meningkatkan literasi sains peserta didik dari rata-rata skor 53 menjadi 87. Secara keseluruhan, hasil penelitian ini menunjukkan bahwa e-modul berbasis PBL dapat menjadi alternatif bahan ajar digital yang efektif dan mampu mendukung pengajaran kimia kontekstual serta menumbuhkan keterampilan literasi sains yang dibutuhkan pada pendidikan abad ke-21.
Kata Kunci: *E-Modul, Problem Based Learning, Literasi Sains, Laju Reaksi, ADDIE*

ABSTRACT

Students' low scientific literacy in reaction rate learning remains a challenge in chemistry education because existing instructional materials often fail to relate scientific concepts to real-world contexts and provide limited opportunities for active learning. Therefore, innovative teaching materials are needed to promote meaningful, student-centered learning. This study set out to develop a Problem-Based Learning (PBL)-based e-module and and to examine how valid, practical, and effective it is in strengthening students' scientific literacy on the reaction rate topic. The research employed a Research and Development (R&D) approach using the ADDIE model. Validity was established through assessments from both material and media experts, practicality was gauged via student response questionnaires, and effectiveness was tracked through pretest-posttest scientific literacy scores. The material expert validation produced a score of 87.78%, while the media expert validation reached 92.73%, both falling into the very valid category. Student feedback was equally favorable, with practicality percentages of 93.1% in the small-group trial and 92.1% in the large-group trial. In addition, the mean scientific literacy score rose from 53 in the pretest to 87 in the posttest. Taken together, these results

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indicate that the PBL-based e-module serves as an effective digital resource capable of supporting contextual chemistry instruction and cultivating the scientific literacy skills demanded by twenty-first-century education.
Keywords: *e-module, Problem Based Learning, Scientific Literacy, Reaction Rate, ADDIE*

INTRODUCTION

Living through the twenty-first century's rapid scientific and technological progress has reshaped what students are expected to be able to do. It is no longer enough for learners to simply grasp scientific concepts; they must also apply that knowledge to everyday situations and reach decisions grounded in scientific evidence. Reflecting these demands, scientific literacy now stands as one of the central competencies prioritized within Indonesia's education system. In essence, being scientifically literate means understanding scientific ideas and processes, using scientific knowledge to make decisions, and addressing problems tied to natural phenomena (Firdausi et al., 2025; Putri et al., 2026). Yet data from the 2022 Programme for International Student Assessment (PISA) tell a different story: Indonesian students recorded an average science score of 383, well below the OECD average of 485 (OECD, 2023). Such a gap points to the pressing need for instructional strategies capable of genuinely cultivating scientific reasoning and problem-solving abilities.

A major driver behind students' weak scientific literacy is the continued dominance of teacher-centered teaching methods that prioritize memorizing theory over applying it in practice (Jusniar et al., 2021; Munawwarah & Ashari, 2025). Within chemistry classrooms specifically, students often struggle to connect abstract concepts with phenomena they encounter in daily life (Munawwarah & Ashari, 2025). This difficulty is especially pronounced for reaction rates, a topic loaded with intricate ideas such as reaction theory, activation energy, and the various factors influencing how fast reactions occur (Sholeh et al., 2025; Rahayu et al., 2024). As a result, many students fall back on memorizing facts rather than building the kind of conceptual grasp needed to work through contextual scientific problems (Jusniar et al., 2021; Driya et al., 2026). This underscores the importance of instructional approaches that actively involve students in meaningful learning, since such engagement is key to improving both learning outcomes and scientific literacy.

Among the instructional models recognized for boosting scientific literacy, Problem-Based Learning (PBL) stands out because it draws students directly into scientific inquiry and problem-solving (Aripin et al., 2025; Darmawati et al., 2025). Rather than beginning with abstract theory, PBL opens with authentic, contextual problems that push students to define the issue, collect relevant information, weigh evidence, and craft solutions rooted in scientific reasoning. Earlier research has consistently linked PBL to gains in academic achievement, problem-solving capacity, and scientific literacy (Aripin et al., 2025; Sinusi et al., 2026). Meanwhile, advances in digital technology have popularized electronic modules (e-modules) as flexible, interactive resources that support self-paced learning (Nipus et al., 2025; Sulhan et al., 2023). Combining PBL with an e-module format therefore holds real promise for creating a more engaging, context-rich learning experience particularly for a demanding topic like reaction rates (Tarigan & Herlinawati, 2025; Sulhan et al., 2023).

