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Development of a Context-Based E-Book Design to Support Science Process Skills in Reaction Rate Learning

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Abstrak

Context-based e-books have the potential to support meaningful chemistry learning and science process skills in reaction rate learning. Therefore, this study aims to develop a context-based e-book using the Four Steps Teaching Material Development (4STMD) method and to evaluate the characteristics, feasibility, and comprehensibility of the e-book. This study employed a Design and Development Research (DDR) approach, while the e-book was developed using the 4STMD method. Data were collected using expert review sheets, text characterization sheets, feasibility assessment sheets, and comprehensibility test sheets. The study participants included two chemistry education experts as reviewers of the e-book's characteristics at each stage of the 4STMD framework, 60 11th-grade students from two high schools in Bandung for the text characterization and comprehensibility tests, and three high school chemistry teachers as raters in the feasibility assessment. The developed e-book met the required characteristics at every stage of the 4STMD method. The feasibility assessment, which covered five aspects (content, design, presentation, graphics, and science process skills), the feasibility assessment yielded an average score of 98.87%, indicating a highly feasible category. The comprehensibility test yielded an average score of 97%, indicating a high level of comprehensibility. The e-book has the potential to serve as an alternative self-directed learning resource. The developed e-book has the potential to serve as an alternative context-based teaching material for reaction rate learning, with activities designed to support student's science process skills.

Keywords: *Context-Based E-Book, 4STMD Method, Reaction Rates, Science Process Skills*

Introduction

There are three main components in the learning process: teachers, students, and teaching materials. The absence of one of these essential components may hinder the effective implementation of the learning process (Anwar, 2024). Problems are still frequently encountered in the teaching materials used by teachers because the content may be too broad or too narrow, too detailed or too superficial, or may not adequately correspond to the competencies that students are expected to achieve (Aisyah et al., 2020). Therefore, teaching materials play an important role in helping students understand concepts effectively by presenting learning content in a systematic, relevant, and meaningful manner. Teaching materials consist of systematically organized content designed to facilitate learning, including independent learning, while remaining aligned with the applicable curriculum (Magdalena et al., 2020).

Advances in science and technology have increased the need for innovative, engaging, interactive, and accessible teaching materials. One form of digital teaching material that can respond to these developments is the electronic book (e-book). Interactive e-books can integrate multimedia elements, including text, images, animations, audio, video, and interactive quizzes, to provide students with more varied learning experiences (Tuljannah & Khabibah, 2021). The use of e-books is particularly relevant in chemistry learning because chemical concepts can be

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presented through multiple representations that help students connect macroscopic, submicroscopic, and symbolic aspects of chemistry (Munawwarah et al., 2022). Recent research has also demonstrated that interactive animation-based media can support students in understanding abstract chemistry concepts through appropriate visualization and interactivity (Hutajulu et al., 2026).

The effectiveness of digital teaching materials is also supported by research comparing different forms of learning resources. The implementation of Problem-Based Learning (PBL) supported by e-modules resulted in higher learning outcomes than PBL supported by student worksheets (*Lembar Kerja Peserta Didik* [LKPD]) on the periodic system of elements at SMA Negeri 14 Kota Jambi, with mean final scores of 75 in the e-module group and 69 in the LKPD group (Sari et al., 2026). These findings indicate that e-modules can provide more effective learning support when integrated with an appropriate instructional model. Nevertheless, many existing e-books and e-modules remain dominated by text and static images and provide limited opportunities for students to interact actively with learning content (Anwar et al., 2023). This limitation suggests that the development of digital teaching materials should not focus merely on converting printed materials into electronic formats but should also consider contextualization, interactivity, and students' active engagement in constructing scientific understanding.

