JPII 15 (1) (2026) 88-102

Jurnal Pendidikan IPA Indonesia

https://journal.unnes.ac.id/journals/jpii

IMPLEMENTING A CHALLENGE-BASED ETHNOSCIENCE E-BOOK ON COLLOID SYSTEMS TO ENHANCE STUDENTS' CRITICAL THINKING AND CONCEPTUAL UNDERSTANDING

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DOI: 10.15294/jpii.v15i1.33866

Accepted: September 14th, 2025. Approved: March 24th, 2026. Published: March 24th, 2026

ABSTRACT

Colloid learning is often difficult for students to relate to real-world phenomena, leading to a lack of conceptual understanding and critical thinking skills. One relevant local context for concretizing the concept of colloids is tofu waste treatment, which involves colloidal systems and environmental issues in the community. Integrating this ethnoscience context through Challenge-Based Learning has the potential to provide more contextual, meaningful, and authentic learning oriented toward problem-solving. This study aims to develop and demonstrate the impact of a Challenge-Based Ethnoscience e-book about colloids in the context of tofu waste treatment on improving students' conceptual understanding and critical thinking skills. This research method used Design and Development Research, consisting of three phases: design (needs analysis and product design), development (based on the 4STMD model), and evaluation (Students' critical thinking and conceptual understanding). Implementation was conducted with 30 eleventh-grade students. Critical thinking skills were measured using the Ennis framework, while conceptual understanding was assessed through context-based essay questions. Data were analyzed using the Wilcoxon test, Spearman correlation, and rank-biserial effect size. Results showed significant improvements in conceptual understanding and critical thinking skills, indicating consistent positive score changes across all participants. A very strong correlation was found between conceptual understanding and critical thinking skills, indicating a high degree of shared variance between the two. It can be concluded that the CBL e-book on ethnoscience related to colloid materials, developed according to the 4STMD, is a feasible and effective learning material for chemistry. This learning material aligns with the learning curriculum, is scientific, and organizes materials systematically through local wisdom, specifically in the context of tofu wastewater treatment, to enhance students' understanding of concepts and critical thinking skills.

Keywords: challenge-based learning; critical thinking skill; e-book; ethnoscience; 4STMD

INTRODUCTION

The landscape of 21st-century education is characterized by rapid digital transformation and accelerating technological change. These developments demand not only knowledge transfer but also the cultivation of essential 21st-century competencies, particularly higher-order thinking skills (HOTS), which are critical for navigating industrial revolutions 4.0 and 5.0 and advances in artificial intelligence (Changwong et al., 2018; Elaish et al., 2023). Among these competencies, critical thinking occupies a central role across disciplines, including science education (Ma et al., 2023; Zhang et al., 2024). However, while widely acknowledged as an educational priority, its manifestation within specific disciplinary contexts—such as chemistry—remains underexplored (Ramesh et al., 2025). In chemistry learning, critical thinking extends beyond analytical reasoning to

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include the ability to connect abstract concepts with real-world phenomena, evaluate scientific claims, and apply principles in authentic contexts. Such integration fosters meaningful conceptual understanding and moves students beyond rote memorization toward analytical and transferable knowledge (Lieber & Graulich, 2020; Rahmadhani et al., 2021; Reyes & Villanueva, 2024).

Despite its recognized importance, the development of critical thinking remains a persistent challenge in Indonesia. PISA 2022 results indicate that Indonesian students perform significantly below the OECD average in scientific reasoning and evidence-based analysis. National studies further confirm limited proficiency in critical thinking and scientific comprehension (Affandy et al., 2019; Linda et al., 2020). This suggests a gap between curriculum expectations emphasizing HOTS and classroom practices that remain largely procedural and teacher-centered (Ameh & Dantani, 2012).

Constructivist pedagogies such as inquiry-based learning, problem-based learning (PBL), project-based learning (PjBL), and generative approaches like the Science Writing Heuristic have demonstrated potential to enhance critical thinking and conceptual understanding (Prayogi & Yuanita, 2018; Karaer et al., 2024). However, these approaches are often implemented independently, without systematic integration of culturally contextualized learning or structured digital materials explicitly designed to target HOTS.

In this context, Challenge-Based Learning (CBL) becomes relevant, unlike problem-based learning or project-based learning, which generally focus on completing specific tasks or projects (Gallagher & Savage, 2022). CBL places authentic challenges as the starting point for learning. These challenges are open-ended, multidimensional, and contextual, encouraging students to integrate knowledge, engage in deep reasoning, and reflect on the solutions they produce (Taconis & Bekker, 2023).

This approach becomes even more meaningful when integrated with ethnoscience, which is rooted in the environmental context and local cultural practices close to students' lives (Hikmah et al., 2025; Mellor et al., 2018; Nurcahyani et al., 2021; Widarti et al., 2025). Through this integration, the authentic challenges raised are not only academically relevant, but also socially and culturally contextual. Thus, learning not only develops problem-solving skills but also strengthens the connection between chemical concepts and the surrounding environmental reality (Jansson et al., 2015; Raman et al., 2024; Shidiq et al., 2025).

The integration of Challenge-Based Learning (CBL) with ethnoscience within authentic real-life contexts—such as tofu waste processing—offers a pedagogically coherent approach to fostering critical thinking and contextualized chemical understanding (Putra, 2021). In Indonesia, tofu production is deeply embedded in local culinary culture and small-scale community industries, making it a culturally familiar practice for students. Scientifically, the tofu-making process directly involves colloidal principles, particularly protein coagulation, phase separation, and the transformation of a colloidal soybean suspension into a semi-solid gel structure (Li et al., 2024). Learning about colloidal systems is not only relevant to everyday life and industry but also aligns with the Sustainable Development Goals, such as SDG 4 on Quality Education (Baduri et al., 2024), SDG 9 on Industry, Innovation, and Infrastructure (Anekawati et al., 2020), and SDG 12 on Responsible Consumption and Production.

Beyond production, tofu waste—both liquid whey and residual solids—also contains dispersed colloidal particles and organic matter that influence turbidity, stability, and sedimentation behavior in water systems (Xu et al., 2018). These characteristics make tofu waste an authentic example of colloidal systems with environmental implications (Zand & Hoveidi, 2015). However, this environmental dimension is rarely addressed in chemistry instruction, where colloid topics are often limited to classification and textbook examples without linking them to local industrial practices or waste management challenges.

Framing tofu waste processing as a challenge within a CBL framework enables students to investigate colloidal behavior in a culturally grounded and environmentally relevant context (Rådberg et al., 2020; Maulisa et al., 2024). Through this approach, learners analyze dispersion stability, coagulation processes, and treatment strategies while engaging in evidence-based reasoning and solution design. Despite this strong scientific and contextual alignment, the integration of ethnoscience and CBL within structured digital chemistry teaching materials—specifically targeting colloid learning through tofu waste issues—remains underexplored in the literature.