Existing literature indicates that e-modules generally strengthen learning outcomes and conceptual understanding, while PBL tends to sharpen higher-order thinking and scientific literacy (Sulhan et al., 2023; Aripin et al., 2025; Darmawati et al., 2025). Even so, much of this research treats e-modules and PBL as separate interventions or narrows its focus mainly to

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cognitive gains (Tarigan & Herlinawati, 2025; Sinusi et al., 2026). Few studies have specifically pursued the development of a PBL-based e-module aimed squarely at improving scientific literacy within the reaction rate topic. Compounding this gap, many current e-modules fail to systematically embed the core dimensions of scientific literacy explaining phenomena, designing investigations, and interpreting data and evidence (OECD, 2023). This shortfall highlights the need for further research into instructional materials that deliberately weave scientific literacy into the learning process itself.

Given these considerations, there is a clear rationale for developing a Problem-Based Learning-based e-module purpose-built to strengthen students' scientific literacy in learning about reaction rates. What distinguishes this study is its attempt to embed the PBL instructional sequence into learning activities that explicitly cover the core dimensions of scientific literacy: contextual problem presentation, scientific investigation, data analysis, and reflective inquiry all within a single digital resource. In line with this rationale, the present study seeks to produce a Problem-Based Learning-based e-module that proves valid, practical, and effective in enhancing students' scientific literacy on reaction rates. It is hoped that the resulting findings will offer an innovative instructional tool that makes chemistry learning more meaningful while equipping students with the competencies twenty-first-century education demands.

RESEARCH METHOD

This study employed a Research and Development (R&D) approach to develop a Problem-Based Learning (PBL)-based electronic module (e-module) on the reaction rate topic using the ADDIE instructional design model, which consists of five stages: Analysis, Design, Development, Implementation, and Evaluation. The study was conducted at SMAN 10 Kupang and involved Grade XII science students as research participants. The developed e-module was designed and published through the Heyzine Flipbook platform by integrating the syntax of Problem-Based Learning with scientific literacy-oriented learning activities.

Data were collected using expert validation sheets, student response questionnaires, and scientific literacy tests. The validation sheets completed by material and media experts were used to determine the content and media validity of the developed e-module. Student response questionnaires were administered during small-group and large-group trials to evaluate the practicality of the e-module, while scientific literacy tests administered before and after implementation were used to examine its effectiveness in improving students' scientific literacy competencies.

Data analysis combined descriptive quantitative and qualitative approaches. Validation and practicality data were analyzed using percentage scores and interpreted according to established validity and practicality criteria (Sudijono, 2014; Taufan et al., 2023). The effectiveness of the developed e-module was determined by comparing students' pretest and posttest scientific literacy scores, focusing on three scientific literacy competencies: explaining scientific phenomena, designing and evaluating scientific investigations, and interpreting scientific data and evidence.

RESULT AND DISCUSSION

This study produced a Problem-Based Learning (PBL)-based electronic module (e-module) designed to strengthen students' scientific literacy in learning about reaction rates. The e-module builds its learning activities around authentic, everyday contextual problems as the entry point, prompting students to actively identify issues, gather relevant information, analyze

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data, and craft evidence-based solutions using scientific concepts. A key feature of the module is how it weaves the PBL instructional sequence together with interactive elements, illustrations, instructional videos, guided activities, and assessments oriented toward scientific literacy. Through these features, students can explore reaction rate concepts independently while staying engaged in meaningful learning.

Results

Analysis

The analysis stage served as the initial phase in developing the Problem-Based Learning (PBL)-based e-module. This opening stage aimed to pin down instructional needs, students' characteristics, and the difficulties encountered in teaching and learning reaction rates, drawing on curriculum review, content analysis, and an assessment of students' need for materials that build scientific literacy. The results of the needs analysis are presented in Table 1.