A contextual approach can provide a meaningful framework for the development of such teaching materials because it connects learning content with situations that students encounter in everyday life (Aminah et al., 2022). Context-based chemistry modules have been reported to contribute positively to students' motivation and learning outcomes (Harahap, 2024). A contextual chemistry module developed for the acid–base topic obtained feasibility scores of 88.8% from subject-matter experts, 95% from design experts, 92% from practitioner validators, and 85.28% in a limited student trial, indicating that contextual teaching materials can achieve a high level of feasibility and acceptance (Andriani et al., 2019). More recent evidence also shows that interactive learning media integrating Contextual Teaching and Learning (CTL) can create more meaningful and engaging chemistry learning experiences and improve students' motivation when learning abstract concepts such as the periodic system of elements (Wahyuni et al., 2026). However, some previously developed e-modules remain predominantly text-based and contain limited interactive features, thereby restricting their capacity to support students in understanding complex chemical concepts (Fauzi et al., 2019). These findings strengthen the need for context-based e-books that integrate real-world phenomena, multimedia representations, and structured learning activities to facilitate more meaningful chemistry learning.

In addition to facilitating conceptual understanding, contextual learning can provide students with opportunities to engage in science process skills. Science process skills enable students to investigate and understand natural phenomena through systematic scientific inquiry involving observation, questioning, hypothesis formulation, experimentation, data analysis and interpretation, and conclusion drawing (Gizaw & Sota, 2023). In this study, science process skills are operationalized through the indicators of observing, classifying, interpreting, predicting, asking questions, formulating hypotheses, planning experiments, using tools and materials, applying concepts, and communicating (Rustaman, 2005). These skills are particularly relevant to chemistry because students are expected not only to understand scientific knowledge but also to construct knowledge through evidence-based inquiry. Recent research has shown that guided inquiry learning can improve students' science process skills, as indicated by an increase in the mean score from 44.2 on the pretest to 73.4 on the posttest, with an N-Gain of 0.54 (Fitria

& Purnomo, 2026). Nevertheless, students' science process skills in chemistry learning remain relatively low in several contexts, including reaction-rate learning, in which approximately 56% of students were categorized as having low science process skills (Fitriana et al., 2019). Therefore, chemistry teaching materials should provide explicit opportunities for students to observe phenomena, formulate questions and hypotheses, plan investigations, interpret evidence, apply concepts, and communicate scientific findings.

Chemistry is often perceived as a difficult subject because students are required to understand abstract concepts, mathematical relationships, and representations at different levels. Students' difficulties in Grade 11 chemistry have been associated with inadequate conceptual understanding, limited mathematical ability, and low learning motivation (Priliyanti et al., 2021). One topic in which these difficulties are particularly evident is reaction rates, especially the factors affecting reaction rates. A three-tier diagnostic test revealed misconceptions concerning concentration, surface area, temperature, and catalysts, with misconception percentages of 22.58%, 16.13%, 38.71%, and 12.90%, respectively (Lestari et al., 2021). These percentages were obtained by combining students' selected answers, reasons for those answers, and levels of confidence through the three-tier diagnostic format, enabling misconceptions to be distinguished more clearly from a lack of knowledge.

The identified misconceptions indicate that students may have difficulty relating observable changes in reaction rates to particle-level explanations and collision theory. Therefore, the teaching materials developed in this study are designed not merely to present definitions of the four factors affecting reaction rates but to address each misconception through contextual situations, multiple representations, and guided science-process activities. Misconceptions concerning concentration can be addressed by linking differences in particle concentration to the frequency of effective collisions, whereas misconceptions concerning surface area can be explored through differences in the size of banana-peel particles used in contextual activities. Misconceptions concerning temperature can be addressed by relating temperature changes to particle kinetic energy and collision frequency, while misconceptions concerning catalysts can be clarified through representations of activation energy and alternative reaction pathways. These conceptual explanations are combined with observing, predicting, questioning, interpreting data, and communicating activities so that students are encouraged to construct the concepts through scientific reasoning rather than merely memorize them. Such an approach is consistent with the need for interactive and visual chemistry learning media to facilitate understanding of abstract concepts (Hutajulu et al., 2026).

To simplify complex scientific concepts without eliminating their essential scientific meaning, the teaching materials in this study are developed using the Four Steps Teaching Material Development (4STMD) method. The 4STMD method consists of four stages: selection, structuring, characterization, and didactic reduction. Among these stages, didactic reduction is particularly important because it involves reducing the complexity of difficult concepts while preserving their scientific accuracy, thereby making the material more accessible to students (Krisandini & Anwar, 2024). Consequently, 4STMD is relevant to reaction-rate learning because it enables difficult concepts identified during the characterization stage to be systematically transformed into forms that are easier for students to understand.