To empirically validate the research gap, a structured search was conducted in the Scopus database covering publications from 2017 to 2026. The search combined keywords related to ethnoscience (e.g., "ethnoscience," "local wisdom"), pedagogical approaches (e.g., "challenge-based learning," "problem-based learning," "inquiry-

based learning"), critical thinking or higher-order thinking skills (HOTS), and science or chemistry education. Only six published articles have reported empirical studies integrating ethnoscience with inquiry-based, problem-based, blended, and virtual learning to enhance critical thinking and 21st-century skills. However, no study was identified that explicitly integrates ethnoscience with Challenge-Based Learning (CBL).

To accommodate CBL with ethnoscience, teaching materials are needed to make learning more focused (Malisetty et al., 2024; Ondrada et al., 2024). With technological advances and environmental sustainability in mind, electronic teaching materials are needed to help students learn systematically and structurally, integrated with critical thinking skills.

Several studies have been conducted to create chemistry teaching materials (e-books). The first study developed a green chemistry book using the Thiagarajan/4D model and demonstrated that the product was valid, practical, and effective, and could improve learning outcomes, although it remained limited to basic cognitive aspects (Anwar et al., 2021). The second study developed an interactive green chemistry e-book on hydrocarbon materials using the DDE model, producing a product that was valid in terms of content and media, with video, links, and evaluation features, but had not yet tested its impact on student abilities (Fitriana & Wiyarsi, 2024). The third study developed a chemistry representation-based e-book aligned with the 2013 curriculum and received excellent responses from teachers and students regarding content, graphics, and readability, but did not empirically measure improvements in learning outcomes or representation skills (Tania & Fadiawati, 2015). Meanwhile, the fourth study developed an e-book on the environmental context of chemical equilibrium using the 4D model. It demonstrated that the product was feasible and valid, received excellent ratings from teachers and students, and demonstrated limited effectiveness in terms of feasibility and response (Utami & Muhtadi, 2020). Overall, these studies indicate that chemistry teaching materials grounded in green chemistry, environmental contexts, and chemical representation have the potential to improve learning quality. Despite these developments, which focus more on graphics, visualization, and representation, there are persistent research gaps in evaluating their impact on higher-order thinking skills, contextualized learning, and the structuring of content to make concepts easier for students to understand.

Accordingly, this study addresses the identified gap by developing a Challenge-Based Learning e-book integrated with ethnoscience in the context of tofu waste processing for colloid learning. The development follows the Four Steps Teaching Material Development (4STMD) framework to ensure scientific validity, pedagogical coherence, and contextual relevance (Anwar, S., 2023).

The development follows the Four Steps Teaching Material Development (4STMD) framework to ensure scientific validity, pedagogical coherence, and contextual relevance. This framework is grounded in the principle of didactical reduction, which systematically transforms complex scientific content into structured, conceptually accessible learning materials without compromising scientific accuracy (Anwar, 2023). Through careful selection, organization, validation, and iterative refinement of content, 4STMD enables abstract and technically demanding topics—such as colloidal systems—to be reconstructed into learning sequences that are cognitively manageable for students.

METHODS

The Design and Development Research (DDR) approach was used as the main research design to produce a valid e-book suitable for use in the learning process. The DDR approach was used to develop teaching materials systematically through several stages: the design stage; the development stage; and the evaluation stage. Within the DDR framework, a one-group pretest–posttest design was embedded in the evaluation stage to provide empirical evidence of the product's initial effectiveness (Richey & Klein, 2007). Thus, this procedure was not positioned as a separate research design, but rather as part of the evaluation phase of DDR aimed at testing the functional effectiveness of the developed product. The three stages of the DDR approach are described in detail as follows.

The design stage began with a preliminary study that involved: analysis of colloid material learning needs, review of relevant literature, and examination of the relevance of the material to sustainable development goals (SDGs). The needs analysis identified learning gaps, student characteristics, and curriculum requirements. Based on these findings, the following were formulated: learning objectives, targeted competencies, an indicator of critical thinking skills, and a conceptual framework integrating Challenge-Based Lear-

ning (CBL) and ethnoscience. The output of this stage was an e-book blueprint that served as the foundation for systematic product development. The development stage translated the blueprint into a prototype by integrating: challenge-based learning (CBL); ethnoscience principles; Four Steps Teaching Material Development (4STMD).

The Four Steps Teaching Material Development (4STMD) method is used during development to ensure that e-books are designed systematically and aligned with learning needs and curriculum standards. This method comprises four main stages: (a) selection, which focuses on selecting colloid materials that are relevant to student needs and the national curriculum context, particularly those related to food processing and tofu waste; (b) structuring, which involves organizing materials according to student ability levels and aligning them with the logical flow of Challenge-Based Learning (Big Idea → Challenge → Solution → Reflection); (c) characterization, which aims to identify the level of difficulty of concepts and potential misconceptions among students in order to adjust the material to the cognitive level of the students; and (d) didactic reduction, which is the simplification of complex concepts through the use of analogies and ethnoscience contexts to make them easier to understand. The product at this stage was Prototype I, which underwent expert validation before field testing.

The evaluation stage aimed to examine the feasibility, comprehensibility, and initial effectiveness of the developed e-book within the Design and Development Research (DDR) framework. In this stage, product feasibility was first assessed through expert validation by three validators, including chemistry educators and a media expert. They evaluated aspects of content validity, language clarity, presentation structure, graphical design, contextual relevance, and the integration of critical thinking skills using a structured validation instrument. The results of this validation were used as the basis for revising and refining the product in accordance with the iterative refinement principle that characterizes DDR.

Following expert validation and revision, a limited field trial was conducted to obtain empirical evidence regarding the product's functional effectiveness. This field testing was embedded within the evaluation stage of DDR and employed a one-group pretest–posttest design. The purpose of this procedure was not to establish causal generalization, but to provide preliminary evidence of learning improvement after students used the developed e-book. Although no control group was included, this approach is considered appropriate in DDR studies for initial product evaluation prior to broader implementation. Students completed pretest and posttest assessments measuring conceptual understanding and critical thinking skills, and the resulting data were analyzed using appropriate inferential statistical techniques to determine whether statistically significant improvements occurred after the intervention.

Participants were involved exclusively in the evaluation stage of DDR and consisted of expert validators and students. The expert validators included two chemistry education experts and one media expert, who were responsible for assessing the feasibility of the developed e-book in terms of content validity, language, presentation, graphical design, contextual relevance, and integration of critical thinking skills. For the field-testing phase, the accessible population initially comprised 60 Grade XI students. However, due to school policy constraints and scheduling considerations that did not permit random assignment or class restructuring, only one intact class of 30 students was selected using convenience sampling. Convenience sampling was used because school policies did not allow random sampling of classes; therefore, the existing intact class was used in the study (Andrade, 2021; Farrokhi & Mahmoudi-Hamidabad, 2012; Memon et al., 2025). Therefore, the reduction from 60 to 30 participants reflects the transition from the accessible population to the actual sample used in the evaluation stage. These 30 students participated in the one-group pretest–posttest implementation to examine the initial effectiveness of the developed e-book.