Table 1. Results of the Needs Analysis

Component of Analysis	Observation Results	Interview Results
Learning process	Instruction on reaction rate remains largely lecture-based and relies heavily on printed textbooks.	Teachers pointed to a shortage of interactive teaching materials as a persistent constraint.
Scientific literacy competencies	Students struggled to connect the concept of reaction rate with everyday phenomena and had not yet developed the ability to explain scientific phenomena, analyze data, or solve science-based problems.	Rather than grasping how concepts apply in real-life situations or scientific investigations, students tend to rely on rote memorization.
Student characteristics	Students are accustomed to using smartphones and digital media throughout the learning process.	Students expressed a preference for more engaging materials—ones that incorporate illustrations, videos, and animations, and that allow for active participation in learning activities.
Curriculum analysis	The topic of reaction rate is closely tied to everyday phenomena and lends itself naturally to experimental activities.	According to teachers, the intended learning outcomes require students to possess adequate scientific literacy competencies.

The analysis revealed that chemistry instruction on reaction rates still relied heavily on printed textbooks and teacher-centered delivery that emphasized transmitting concepts rather than fostering meaningful learning leaving students struggling to connect reaction rate concepts with real-life phenomena and limiting their ability to explain phenomena, analyze data, and solve science-related problems. Learner analysis further showed that although students were already comfortable with digital technology, interactive materials built on innovative pedagogy remained scarce; students expressed a preference for resources featuring illustrations, videos, and activities that invite active participation. These findings pointed to the need for a digital resource that both organizes content systematically and builds scientific literacy through contextual problem-solving. Curriculum analysis also confirmed that reaction rates align closely with core scientific literacy competencies, since the topic requires explaining phenomena, carrying out simple investigations, and interpreting observational data findings that together formed the basis for determining the e-module's learning objectives, content organization, activities, and supporting features.

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Design

Building on the analysis findings, this stage produced an initial blueprint for the e-module, covering its structure, learning objectives, content organization, learning activities, assessment tools, and user interface. The instructional flow incorporated all five PBL phases, orienting students to a contextual problem, organizing them for learning, guiding individual and group investigation, developing and presenting solutions, and analyzing and evaluating the problem-solving process, with each phase anchored in authentic, everyday contextual problems such as food spoilage, iron corrosion, and how temperature affects reaction rates, chosen deliberately to link chemistry concepts with real-world experience. Alongside organizing content and activities, this stage also shaped the module's visual appearance and supporting features, integrating text, images, instructional videos, animations, and interactive exercises meant to boost motivation and engagement. The outcome was a prototype that anchored the subsequent development stage, keeping learning objectives, content, activities, and targeted scientific literacy competencies aligned.

Development

This stage turned the initial design into a finished instructional product ready for use, assembling every component of the PBL-based e-module introduction, user guidelines, learning outcomes, reaction rate content, problem-based activities, worksheets, assessments, and references into a digital format combining text, figures, illustrations, videos, and interactive elements. Canva was used for content design, with the finished material published through the Heyzine Flipbook platform. The PBL syntax was embedded into every learning activity so students would learn by working through problem identification, investigation, data analysis, and evidence-based solution-building.

Learning activities were purposefully shaped to build scientific literacy by having students explain phenomena related to reaction rates, design and evaluate simple investigations, and interpret data drawn from observation or experiment. Authentic contextual problems drawn from daily life were woven throughout to help students see the relevance of reaction rate concepts to real situations. Figures 1 and 2 depict the interface of the finished e-module.