A potential real-world context for reaction-rate learning is the utilization of organic waste from the surrounding environment, particularly banana-peel waste. Bananas are widely consumed and processed in Indonesia, resulting in considerable amounts of banana-peel waste that may contribute to environmental pollution when not properly managed (Sunaryadi & Jasili, 2023). One alternative utilization of banana-peel waste is its processing into liquid organic fertilizer (*pupuk organik cair* [POC]). Banana peels contain several elements relevant to plant nutrition, including nitrogen, phosphorus, potassium, magnesium, and sodium, making them potentially useful as raw materials for organic fertilizer (Utami et al., 2025). The application of banana-peel-based POC has also been reported to influence plant height and leaf width in young mustard greens (Damanik et al., 2023). Thus, banana-peel-based POC provides an environmentally relevant context that can connect chemical concepts with waste utilization and situations encountered in daily life.

Previous studies have investigated banana-peel waste for environmental and agricultural purposes, particularly its utilization as a raw material for POC. However, these studies have generally emphasized its effects on plants, soil, fertilizer quality, or organic-waste management rather than its systematic integration into chemistry teaching materials. Previous research has also developed teaching materials on reaction rates using POC derived from bamboo shoots as the learning context (Permana et al., 2023). Although these studies provide an important foundation, an unresolved gap remains regarding the development of a digital reaction-rate teaching material that simultaneously integrates a locally accessible waste context, systematic didactic reduction, and explicit opportunities to engage in science process skills.

Accordingly, the distinctive characteristic of the product developed in this study is the integration of banana-peel-based POC production as a real-world context for reaction-rate concepts within a context-based e-book developed using the 4STMD method. Unlike conventional e-books that primarily present information through text and images, the proposed e-book is designed to organize reaction-rate concepts through the selection, structuring, characterization, and didactic-reduction stages while incorporating contextual phenomena and activities associated with science process skills. This design is consistent with evidence indicating that contextual and interactive learning media can provide more meaningful chemistry learning experiences (Wahyuni et al., 2026) and that learning activities involving active scientific inquiry can support the development of science process skills (Fitria & Purnomo, 2026).

Therefore, the novelty of this study lies in the integration of three components that have rarely been examined simultaneously: banana-peel-based POC as a contextual phenomenon for reaction-rate learning, the 4STMD method as a systematic framework for reducing the complexity of chemical concepts, and science process skills as a consideration in designing the e-book's learning activities. The methodological gap addressed by this study concerns the limited evidence regarding how a context-based chemistry e-book developed through 4STMD can transform difficult reaction-rate concepts into comprehensible learning content while simultaneously providing opportunities for students to engage in scientific inquiry. Therefore, this study aims to develop a context-based e-book on reaction rates using the 4STMD method and banana-peel-based POC as the learning context, and to determine the characteristics of the developed e-book, evaluate its feasibility, and assess its comprehensibility for students.

Method

The research method used in this study was Design and Development Research (DDR), specifically Type 1 DDR, which focuses on the design, development, and evaluation of an educational product (Richey & Klein, 2007). In this study, Type 1 DDR was implemented through the Design, Development, and Evaluation (DDE) framework. The DDE framework served as the overall research procedure, while the Four Steps Teaching Material Development (4STMD) method was applied specifically within the Development stage. Thus, the research procedure consisted of the Design stage, the Development stage comprising Selection, Structuring, Characterization, and Didactic Reduction, and the Evaluation stage. The 4STMD method used in developing the e-book consisted of selection, structuring, characterization, and didactic reduction (Anwar, 2024).

This research involved 60 Grade 11 senior high school students from two schools in Bandung City who had previously studied reaction-rate material. The students participated in the characterization and comprehensibility tests of the developed e-book. The developed context-based reaction-rate e-book was designed to provide opportunities for students to engage in science process skills and was assessed for feasibility by three senior high school chemistry teachers. Chemistry education experts were also involved in reviewing the teaching materials during the Selection, Structuring, and Didactic Reduction stages.