To ensure clarity and avoid redundancy, the instruments used in this study were organized by the DDR framework's stages. During the design and development stages, several instruments were employed to support systematic material construction, including a content selection checklist, a material structuring rubric, and a readability evaluation form. These instruments were intended to ensure scientific accuracy, alignment with curriculum standards, logical organization of concepts, and contextual relevance of the developed e-book. The use of these tools supported the conceptual reconstruction process and ensured that the product met academic and pedagogical requirements before proceeding to validation.

In the evaluation stage, multiple instruments were used to assess product feasibility, usability, and learning effectiveness. A feasibility validation sheet was administered to expert validators using a Likert-scale format to evalua-

te content validity, language clarity, presentation quality, graphical design, contextual integration, and the incorporation of critical thinking skills. In addition, a comprehension questionnaire was distributed to students to examine the clarity, attractiveness, and usability of the e-book after implementation. To measure learning outcomes, pretest and posttest essay question instruments were administered to assess students' conceptual understanding and critical thinking skills. The indicators of critical thinking were adapted from Facione (2015) and operationalized based on Ennis (1985), covering key components such as clarification, basic support, inference, advanced clarification, and strategic thinking. Instrument validity was established through expert judgment to ensure alignment with the intended learning outcomes.

Instrument validity was established through expert judgment to ensure alignment with the intended learning outcomes. Reliability analysis using Cronbach's alpha yielded coefficients of 0.71 for conceptual understanding and 0.75 for critical thinking skills, indicating acceptable internal consistency. These procedures were conducted to evaluate the quality of the instruments and ensure they accurately and consistently measured the intended constructs before use in the effectiveness analysis.

Data analysis was conducted in accordance with the objectives of each stage within the DDR framework. The first stage involved qualitative descriptive analysis, which utilized expert reviews, open-ended responses, and observational data to examine the content accuracy, usability, and overall quality of the developed e-book (Tania & Fadiawati, 2015). Experts further refined this analysis through evaluative feedback to enhance the clarity, relevance, and pedagogical appropriateness of the product as part of the iterative revision process characteristic of DDR. The scores from the feasibility and comprehension instruments were converted to percentages and categorized into levels of feasibility (very feasible, feasible, less feasible, or not feasible) according to the criteria proposed by Arikunto (2017) to determine the overall appropriateness of the product.

For the effectiveness analysis embedded in the DDR evaluation stage, pretest and posttest data were first examined to test statistical assumptions. Normality was assessed using the Shapiro–Wilk test, supported by visual diagnostics such as Q–Q plots and histograms. Because the distribution of difference scores did not meet the normality assumption required for parametric testing and the critical thinking scores were partly based on ordinal rubric assessments, a non-parametric approach was considered more appropriate. Therefore, the Wilcoxon Signed-Rank Test was employed to analyze differences between pretest and posttest scores. This analysis aimed to determine whether there was a statistically significant improvement in students' conceptual understanding and critical thinking skills after the implementation of the developed e-book. Statistical significance was set at $p < 0.05$, and all analyses were performed using SPSS version 26.0. To complement the significance testing, the effect size was calculated using rank-biserial correlation, which is recommended for non-parametric paired-sample comparisons.

RESULTS AND DISCUSSION

The Challenge-Based Ethnoscience E-book on Colloids was designed using the 4STMD model in two main phases: design and development, to be scientifically accurate, systematic in organization, and understandable to students. The contextual theme of tofu wastewater treatment was selected to integrate local wisdom with scientific learning, supporting SDG 4 on Quality Education and SDG 12 on Responsible Consumption and Production.

During the Selection stage, the content was focused on the learning of basic colloid concepts, such as the difference between solutions, colloids, and suspensions; types and properties of colloids (Tyndall effect, coagulation, adsorption, Brownian motion, and electrophoresis); and application in green waste treatments, aligned with the National Curriculum. In the Structuring stage, the concept map and macrostructure guided the learning flow through three representational levels: macroscopic (visible phenomena of tofu wastewater turbidity), submicroscopic (interactions among colloidal particles), and symbolic (chemical equations).

During Characterization, comprehension tests with 30 students showed that most texts were easy to understand, while three sections were identified as difficult because of abstract or complex explanations. These were improved in the Didactic Reduction stage by simplifying sentences, adding visual aids, and providing concrete examples. For example, the text on Bredig's arc method was enhanced with an explanatory diagram, and the text on hydrolysis reactions was clarified with real industrial applications.

Scientific accuracy, contextual relevance, and pedagogical clarity were well integrated in this e-book, making abstract colloid concepts

more concrete and meaningful. Its design encourages active learning, critical thinking, and environmental awareness, which are aligned with the key outcomes of sustainable chemistry education (Astawan et al., 2025; Atmojo et al., 2025; Sayadi & Pangandaman, 2025).

The results of the e-Book feasibility and understandability tests are presented in Table 1 and Figure 1.

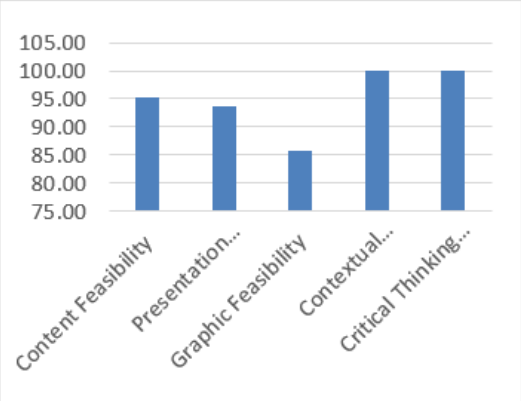

Figure 1. Feasibility Test Results

Figure 1 shows the feasibility test results for a colloidal e-book in the context of liquid tofu waste processing, involving three high school chemistry teachers as education practitioners, using criteria from the curriculum and book center of the Ministry of Primary and Secondary Education. The assessment covered several aspects: content, language, presentation, graphics, context, and critical thinking skills. Based on the results shown in Figure 1, the ethnoscience and CBL-based e-book met the main criteria, such as content, discussion, presentation, and contextual feasibility, with a percentage above 80%. Teachers assessed this e-book as very accurate in its material, relevant to real-world contexts such as tofu waste processing, and aligned with the learning outcomes of the National Curriculum across the 4STMD stages.

The research results show that the developed e-book material aligns with the learning outcomes and instructional objectives of the taught topic. The content presented is scientifically accurate, up to date, and relevant to current scientific developments. The presentation also stimulates students' curiosity through problem-solving examples in real-life contexts, thereby encouraging the development of life skills such as critical thinking and problem-solving. However, several aspects of student communication, interaction, and collaboration still need strengthening, as e-books are typically used individually and therefore do not fully facilitate collaboration. These findings reinforce the idea that systematically designed digital teaching materials can play a strategic role in pedagogical practice, serving not only as a source of information but also enhancing students' conceptual understanding and thinking skills (Kattoua et al., 2016; Ananga, 2020; Boada, 2022). Furthermore, previous studies have shown that high-quality teaching materials play a crucial role in online, offline, and blended learning, particularly by providing a more interactive, contextual, and accessible learning experience for students (Castro & Zermeno, 2020; Safarifard et al., 2024).