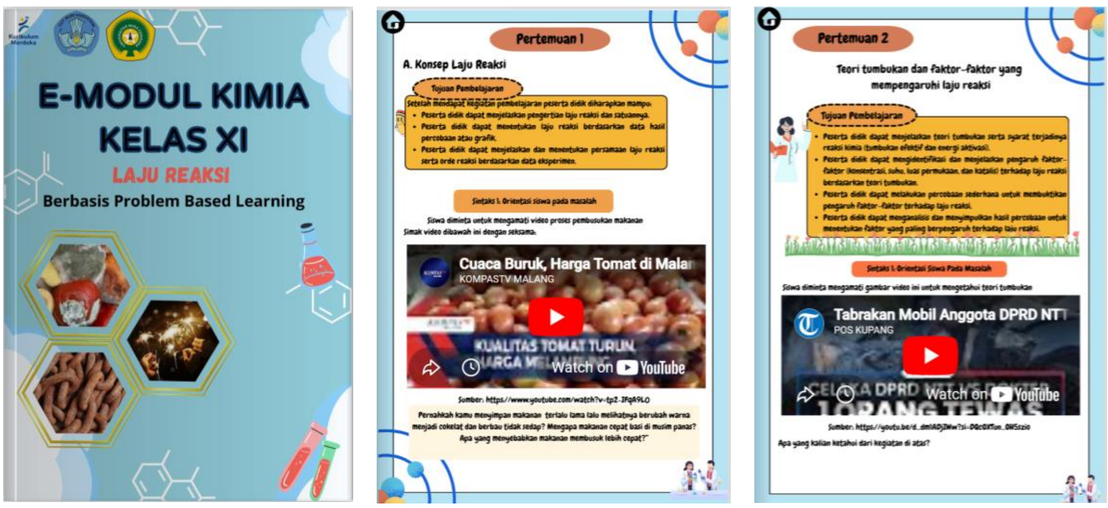

Figure 1. Interface of the PBL-Based E-Module

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Figure 2. Learning and Evaluation Stages

Once the initial product was complete, validation was carried out by subject-matter and media experts, whose feedback guided revisions until the e-module met the required validity standards and was judged ready for classroom implementation. Tables 2 and 3 summarize the validation results contributed by three subject-matter experts and three media experts, respectively.

Table 2. Results of Subject Matter Expert Validation

Assessment Aspect	Expert I	Expert II	Expert III	Total Score per Aspect	Maximum Score	Validity Percentage
Content Relevance	16	17	20	53	60	88%
Content Organization	25	26	26	77	90	86%
Language Appropriateness	15	13	14	42	45	93.33%
Effectiveness	20	24	21	65	75	86.67%
Total	76	80	81	237	270	87.78%

As presented in Table 2, the expert review indicates that the developed e-module demonstrates strong content quality in terms of material relevance, content organization, language appropriateness, and instructional effectiveness. These findings suggest that the learning materials have been systematically organized, are scientifically accurate, and are aligned with the intended learning objectives and Problem-Based Learning framework. Consequently, the e-module meets the content feasibility requirements to support chemistry instruction focused on developing students' scientific literacy.

Table 3. Results of Media Expert Validation

Assessment Aspect	Expert I	Expert II	Expert III	Total Score per Aspect	Maximum Score	Validity Percentage
Visual Design	38	37	34	109	120	91%

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Interactivity	15	15	14	44	45	98%
Total	53	52	48	153	165	92.73%

As shown in Table 3, the media validation confirms that the e-module possesses an appropriate visual design and interactive features to support digital learning. The evaluation indicates that the interface, navigation, and multimedia components have been designed to facilitate user engagement and ease of use during the learning process. These characteristics enhance the usability of the e-module and support its implementation as an interactive learning resource for chemistry instruction.

Implementation

Limited implementation came next, intended to gather early evidence on the module's practicality and effectiveness. This trial involved a small group of students representative of the target users, with three main goals: checking how usable the e-module proved in classroom settings, spotting obstacles that surfaced during use, and collecting feedback to guide further refinement.

During this stage, students used the PBL-based e-module as their main learning resource for studying reaction rates. Learning began with contextual problems related to reaction rates, prompting students to identify the issues involved, gather and analyze relevant information, and work collaboratively toward solutions grounded in scientific reasoning. Serving as an all-in-one learning guide, the e-module combined instructional material, hands-on investigative tasks, practice exercises, and assessments aligned with scientific literacy indicators.

Alongside observing how the implementation unfolded, the researchers also gathered student response data during this limited trial. Tables 4 and 5 present results from both the small-group and large-group testing of the PBL-based e-module.

Table 4. Results of Student Responses in the Small-Group Trial

Assessment Aspect	Total Score	Maximum Score	Percentage (%)
Learning Process	249	270	92.2%
Language	43	45	95.6%
Visual Design	85	90	94.4%
Total	377	405	93.1%

Table 5. Results of Student Responses in the Large-Group Trial

Assessment Aspect	Total Score	Maximum Score	Percentage (%)
Learning Process	819	900	91%
Language	144	150	96%
Visual Design	280	300	93.3%
Total	1.243	1350	92.1%

As shown in Table 4 and Table 5, student response data revealed strongly positive reception in both trials, with overall percentages of 93.1% for the small group and 92.1% for the large group. Measured against the established assessment criteria, both scores fall in the

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very good category, confirming that the e-module was well received by students and judged suitable for chemistry instruction.