Design

The teaching-material development process began with the Design stage. This stage involved determining the learning context, conducting a literature review related to reaction-rate learning, and analyzing the senior high school chemistry curriculum based on BSKAP Regulation No. 46 of 2025. The curriculum analysis focused on the Phase F learning outcome relevant to the reaction-rate topic, namely students' ability to analyze factors affecting reaction rates (BSKAP, 2025). This learning outcome was used as the basis for developing learning objectives, the sequence of learning objectives, and concept labels related to the definition of reaction rate, reaction-rate equations, collision theory, concentration, surface area, activation energy, catalysts, and temperature.

A literature review was also conducted to identify real-life contexts that could be linked to reaction-rate concepts. One of the contexts identified was the production of liquid organic fertilizer from banana-peel waste through a fermentation process. The fermentation process can be influenced by several factors related to reaction rates, including temperature, concentration, particle size, the use of bioactivators such as EM4, and fermentation duration (Rahmah, 2021). Banana-peel waste was selected as the main context because it is commonly found in students' surroundings and can connect chemical concepts with real-world environmental phenomena, thereby supporting more meaningful learning (Gunawan & Daulay, 2024). The science process skill indicators incorporated into the e-book were based on the established science process skills framework (Rustaman, 2005).

Development

The teaching materials designed in the previous stage were subsequently developed through the 4STMD method, consisting of Selection, Structuring, Characterization, and Didactic Reduction.

Selection Stage

The Selection stage consisted of developing learning objectives, arranging the sequence of learning objectives, and determining concept labels based on the selected Phase F learning outcome related to reaction rates. The concept labels included the definition of reaction rate, reaction-rate equations, collision theory, the effect of concentration, surface area, activation energy, catalysts, and temperature on reaction rates. Standard concepts were subsequently developed based on the identified concept labels through an analysis of several general chemistry textbooks. The standard concepts were reviewed by chemistry education experts to determine their alignment with the learning objectives, sequence of learning objectives, learning outcomes, concept labels, content context, pedagogical context, and science process skills.

The review was conducted using an expert review sheet with the response options "Appropriate" and "Not Appropriate." The results were analyzed descriptively. Sections that received comments or suggestions from the chemistry education experts were revised before being incorporated into the teaching-material draft. The contextual content developed in this stage was connected with phenomena, facts, data, and real-world applications. One of the main contexts incorporated into the e-book was the production of liquid organic fertilizer from banana-peel waste. The context was used to explain several factors affecting reaction rates, including variation in banana-peel mass as a representation of substrate concentration, variation in banana-peel particle size as a representation of surface area, and the use of EM4 as a bioactivator.

The pedagogical context was designed to provide learning activities related to science process skills. For example, students were directed to observe various reaction-rate phenomena and gas production during the fermentation of banana-peel liquid organic fertilizer. Students were also asked to classify gas-volume data based on variations in banana-peel mass and particle size and to interpret fermentation data by constructing graphs of CO_2 volume against time and relating the observed patterns to collision theory. These activities were developed based on science process skill indicators (Rustaman, 2005).

Structuring Stage

The Structuring stage involved the development of a concept map, macro structure, and three levels of chemical representation, namely macroscopic, submicroscopic, and symbolic representations. The concept map was reviewed by chemistry education experts based on the appropriateness of relationships among concepts, hierarchical relationships, connecting words, cross-links, and examples. The macro structure was reviewed based on the relationship among concepts, alignment with the curriculum, breadth and depth of the content, coherence among learning units, and the sequence of prerequisite, main, and supplementary materials.

The three levels of chemical representation were also developed to provide coherent explanations of reaction-rate concepts. The macroscopic level represented observable chemical phenomena, the submicroscopic level explained processes occurring at the particle level, and the symbolic level presented chemical equations, formulas, graphs, and other symbolic representations. The coherence among these three levels was examined to ensure that the observable phenomenon, particle-level explanation, and symbolic representation referred to the same chemical concept. Several contextual phenomena were used in the three levels of chemical representation, including fireworks, the reaction between vitamin C and Betadine, the reaction between bromine and formic acid, corrosion, and the fermentation of banana-peel waste. Feedback from the chemistry education experts was used as the basis for revising the concept map, macro structure, and three levels of chemical representation. The result of the Structuring stage was the first draft of the teaching materials.