In terms of language, the e-book is generally acceptable, though a few typos need correction. The presentation of the material still needs improvement in terms of writing consistency, balance between chapter and sub-chapter content, and the numbering of text, tables, and images. Graphically, the cover and illustrations are acceptable, but the layout, colors, and embellishments need refinement to make them more attractive and harmonious.

The contextual aspect received the highest score due to its integration with environmental issues, indicating that the e-book content is appropriate, reliable, up-to-date, and scientifically valid in connecting theoretical chemistry concepts with real-world problems in tofu waste management. This authentic context also supports the achievement of SDG 4 (Quality Education) and SDG 12 (Responsible Consumption and Production) by encouraging sustainable science learning (Forsler et al., 2024; Kartamiharja et al., 2020; Paramitadevi et al., 2019; Stöckert & Bogner, 2020). The use of tofu waste processing as an ethnoscience approach has also proven effective in bridging colloid concepts with students' real-life experiences. This contextual approach aligns with the view that science learning becomes more meaningful when students are exposed to authentic phenomena from everyday life (as expressed by Vygotsky and modern constructivist theory, for example). Thus, integrating environmental issues into tofu waste processing not only strengthens conceptual understanding but also fosters environmental literacy and sensitivity to socio-scientific issues.

In the realm of critical thinking skills, this e-book was developed to train five main aspects: basic clarification, basic support, inference, assessment, and strategy and tactics. In line with Larassati & Rachmadiarti (2021), significant improvements in students' thinking skills and conceptual understanding can be achieved by appropriate learning media or effectively designed teaching materials. Quality learning media

not only conveys information but also facilitates high-level cognitive activities that encourage students to analyze, interpret, and relate concepts to real-life situations (Kattoua et al., 2016; Ananga, 2020; Boada, 2022). Previous research has also confirmed that interactive, contextual, and culturally relevant digital learning materials can increase student participation, foster curiosity, and strengthen the connection between theory and practice (Engerman & Otto, 2021; Anyichie et al., 2023). This e-book has been shown to stimulate curiosity and enhance critical thinking skills through a contextual socio-scientific approach, thus encouraging students to analyze, interpret, and synthesize colloidal concepts in greater depth.

The understandability test evaluated students' understanding of the e-book text after the didactic reduction process was also conducted. The instrument was like the one used in the characterization stage, but the text was minimally reduced to maintain its level of difficulty. The average understandability score was 86.5 percent, indicating a high and independent category as shown in Table 1. The comprehension test was designed to measure students' ability to interpret meaning, connect new information with prior knowledge, and understand the context in which the text is presented (Tarlani-Aliabadi et al., 2022). This assessment evaluates the extent to which students can comprehend the e-book content that has undergone a didactic reduction process, systematically simplifying complex scientific material without removing essential concepts needed for deep learning. This approach has been recommended in various studies on the development of digital learning materials to preserve conceptual integrity while maintaining an appropriate level of difficulty for students.

The decision to retain a certain level of textual complexity aimed to preserve intellectual depth and promote higher cognitive engagement, particularly in the colloid chemistry material contextualized within tofu liquid waste processing. The test instrument was developed to assess students' comprehension of this balanced presentation of content. The results showed that high school students achieved consistently above-average scores, placing them in the category of highly independent learners. These findings indicate that the e-book design provides sufficient conceptual support, enabling students to identify and articulate key concepts independently. This achievement aligns with international research demonstrating the effectiveness of systematically structured e-books in enhancing science comprehension (Suriani et al., 2023; Kurniadin, 2025).

Table 1. Feasibility of the Understandability Test Results

Text Number	% of Students Correct	Text Number	% of Students Correct
1	89	24	71
2	86	25	86
3	89	26	71
4	96	27	68
5	82	28	79
6	100	29	86
7	96	30	96
8	82	31	82
9	86	32	82
10	89	33	86
11	75	34	86
12	89	35	82
13	93	36	75
14	89	37	93
15	79	38	82
16	82	39	96
17	86	40	89
18	89	41	89

19	100	42	96
20	86	43	100
21	93	44	79
22	75	45	93
23	93	46	86
Average	86.5		

This study was also conducted in pairs using digital devices. The high level of comprehension is consistent with Johnstone's observation that understanding chemistry improves when material is presented through the three levels of representation: macroscopic, submicroscopic, and symbolic (Wood, 2013). The integration of these three representations in the e-book likely strengthened students' conceptual understanding of colloid systems. In addition, using tofu liquid waste processing as an ethnoscience-based context provided a real-life situation that bridges scientific knowledge with students' empirical experiences, as highlighted in recent research on integrating cultural knowledge into science education (Aikenhead, 2021).

Several factors explain the high comprehension scores. First, feasibility test results showed that even with minimal didactic reduction, the language and presentation remained accessible without compromising scientific validity. Second, the 4STMD structure offered a systematic learning sequence that supported students in constructing knowledge more efficiently (Anwar, 2023). Third, dividing students into two groups likely helped reduce cognitive load, allowing them to focus on specific sections of the text. The consistent average score of 86.5 percent in both groups, with no significant difference in comprehension levels, indicates the stability and robustness of the e-book design as an effective learning medium. The implications of these findings are highly significant for the development of digital-based chemistry education. The 86.5 percent comprehension score indicates students' ability to process information independently, an essential competency in today's digital learning ecosystem. These results strengthen empirical evidence that an ethnoscience approach can enhance the relevance of chemistry learning by connecting the content to students' lived experiences.

Student improvement performance from low to high understanding categories is shown in Table 2.

Table 2. Pretest and Posttest Categorization of Concept Understanding

Category	Score	Pretest (n)	Posttest (n)
Low	0–33.29	14	0
Moderate	33.30–66.59	13	12
High	66.60–100	3	18
Total		30	30

Table 2 describes the categorization of students' conceptual understanding before and after the implementation of an e-book integrated with the CBL approach. From Table 2, it is evident that there is a remarkable improvement in students' understanding of colloid concepts. Before learning, 14 students were in the low category, 13 in the moderate category, and only three in the high category. After learning, none remained in the low category, 12 in the moderate category, and 18 in the high category.

This shift clearly points to an enhancement in conceptual understanding, indicating that the integration of the e-book with CBL effectively supported students in moving from basic to advanced understanding. This also revealed that the contextualized, inquiry-driven learning environment successfully facilitated deeper engagement and higher-level thinking, enabling students to construct and apply scientific concepts more autonomously (Sun et al., 2024; Sulastri et al., 2025). The improvement in the students' understanding of concepts is also shown in Table 3, which presents the results of the Wilcoxon Signed-Rank Test.