Preliminary effectiveness was gauged by comparing pretest and posttest scores before and after students worked through the e-module's learning activities. Administered to 40 Grade XII students at SMAN 10 Kupang, the pretest produced an average score of 53, equivalent to a 38% achievement level. After students completed learning through the e-module, the posttest average climbed to 87, corresponding to a 62% achievement level; Figure 3 illustrates this pretest-posttest comparison.

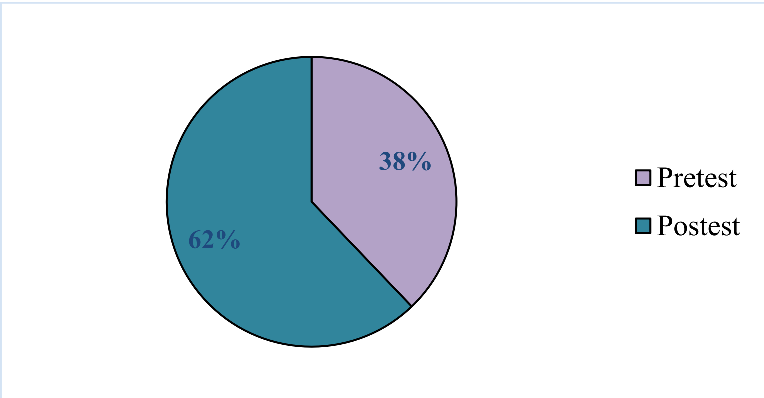

Figure 3. Comparison of Students' Scientific Literacy Competencies

As shown in Figure 3, implementing the PBL-based e-module was followed by a clear rise in students' scientific literacy competencies, with the average achievement level climbing from 38% to 62%. This improvement showed up in students' strengthened capacity to explain scientific phenomena, design and evaluate scientific investigations, and interpret data and evidence tied to the reaction rate topic. Although based on a limited trial, these results point both to strong user acceptance and to early evidence that the developed PBL-based e-module can effectively foster students' scientific literacy.

Evaluation

The evaluation stage checked whether the finished instructional media achieved what it was designed to accomplish supporting students in reaching the intended learning outcomes, functioning smoothly in real classrooms, and generating useful feedback for future refinement. Rather than being confined to one stage, evaluation ran continuously across every phase of the ADDIE process, allowing weaknesses to be identified and addressed as they arose.

This ongoing evaluation confirmed that the finished e-module met the feasibility standards for content quality, language, and media design. Students' feedback further showed that they found the e-module easy to navigate, could follow its instructions without difficulty, and were able to complete the learning activities as intended. Both the module's appealing visual interface and its well-organized content contributed to these consistently positive responses.

Viewed through the lens of effectiveness, evaluation findings confirmed measurable gains in students' scientific literacy following their use of the PBL-based e-module. From the perspective of effectiveness, the evaluation results indicated that students' scientific literacy improved after participating in learning activities using the PBL-based e-module on the reaction rate topic.

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Discussion

This study's decision to develop a Problem Based Learning (PBL)-based e-module on reaction rate stems from two intertwined needs. On one hand, digital teaching materials are needed to keep up with the broader shift toward digital-era learning. On the other, these materials must go further by fostering students' scientific literacy competencies. The superiority of the developed e-modules lies not only in the digital presentation of the material, but also in the integration of Problem-Based Learning syntax, which facilitates students in developing scientific literacy competencies. Each instructional stage is structured to guide students toward recognizing context-based problems, collecting pertinent information, formulating potential solutions, analyzing observed data, and generating evidence-supported conclusions. Such activities correspond directly to the three fundamental dimensions of scientific literacy outlined in the PISA framework, namely explaining phenomena through a scientific lens, evaluating and formulating scientific inquiry, and interpreting data and evidence in a scientific manner. This process reorients learning away from mere concept transfer and toward the cultivation of scientific reasoning, critical thinking, and evidence-based decision-making. The effectiveness of PBL observed in this study can be traced to its defining features: starting instruction with authentic problems, then guiding students to construct knowledge through inquiry, discussion, reflection, and collaboration. Because students remain actively involved throughout each learning stage, they are able to merge conceptual understanding with science process skills, yielding comprehension that is both deeper and more meaningful (Afsas, 2023). Beyond building conceptual understanding of reaction rates, these activities are also intended to sharpen students' ability to explain scientific phenomena, interpret observational data, and apply chemical knowledge to problems encountered in everyday life (Iqlima et al., 2026).