Characterization Stage

The Characterization stage was conducted to determine whether each text contained in the first draft of the e-book was categorized as easy or difficult for students to understand. The first draft of the e-book, which had previously been reviewed and revised based on feedback from chemistry education experts, was divided into 45 texts. A total of 60 Grade 11 students from two senior high schools in Bandung City participated in the characterization test. The 60 students were divided into three groups, with 20 students in each group. Each group received one text package consisting of 15 texts. Package 1 contained Texts 1–15, Package 2 contained Texts 16–30, and Package 3 contained Texts 31–45. Therefore, each text was assessed by 20 students.

The characterization test used a text-characterization sheet. Students were asked to identify the main idea of each text provided. Students who considered a text difficult were also asked to state the reason for their difficulty. The data were analyzed descriptively by calculating the percentage of students who correctly identified the main idea of each text. The percentage score for each text was calculated using the number of students who correctly identified the main idea divided by the total number of students assessing the text. Texts with $x > 50\%$ were categorized as easy, whereas texts with $x \leq 50\%$ were categorized as difficult (Anwar, 2024). Based on the characterization results, three texts were categorized as difficult. Text 25 obtained a score of 35%, with 7 of 20 students correctly identifying the main idea. Text 29 obtained a score of 50%, with 10 of 20 students correctly identifying the main idea, while Text 45 also obtained a score of 50%, with 10 of 20 students correctly identifying the main idea. These texts were subsequently analyzed during the Didactic Reduction stage.

Didactic Reduction Stage

The Didactic Reduction stage was conducted on texts categorized as difficult during the Characterization stage. The purpose of didactic reduction was to reduce the difficulty of the texts so that the concepts could be understood more easily without eliminating their essential scientific meaning. The characteristics of difficult texts were identified based on the reasons provided by students. Texts were categorized as abstract, complex, or complicated according to their characteristics. Abstract texts referred to concepts or processes that could not be directly observed or were difficult to visualize, whereas complex texts involved several concepts that had to be connected simultaneously.

Based on the characterization analysis, Texts 25 and 29 were categorized as abstract, while Text 45 was categorized as complex. Text 25 contained abstract concepts related to potential energy, activated complexes, and energy changes. Text 29 discussed particle-level changes related to variations in acetic acid concentration, while Text 45 required students to simultaneously connect the concepts of enzymes, effective collisions, activation energy, and fermentation. Different didactic reduction strategies were applied according to the characteristics of each difficult text. Text 25 was improved through qualitative text presentation, explanatory images, sentence reformulation, and the use of familiar terminology. Text 29 was improved through illustrations or analogies and sentence reformulation. Text 45 was improved through omission of unnecessary information, the use of analogies, sentence reformulation, and familiar terminology. The revised texts were reviewed by a chemistry education expert and subsequently incorporated into the second draft of the e-book. The texts that had undergone didactic reduction were then retested during the comprehensibility test to determine whether they had become easier for students to understand.

Evaluation

The Evaluation stage was conducted to assess the feasibility and comprehensibility of the developed context-based reaction-rate e-book.

E-Book Feasibility Test

The feasibility test was conducted on the e-book draft resulting from the Didactic Reduction stage. Before being assessed by the feasibility evaluators, the e-book was reviewed by chemistry education experts and revised based on their feedback. The feasibility assessment was conducted by three senior high school chemistry teachers. The assessment covered five dimensions: content feasibility, presentation feasibility, design feasibility, graphic feasibility, and science process skills feasibility. The content, presentation, design, and graphic dimensions were based on the applicable national standards for instructional materials (Kementerian Pendidikan, Kebudayaan, Riset, dan Teknologi & Badan Standar, Kurikulum, 2022). The science process skills dimension was based on the indicators proposed by Rustaman (2005).

The feasibility instrument consisted of 129 items, including 26 items for content, 35 items for presentation, 15 items for design, 28 items for graphics, and 25 items for science process skills. The assessment used a binary response format. A response of "Yes" received a score of 1, whereas a response of "No" received a score of 0. The binary response format was used because each item was intended to identify whether the specified feasibility criterion had been fulfilled. The feasibility percentage for each dimension was calculated using the following formula:

$$Feasibility\ (\%) = (Number\ of\ \text{“}Yes\text{”}\ responses\ /\ Total\ number\ of\ assessment\ items) \times 100\%$$

The percentage score for each dimension was calculated and subsequently averaged to determine the overall feasibility percentage of the e-book.