The improvement in the students' understanding of concepts is also shown in Table 3, which presents the results of the Wilcoxon Signed-Rank Test. During the classroom engagement phase, students encountered contextual

problems. Then, in the Investigate phase, they worked collaboratively, formulated guiding questions, accessed the e-book, and completed the e-book and tailored worksheets. The results were striking, with all 30 participants showing significant improvements, as confirmed by the Wilcoxon Signed-Rank Test (W = 0 < W critical = 137, $\alpha = 0.05$). The posttest results further underscored the effectiveness of the CBL-integrated e-book in enhancing the students' understanding of colloid concepts. Notably, more students shifted from a lower level of understanding, demonstrating the power of contextual, ethnoscience-based, and challenge-oriented digital learning to promote scientific literacy, critical thinking, and the integration of classroom learning with real-life environmental challenges.

Table 3. Results of the Wilcoxon Signed-Rank Test of Concept Understanding in Concept Understanding

	N	Sum of Ranks
Negative Rank	0	0
Positive Rank	30	465
Ties	0	0
Total	30	
W	0	
W critical	137	

In essence, CBL and nano-challenge activities offer a robust approach to educating learners on how to manage tofu waste and mitigate pollution (Membrillo-Hernández et al., 2019). This not only deepens their understanding of waste management but also equips them with practical skills to tackle environmental challenges in conservation and sustainability (Kartamiharja et al., 2020; Nizami et al., 2023). The research findings suggest a promising future in which students are not just aware of environmental issues but also capable of addressing them. Critical thinking skills were measured through integrated tests with e-books and CBL and analyzed using the Wilcoxon Signed-Rank Test in Table 4. Table 4 illustrates the results of the Wilcoxon Signed-Rank Test for students' critical thinking performance after using the e-book integrated with a Challenge-Based Learning approach. The test results reveal that W = 0 < W critical = 98 ($\alpha = 0.05$); thus, the result is significant. Additionally, all positive rank changes occurred across all subjects (n = 30), indicating that posttest scores were higher than pretest scores for each subject, without decreasing or remaining the same.

Table 4. Results of the Wilcoxon Signed-Rank Test for Critical Thinking Skills

	N	Sum of Ranks
Negative Rank	0	0
Positive Rank	30	465
Ties	0	0
Total	30	
W	0	
W critical	98	

To complement the significance test results, an effect size was calculated using a rank-biserial correlation, yielding $r_{(rb)} = 1.00$. In a rank-based analysis, this value indicates a maximal positive effect, as all participants improved. However, this value is not interpreted as a percentage of causal influence but rather as an indicator of the strength of the relationship between pretest and posttest scores. Thus, the improvement in critical thinking skills was not only statistically significant but also had a very large effect size in practice.

These results show that a uniform increase indicates the effectiveness of the learning activity in enhancing students' analysis, evidence evaluation, and reasoning in reaching conclusions (Vu, 2025). These results are further supported by the findings in Table 5, which show the distribution of students' critical thinking skill categories befo-

re and after the intervention. Before the intervention, 14 students were in the low category; after the intervention, none remained in that category. Conversely, the number of students in the high category increased from 2 in the pretest to 11 in the posttest. This substantial distribution shift indicates a descriptively meaningful performance improvement and aligns with the results of the inferential analysis (Jones, 2007; Fadiawati et al., 2020; Li & Liu, 2021).

Table 5. Pretest and Posttest Categorization of Critical Thinking Skills

Category	Score	Pretest (n)	Posttest (n)
Low	0–33.29	14	0
Moderate	33.30–66.59	14	19
High	66.60–100	2	11
Total		30	30

Pedagogically, this improvement can be explained by the characteristics of CBL, which emphasize the stages of engage, investigate, and act. The iterative, collaborative, and contextual problem-based inquiry cycle encourages students to analyze information, evaluate evidence, and logically construct arguments before reaching a conclusion. The integration of an ethnoscience context into the e-book also enhances the relevance of learning to students' real-life situations, thereby increasing motivation, curiosity, and cognitive engagement in higher-order thinking. These findings align with previous research showing that challenge-based and inquiry-oriented learning significantly contributes to the development of critical thinking skills (Bae & Lai, 2020; Gold, 2021; Nizami et al., 2023; Vu, 2025).

The relationship between students' conceptual understanding and critical thinking skills was analyzed using Spearman's rho. This non-parametric test was chosen because it is appropriate for assessing associations between variables that do not always meet the assumption of normality. Unlike the improvement analysis in the previous section, this analysis specifically aims to identify the strength and direction of the relationship between the two constructs. The results of the analysis, presented in Table 6, show a correlation coefficient of $r = 0.9496$, indicating a very strong positive relationship between conceptual understanding and students' critical thinking skills.

The coefficient of determination ($r^2 = 0.9018$) indicates that both variables have a very high level of shared variance. This means that approximately 90% of the variation in scores on both variables moves in step or increases simultaneously. However, this value cannot be interpreted as a percentage effect or causal relationship; it only indicates a strong statistical association. Given the study's non-experimental design, neither the direction nor the mechanism of causality can be inferred from these results. However, this strong relationship aligns with previous research, which indicates that deeper conceptual understanding is closely associated with the development of critical reasoning abilities (Stöckert & Bogner, 2020; Astawan et al., 2025).

Table 6. Correlation Test Results

Description	Value
Correlation Coefficient (r)	0.9496
Coefficient of Determination (r^2)	0.9018

This research has two main focuses. First, this research develops an ethnoscience-based learning e-book integrated with Challenge-Based Learning (CBL) on colloidal materials through the 4STMD approach (Selection, Structuring, Characterization, and Didactic Reduction). This e-book integrates the concept of colloids with the local context, specifically the practice of tofu waste processing, thereby providing a more tangible connection between scientific concepts and environmental issues relevant to students. This integration of local context is designed to increase the relevance of learning, strengthen conceptual connections, and help students understand that scientific concepts cannot be separated from social and environmental realities.

The development process was carried out systematically through the 4STMD stages and aligned with the principles of the Independent Curriculum. In addition to focusing on achieving cognitive competencies, the e-book design also considered its contribution to improving the quality of learning (SDG 4) and awareness of responsible consumption and production (SDG 12). Thus, the resulting product serves not only as a digital learning medium but also as a means of integrating contextual and desire aspects into an integrated learning system.

Second, this study disseminates the application of e-books in improving students' conceptual understanding and critical thinking skills. The analysis results showed a statistically significant increase in scores for both variables, as determined by the Wilcoxon test. To complement this significant result, the effect size was calculated using a rank-biserial correlation, yielding $r_{(}rb_{)} = 1.00$ for both variables. In a rank-based analysis, this value indicates a maximal positive effect because all participants experienced an increase in scores, with no negative ranks or ties. This finding indicates that the improvement is consistent across students and has a significant effect strength in practice. However, this value is not interpreted as a percentage of causal influence but rather as an indicator of the strength of the change in scores between the pretest and posttest.

Furthermore, a very strong positive correlation was found between conceptual understanding and critical thinking skills ($r = 0.95$), indicating a strong relationship between the two constructs. This means that students who improve their conceptual understanding also tend to improve their critical thinking skills. However, given the study design, which lacked a control group, this relationship cannot be considered a direct cause-and-effect.