Findings further suggest that PBL-oriented e-modules foster more substantive learning experiences by positioning students as active participants who build understanding through engagement with contextual phenomena associated with reaction rates. The integration of textual explanations, illustrations, video content, activity worksheets, literacy-based assessment items, and intuitive navigation appears to strengthen learners' motivation and sustained engagement throughout the instructional process (Çeken & Taşkın, 2022; Mikropoulos & Iatraki, 2022). These features contribute to a learner-centered instructional environment in which the teacher's role shifts toward facilitating inquiry and reflective practice. Accordingly, the e-module developed in this research operates not merely as a delivery mechanism for content but as a digital learning ecosystem that nurtures 21st-century competencies, encompassing critical thinking, communication, collaboration, creativity, and both digital and scientific literacy.

Applying PBL to reaction rate material makes particular sense, given how closely this topic connects to phenomena we encounter daily: food spoiling, fuel burning, metals corroding, fermentation taking place, or temperature speeding up a reaction. Beyond grasping abstract, particle-level concepts, students working with reaction rate material also need to analyze relationships between variables, interpret data from experiments, and explain using scientific evidence why certain factors affect reaction speed the way they do. These demands line up well with PBL's syntax, which centers on identifying problems, conducting scientific investigation, analyzing data, and building solutions grounded in scientific argumentation. As a result, weaving PBL into the e-module helps bridge macroscopic, submicroscopic, and symbolic representations in chemistry instruction, allowing students to develop a more complete

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conceptual grasp while sharpening their ability to apply that understanding to real-world situations (Aripin et al., 2025).

Overall, the findings of this study align with those reported in earlier research that PBL implementation in science education consistently strengthens students' scientific literacy, higher-order thinking, and problem-solving competence, as learners are actively engaged in constructing knowledge through authentic, problem-oriented experiences (Anazifa & Djukri, 2017; Marsa et al., 2023; Yew & Goh, 2016). These parallels suggest that PBL's effectiveness holds up fairly consistently across different science learning contexts largely because its syntax, from start to finish, is built around constructing knowledge through investigating authentic problems. That said, how much scientific literacy competency improves from one study to another can vary quite a bit, shaped by factors like student characteristics, how ready teachers are to implement PBL, the quality of e-module design, how heavily digital media gets used, and the specific material being taught. In this particular study, the gains in scientific literacy competency appear more substantial, likely because the e-module goes beyond just incorporating PBL syntax it also brings in interactive multimedia, exercises tied directly to scientific literacy indicators, and contextual activities carefully designed around the learning outcomes for reaction rate material. Pairing this pedagogical approach with digital technology creates a more meaningful learning experience overall, which in turn supports a more comprehensive achievement of scientific literacy competency.

CONCLUSION

The development of the Problem-Based Learning (PBL)-based e-module demonstrates that integrating problem-oriented learning with scientific literacy competencies can provide a meaningful approach to chemistry instruction, particularly for the reaction rate topic. By embedding contextual problems, scientific investigation, data interpretation, and reflective learning activities within a digital learning environment, the e-module offers an instructional design that supports students in constructing scientific understanding while simultaneously developing the competencies required for twenty-first-century learning. These findings suggest that integrating pedagogical models with digital learning resources represents a promising strategy for strengthening scientific literacy in secondary chemistry education.

The developed e-module also provides practical implications for chemistry teachers and instructional material developers by serving as a reference for designing contextual, interactive, and student-centered digital learning resources aligned with scientific literacy goals. Nevertheless, this study was conducted in a single school with limited implementation, indicating that broader empirical evidence is still required. Future studies are therefore encouraged to examine the effectiveness of the e-module across different educational contexts, larger and more diverse samples, various chemistry topics, and longer implementation periods to further validate its impact on scientific literacy, critical thinking, and problem-solving skills.

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