Table 1. Categories of Teaching Material Feasibility (Hendri & Setiawan, 2016)

Score Percentage (%)	Criteria
90% < x ≤ 100%	Very feasible
75% < x ≤ 90%	Feasible
60% < x ≤ 75%	Moderately feasible
x ≤ 60%	Less feasible

Table 1 shows that feasibility scores were classified into four categories ranging from less feasible to very feasible. Higher percentage scores indicate a greater level of conformity with the specified feasibility criteria, with scores above 90% categorized as very feasible.

E-Book Comprehensibility Test

The comprehensibility test was conducted to assess students' understanding of the texts contained in the developed e-book after the didactic reduction and feasibility assessment. The comprehensibility test involved 60 Grade 11 students from two senior high schools in Bandung City. The 45 texts were divided into three packages consisting of 15 texts each, similar to the distribution used in the Characterization stage. However, Texts 25, 29, and 45 had been revised through didactic reduction before being included in the comprehensibility test. Students' comprehensibility was assessed based on their ability to identify the main idea of each text. The percentage of students who correctly identified the main idea was calculated for each text using the following formula:

$$K\ (\%) = (Number\ of\ students\ correctly\ identifying\ the\ main\ idea\ /\ Total\ number\ of\ students\ assessing\ the\ text) \times 100\%$$

The percentage scores for all texts were then averaged to obtain the overall comprehensibility score of the developed e-book. For the three texts that underwent didactic reduction, the characterization and comprehensibility results were compared descriptively. Text 25 increased from 7 of 20 correct responses (35%) to 18 of 20 correct responses (90%). Text 29 increased from 10 of 20 correct responses (50%) to 20 of 20 correct responses (100%). Text 45 increased from 10 of 20 correct responses (50%) to 19 of 20 correct responses (95%). The changes were interpreted descriptively based on the proportion of students who correctly identified the main idea before and after didactic reduction. The comparison was not intended to establish a causal effect because no control condition was used.

Table 2. Interpretation of Comprehensibility Levels (Arifin & Sjaeful, 2016)

Percentage Score (K)	Comprehension Level	Category of Teaching Material
$60\% < K \leq 100\%$	High	Independent
$40\% < K \leq 60\%$	Moderate	Instructional
$K \leq 40\%$	Low	Frustration

The overall comprehensibility score was interpreted according to the categories shown in Table 2. In this study, the percentage obtained from the main-idea identification test was used primarily as an indicator of text comprehensibility. Therefore, higher percentage scores reflected a higher level of students' understanding of the tested texts, while the categories presented in Table 2 were used only as interpretive classifications and not as sole evidence of students' ability to learn independently from the e-book.

Result and Discussion

E-Book Design

The design phase began with an analysis of the Merdeka Curriculum for senior high school chemistry to identify the learning outcome relevant to the reaction rate topic. The analysis showed that reaction rate is included in Phase F, generally taught in Grade XI, with the specific learning outcome requiring students to analyze factors affecting reaction rates. This selected learning outcome was used as the basis for developing the learning objectives, sequence of learning objectives, concept labels, and contextual content of the e-book (BSKAP, 2025).

Table 3. Results of the Analysis of Learning Outcomes for Phase F: Chemistry Understanding

Phase	Learning Outcomes	Selected Outcome	Relevance to This Study
Phase F (Grades XI–XII)	Includes several chemistry competencies, one of which is analyzing factors affecting reaction rates.	Analyzing factors affecting reaction rates.	Used as the basis for developing learning objectives, concept labels, and contextual e-book content on reaction rates.

Source: BSKAP Regulation No. 46 of 2025 (BSKAP, 2025).

Based on the curriculum analysis presented in Table 3, the development of the e-book focused specifically on the learning outcome related to factors affecting reaction rates. This selected outcome provided a clear basis for organizing the reaction-rate concepts, determining the learning objectives, and integrating relevant contextual phenomena into the e-book.