The main contribution of this study lies in integrating three pedagogical approaches —ethnoscience, CBL, and the 4STMD framework— into a single, structured digital learning system. While each approach has been extensively researched separately, the combination of the three in the context of intuition-based chemistry learning remains relatively limited. This integration demonstrates the potential of a learning model that simultaneously clarifies conceptual understanding, develops higher-order thinking skills, and raises awareness of environmental issues.

While the results demonstrate significant and consistent improvements, several methodological limitations should be considered. One-group pretest-posttest design without a control group is potentially affected by threats to internal validity, such as testing effects, where students may experience improvement due to familiarity with the testing instrument; maturation effects, which are natural cognitive developments over the course of the study; and novelty effects, which are increased motivation due to the use of a relatively new learning medium.

However, this study used a single-group pretest-posttest design, with no control group, and a small sample size makes generalization difficult. Furthermore, the use of a single-group pretest-posttest design should be interpreted with caution, as it cannot be used to examine causal effects on concept mastery and critical thinking skills. Moreover, an actual experimental (Quasi-Experimental) study should be conducted, as larger sample sizes will enhance internal validity. Furthermore, based on the CBL-Ethnoscience-4STMD strategy, new topics in chemistry, such as thermodynamics or organic chemistry, should be developed and implemented in computer-assisted learning environments to assess their lasting impact on student attitudes and performance.

In this study, non-parametric statistics were chosen not because of sample size but because of the data's characteristics. Preliminary tests indicated that the data did not meet normality assumptions, and both conceptual understanding and critical thinking scores were based on ordinal rubrics. Therefore, Spearman's rho was the most appropriate method. However, this study served as an initial development and feasibility evaluation of the integrated e-book, and institutional constraints prevented the formation of a control group. This limitation has been acknowledged, and we recommend that future studies employ an experimental or quasi-experimental design with a control group for stronger validation. Therefore, although the effect size indicates a significant change in strength, the interpretation of these findings still requires caution. Future research is recommended to use experimental designs with control groups or longitudinal designs to strengthen causal inferences and test the intended learning impact.

CONCLUSION

From the results and discussion, the CBL e-book on ethnoscience related to colloid materials, developed according to the 4STMD, is a feasible and effective learning material for chemistry. This learning material aligns with the learning curriculum, is scientific, and organizes materials systematically through local wisdom, specifically in the context of tofu wastewater treatment, to enhance students' understanding of concepts and critical thinking skills. The analysis revealed that experts highly scored feasibility, and students achieved 86.5% understanding. The correlation analysis results show a very strong positive relationship between conceptual understanding and critical thinking skills ($r = 0.9496$). The coefficient of determination ($r^2 = 0.9018$) indicates that 90.18% of the variation in critical thinking skills can be explained by conceptual understanding. Based on the above findings, it is evident that digital learning materials grounded

in ethnoscience and context positively enhance students' critical thinking skills and help them associate the learning of chemistry with SDG 4 and SDG 12. This e-book, when implemented in a class setting, stimulates problem-solving skills, teamwork, and appreciation for the environment through real-world problems that are meaningful to different cultures. Thus, this model holds promise for making chemistry learning more significant, student-centered, and sustainability-infused.

REFERENCES

Affandy, H., Aminah, N. S., & Supriyanto, S. (2019). Analisis Keterampilan Berpikir Kritis Siswa pada Materi Fluida Dinamis di SMA Batik 2 Surakarta. *Jurnal Materi dan Pembelajaran Fisika*, *9*(1), 25-33.

Aikenhead, G. (2021). Epilogue: Communicating Innovative Research. Science Education Research and Practice from Japan, 193.

Ameh, P. O., & Dantani, Y. S. (2012). Effects of Lecture and Demonstration Methods on the Academic Achievement of Students In Chemistry in Nassarawa Local Government Area of Kano State. *International Journal of Modern Social Sciences*, *1*(1), 29-37.

Ananga, P. (2020). Pedagogical Considerations of E-Learning in Education for Development in the Face of COVID-19. *International Journal of Technology in Education and Science*, *4*(4), 310–321.

Andrade, C. (2021). The Inconvenient Truth About Convenience and Purposive Samples. Indian *Journal of Psychological Medicine*, *43*(1), 86–88.

Anekawati, A., Otok, B. W., Purhadi, P, & Sutikno, S. (2020). Exploring the related factors in education quality through spatial autoregressive modeling with latent variables: a rural case study. *Education Research International*, *2020*(1), 8823186.

Anwar, M., Alimin, A., & Munawwarah, M. (2021). An interactive e-book development based on green chemistry study on Hydrocarbon. *Journal of Physics: Conference Series*, *1899*(1), 12161.

Anwar, S. (2023). *Metode Pengembangan Bahan Ajar Four Steps Teaching Material DevelopmenT (4STMD).* Indonesia Emas Group

Anyichie, A. C., Butler, D. L., & Nashon, S. M. (2023). Exploring Teacher Practices for Enhancing Student Engagement in Culturally Diverse Classrooms. *Journal of Pedagogical Research*, *7*(5), 183-207.

Arikunto, S. (2017). Pengembangan Instrumen Penelitian dan Penilaian Program. Yogyakarta: Pustaka Pelajar.

Astawan, I. G., Margunayasa, I. G., Jayanti, L. S. S. W., Fakhriyah, F., & Deng, J. (2025). The Impact of Problem-Based Learning on Reducing Science Misconceptions and Enhancing Scientific Literacy: Integrating Balinese Local Wisdom And Cognitive Style. *Jurnal Pendidikan IPA Indonesia*, *14*(3), 522–535.

Atmojo, S. E., Anggriani, M. D., Rahmawati, R. D., Skotnicka, M., Wardana, A. K., & Anindya, A. P. (2025). Bridging Stem and Culture: The Role of Ethnoscience in Developing Critical Thinking and Cultural Literacy. *Jurnal Pendidikan IPA Indonesia*, *14*(2), 251–266.

Bhaduri, I., Aryamol, K. B., & Sahoo, B. L. (2024). Leveraging Technology for Multidisciplinary and Transdisciplinary Learning to Achieve Sustainable Development Goal 4: Quality Education. In *Achieving Sustainable Business through AI, Technology Education and Computer Science: Volume 1: Computer Science, Business Sustainability, and Competitive Advantage* (pp. 127-142). Cham: Springer Nature Switzerland.

Bae, C. L., & Lai, M. H. (2020). Opportunities to participate in science learning and student engagement: A mixed methods approach to examining person and context factors. *Journal of Educational Psychology*, *112*(6), 1128.

Boada, D. A. (2022). Cultivating an Online Teacher Community of Practice around the Instructional Conversation Pedagogy: A Social Network Analysis. *Educational Technology Research and Development*, *70*, 289–319.

Castro, M. P., & Zermeno, M. G. G. (2020). Challenge based Learning: Innovative Pedagogy for Sustainability through E-learning in Higher Education. *Sustainability*, *12*(10), 4063.

Changwong, K., Sukkamart, A., & Sisan, B. (2018). Critical Thinking Skill Development: Analysis of A New Learning Management Model for Thai High Schools. *Journal of International studies*, *11*(2), 37-48.

Elaish, M. M., Hussein, M. H., & Hwang, G. J. (2023). Critical Research Trends of Mobile Technology-Supported English Language Learning: A Review of the Top 100 Highly Cited Articles. *Education and Information Technologies*, *28*(5), 4849-4874.

Engerman, J. A., & Otto, R. F. (2021). The Shift to Digital: Designing for Learning from a Culturally Relevant Interactive Media Perspective. *Educational Technology Research and Development*, *69*(1), 301-305.

Ennis, R. (1985). *A Logical Basis for Measuring Critical Thinking Skills*. USA: University of Illinois.

Fadiawati, N., Diawati, C., & Syamsuri, M. (2020). Using Problem-Based Learning to Improve Students'critical Thinking Skills to Deal Hoax Information in Chemistry. *Periodico Tche Quimica*, *17*(35), 120-134.

Farrokhi, F., & Mahmoudi-Hamidabad, A. (2012). Rethinking Convenience Sampling: Defining Quality Criteria. *Theory and Practice in Language Studies*, *2*(4), 784–792.

Facione, P. A. (2011). Critical thinking: What it is and why it counts. *Insight assessment*, *1*(1), 1-23.

Fitriana, A. N., & Wiyarsi, A. (2024). Development of Chemical Equilibrium E-Book in the Environ-

mental Context to Promote Students' Chemical Representation Ability. *IOP Conference Series: Earth and Environmental Science*, *1425*(1), 12032.

Forsler, A., Nilsson, P., & Walan, S. (2024). What and Why in Teaching about Sustainability - Swedish Science Teachers' Emphasis on Content Choice when Teaching Sustainable Development. *Nordic Studies in Science Education*, *20*(1), 4–21.

Gallagher, S. E., & Savage, T. (2022). Challenge Based Learning: Recommendations for the Future of Higher Education. *The Emerald Handbook of Challenge Based Learning*, 391.

Gold, J. D. (2021). Cognitive and sociocultural perspectives: Approaches and implications for learning, teaching and assessment. *The European Journal of Social & Behavioural Sciences*, *30*(3), 217-235.

Hikmah, N., Yohandri, Y., Arsih, F., Azhar, M., & Razak, A. (2025). Uncovering The Potential of Ethnoscience in Science Learning to Improve Students' Literacy: A Systematic-Literature Review (2014–2024). *Jurnal Pendidikan IPA Indonesia*, *14*(3), 550–562.

Jansson, S., Söderström, H., Andersson, P. L., & Nording, M. L. (2015). Implementation of Problem-Based Learning in Environmental Chemistry. *Journal of Chemical Education*, *92*(12), 2080–2086.

Jones, A. (2007). Multiplicities or Manna from Heaven? Critical Thinking and the Disciplinary Context. *Australian journal of education*, *51*(1), 84-103.

Karaer, G., Hand, B., & French, B. F. (2024). Examining the Impact of Science Writing Heuristic (SWH) Approach on Development of Critical Thinking, Science and Language Skills of Students with and without Disabilities. *Thinking Skills and Creativity*, *51*, 101443.

Kartamiharja, M. R., Sopandi, W., & Anggraeni, D. (2020). Implementation of Problem-Based Learning (PBL) Approach in Chemistry Instructional with Context Of Tofu Liquid Waste Treatment. *International Journal of Learning Teaching and Educational Research*, *19*(5), 47–77.

Kattoua, T., Al-Lozi, M., & Alrowwad, A. A. (2016). A Review of Literature on E-Learning Systems in Higher Education. *International Journal of Business Management and Economic Research*, *7*(5), 754-762.

Kurniadin, M. Z. (2025). The Role of Interactive E-Books in Enhancing Science Literacy: A Review of Studies from 2015 to 2024. *International Journal of Science Education and Science, 2*(1), 17-25.

Larassati, F., & Rachmadiarti, F. (2021). The Development of E-Book based on Modified Free Inquiry on Ecology Topic to train critical thinking skills in Class X High School Students. *Berkala Ilmiah Pendidikan Biologi (BioEdu)*, *10*(2), 302-313.

Li, Q., Hua, Y., Li, X., Kong, X., Zhang, C., & Chen, Y. (2024). Colloidal state–based studies on the chloride salts of magnesium- and calcium-induced coagulation of soymilks. *Journal of Food Science*, *89*(12), 8555–8568.

Li, X., & Liu, J. (2021). Mapping The Taxonomy of Critical Thinking Ability in EFL. *Thinking Skills and Creativity*, *41*, 100880.

Lieber, L., & Graulich, N. (2020). Thinking in Alternatives - A Task Design for Challenging Students' Problem-Solving Approaches in Organic Chemistry. *Journal of Chemical Education*, *97*(10), 3731–3738.

Linda, R., Nufus, H., & Susilawati, S. (2020, June). The implementation of chemistry interactive e-module based on Kvisoft Flipbook Maker to improve student'self-learning. In *AIP Conference Proceedings* (Vol. 2243, No. 1, p. 030011). AIP Publishing LLC.

Ma, X., Zhang, Y., & Luo, X. (2023). Students' and teachers' critical thinking in science education: are they related to each other and with physics achievement?. *Research in Science & Technological Education*, *41*(2), 734-758.

Malisetty, S., Rastegari, E., Siu, K. C., & Ali, H. H. (2024). Bridging Learning Gaps in Computing Education: A Focus on Assessing the Impact of Accessing Educational Material under Different Teaching Modalities. *45th International Conference on Information Systems Icis 2024.*

Maulisa, A., Herliana, F., Mahzum, E., Elisa, E., Farhan, A., & Nurulwati, N. (2024). Development of problem based learning teaching modules based on blended learning in the implementation of the independent curriculum. *Current STEAM and Education Research*, *2*(2), 69-80.

Mellor, K. E., Coish, P., Brooks, B. W., Gallagher, E. P., Mills, M., Kavanagh, T. J., ... & Anastas, P. T. (2018). The safer chemical design game. Gamification of green chemistry and safer chemical design concepts for high school and undergraduate students. *Green Chemistry Letters and Reviews*, *11*(2), 103-110.

Membrillo-Hernández, J., J. Ramírez-Cadena, M., Martínez-Acosta, M., Cruz-Gómez, E., Muñoz-Díaz, E., & Elizalde, H. (2019). Challenge based learning: the importance of world-leading companies as training partners. *International Journal on Interactive Design and Manufacturing (IJIDeM)*, *13*(3), 1103-1113.

Memon, M. A., Thurasamy, R., Ting, H., & Cheah, J.-H. (2025). Convenience Sampling: A Review and Guidelines for Quantitative Research. *Journal of Applied Structural Equation Modeling*, *9*(2), 1-23.

Nizami, M. Z. I., Xue, V. W., Wong, A. W. Y., Yu, O. Y., Yeung, C., & Chu, C. H. (2023). Challenge-based learning in dental education. *Dentistry journal*, *11*(1), 14.

Nurcahyani, D., Yuberti, Y., Irwandani, I., Rahmayanti, H., Ichsan, I. Z., & Mehadi, M. R. (2021, February). Ethnoscience learning on science literacy of physics material to support environ-

ment: A meta-analysis research. In *Journal of Physics: Conference Series* (Vol. 1796, No. 1, p. 012094). IOP Publishing.

Ondrada, J. J., Mario, J. A. B., Makilan, N. C., Langcoy, M. G. F., & Acanto, R. B. (2024). Innovative contextualized instructional materials utilizing ethanolic crude extract from blue porter weed (Stachytarpheta Jamaicensis) for enhancing science learning in the Philippines. *Edelweiss Applied Science and Technology*, *8*(5), 1740–1772.

Paramitadevi, Y. V., Resmeiliana, I., & Apriliani, F. (2019, December). Combining Both ends of pipe treatment and cleaner production–A Case study of tofu SME in Bogor. In *IOP Conference Series: Earth and Environmental Science* (Vol. 399, No. 1, p. 012052). IOP Publishing.

Prayogi, S., & Yuanita, L. (2018). Critical Inquiry Based Learning: A Model of Learning to Promote Critical Thinking among Prospective Teachers of Physic. *Journal of Turkish Science Education*, *15*(1), 43-56.

Putra, H. S. (2021). Ethnoscience a bridge to back to nature. In *E3S Web of Conferences* (Vol. 249, p. 01002). EDP Sciences.

Rådberg, K. K., Lundqvist, U., Malmqvist, J., & Hagvall, O. (2020). From CDIO to Challenge-Based Learning Experiences–Expanding Student Learning as well as Societal Impact?. *European Journal of Engineering Education*, *45*(1), 22-37.

Rahmadhani, P., Sutrisno, S., & Widarti, H. R. (2021, March). Increasing students' critical thinking skills in fundamental of analytical chemistry using inquiry-based learning with OE3R strategy. In *AIP Conference Proceedings* (Vol. 2330, No. 1, p. 020013). AIP Publishing LLC.

Raman, Y., Surif, J., & Ibrahim, N. H. (2024). The Effect of Problem Based Learning Approach in Enhancing Problem Solving Skills in Chemistry Education: A Systematic Review. *International Journal of Interactive Mobile Technologies*, *18*(5), 91–111.

Ramesh, V. B., Seery, M. K., & Cole, R. (2025). Assessing Science Practices in Undergraduate Chemistry Laboratories: Why We Need to Do Better and How We Should. *Journal of Chemical Education*, *103*(1), 27.

Reyes, R. L., & Villanueva, J. A. (2024). Narrative-Based Concept Representations: Fostering Visual Cognition in the Introductory Chemistry Classroom. *Journal of Chemical Education*, *101*(3), 1106–1119.

Richey, R. C., & Klein, J. D. (2007). *Design and Development Research: Methods, Strategies, and Issues*. New York: Lawrence Erlbaum Associates.

Safarifard, R., Lavasani, M. G., Hejazi, E., & Thani, F. N. (2024). Pedagogical Aspect of e-Learning in Higher Education: A Systematic Literature Review. *Knowledge Management & E-Learning*, *16*(3), 521-546.

Sayadi, D., & Pangandaman, H. (2025). Technology-Enhanced Science Teaching for 21st-Century Learning: A Systematic Review of Evidence-Based Strategies and Their Alignment with SDG 4. *Jurnal Pendidikan IPA Indonesia*, *14*(3), 585-598.

Shidiq, A. S., Nurlatifah, V., Yamtinah, S., Ulfa, M., & Fadilah, M. (2025). Promoting Sustainability-Oriented Chemistry Learning with Simple Photometer. *Journal of Chemical Education*, 102(12), 5149–5159.

Stöckert, A., & Bogner, F. X. (2020). Cognitive Learning about Waste Management: How Relevance and Interest Influence Long-Term Knowledge. *Education Sciences*, *10*(4), 102.

Sulastri, S., Rasul, M. S., & Zatya, I. (2025). STEM-Based Guided Inquiry in Colloid Practicums and Its Influence on Students' Concept Mastery. *Jurnal Pendidikan IPA Indonesia*, *14*(2).

Sun, X., Lin, G., Zhan, M., Zheng, Y., Ye, J., & Chen, D. (2024). Effects of a Microcomputer-Based Laboratory on the Triple-Representation of a Preservice Chemistry Teacher: An Eye-Tracking Design and Evidence. *Journal of Chemical Education*, *101*(3), 858–867.

Suriani, N. M., Agustini, K., Sudhata, I. G. W., & Dantes, G. R. (2023). The effectiveness of E-book in learning process: A Systematic Literature Review. *International Journal of Social Sciences, 6*(2), 43-50.

Taconis, R., & Bekker, T. (2023, August). Challenge Based Learning as authentic learning environment for STEM identity construction. In *Frontiers in education* (Vol. 8, p. 1144702). Frontiers Media SA.

Tania, L., & Fadiawati, N. (2015). The development of interactivee-book based chemistry representations referred to the curriculum of 2013. *Jurnal Pendidikan IPA Indonesia*, *4*(2), 164–169.

Tarlani-Aliabadi, H., Tazik, K., & Azizi, Z. (2022). Exploring the role of language knowledge and background knowledge in reading comprehension of specific-purpose tests in higher education. *Language Testing in Asia*, *12*(1), 48.

Utami, R. A., & Muhtadi, A. (2020, May). TPACK-based e-book for learning chemistry in senior high school. In *International Conference on Online and Blended Learning 2019 (ICOBL 2019)* (pp. 166-168). Atlantis Press.

Vu, X. H. (2025). Leveraging Technology for Higher-Order Thinking Development: Instructional Design Strategies in Higher Education. *International Journal of Technologies in Learning*, *32*(2), 25–46.

Widarti, H. R., Wiyarsi, A., Yamtinah, S., Shidiq, A. S., Sari, M. E. F., Fauziah, P. N., & Rokhim, D. A. (2025). Analysis of content development in chemical materials related to ethnoscience: a review. *Journal of Education and Learning*, *19*(1), 422–430.

Wood, L. (2013). *Representing Chemistry: How Instructional Use of Symbolic, Microscopic, and Macroscopic Mode Influences Student Conceptual Understanding in Chemistry*. Arizona State University.

Xu, H., Xu, M., Li, Y., Liu, X., Guo, L., & Jiang, H. (2018). Characterization, origin and aggregation behavior of colloids in eutrophic shallow lake. *Water Research*, *142*, 176–186.

Zand, A. D., & Hoveidi, H. (2015). Comparing aluminium sulfate and poly-aluminium chloride (PAC) performance in turbidity removal from synthetic water. *Journal of Applied Biotechnology Reports*, *2*(3), 287–292.

Zhang, H., Xu, X., Zhang, Y., & Sun, Y. (2024). Promoting Higher Order Thinking Skills in Undergraduates: Conceptualizing Challenge-Based Learning Through Personal Learning Environments Platform. In *Machine Learning and Intelligent Systems* (pp. 1-7). IOS Press.