A literature review was conducted to identify real-life contexts in daily life that could be linked to the topic of chemical reaction rate in the development of an e-book. One of the results was the production of liquid organic fertilizer from banana peel waste through a fermentation process that can be influenced by temperature, concentration, particle size, catalysts (bioactivators) such as EM4, and fermentation duration (Rahmah, 2021). Thus, the use of liquid organic fertilizer from banana peel waste is relevant because banana peel waste can be easily found in the students' surroundings. Therefore, selecting a context close to the students' environment is expected to help connect chemical concepts with real-world phenomena, thereby making the learning process more meaningful (Gunawan & Daulay, 2024). The developed e-book can also develop students' science process skills, the indicators for science process skills used in this research are based on KPS (Rustaman, 2005).

E-Book Development

Results of the selection stage

The selection phase consists of three steps: developing TP, ATP, and concept labels based on CP regarding reaction rate material, particularly factors that can influence reaction rates. The following are the results of the selection phase:

Table 4. Development Sequence of Learning Objective (ATP) and Concept Labels Learning Outcomes (CP)

Relevant Learning Outcome (CP)	Learning Objective (TP)	Sequence of Learning Objectives (ATP)	Concept Label
Analyze factors affecting reaction rates.	Explain the concept of reaction rate.	1.1 Explain the definition of reaction rate.	Definition of Reaction Rate
		1.2 Write the reaction-rate equation.	Reaction-Rate Equation
	Explain collision theory. Analyze factors affecting reaction rates.	2.1 Explain collision theory.	Collision Theory
		3.1 Analyze the effect of concentration on reaction rate based on collision theory.	Effect of Concentration on Reaction Rate
		3.2 Analyze the effect of surface area on reaction rate based on collision theory.	Effect of Surface Area on Reaction Rate
		3.3 Explain the concept of activation energy.	Activation Energy
		3.4 Analyze the effect of catalysts on reaction rate based on collision theory and activation energy.	Effect of Catalysts on Reaction Rate
		3.5 Analyze the effect of temperature on reaction rate based on collision theory and kinetic energy.	Effect of Temperature on Reaction Rate

Based on TP, ATP, and the concept labels in Table 4, the second step in this stage was carried out, namely the development of standard concepts based on concept labels. The standard concepts created are the result of an analysis of several *general chemistry* textbook sources. The results are as follows: Based on the expert review, the standard concepts developed for the reaction-rate e-book were generally considered scientifically appropriate and consistent with the intended concept labels. The validators' review focused on conceptual accuracy, clarity of explanation, and consistency between the concept labels and the corresponding standard concepts. Most concepts did not require substantive revision. However, the explanation of the reaction-rate equation required clarification regarding the relationship between changes in reactant concentration and reaction order. The explanation was therefore revised to emphasize that reaction order is determined experimentally and is not necessarily identical to the stoichiometric coefficients in the balanced chemical equation. A summary of the accuracy-review results is presented in Table 5, while the complete standard-concept descriptions are provided in the Appendix/Supplementary Material.

Table 5. Summary of the Standard-Concept Accuracy Review

Concept Label	Review Result	Identified Issue	Revision
Definition of Reaction Rate	Appropriate	No substantive conceptual issue identified	No major revision
Reaction-Rate Equation	Revised	The explanation of reaction order and its relationship with changes in reactant concentration required clarification	Examples were clarified, and the explanation emphasized that reaction orders are determined experimentally and are not necessarily equal to

			stoichiometric coefficients
Collision Theory	Appropriate	No substantive conceptual issue identified	No major revision
Effect of Concentration on Reaction Rate	Appropriate	No substantive conceptual issue identified	No major revision
Effect of Surface Area on Reaction Rate	Appropriate	No substantive conceptual issue identified	No major revision
Activation Energi	Appropriate	No substantive conceptual issue identified	No major revision
Effect of Catalysts on Reaction Rate	Appropriate	No substantive conceptual issue identified	No major revision
Effect of Temperature on Reaction Rate	Appropriate	No substantive conceptual issue identified	No major revision

Table 5 shows that most of the standard concepts were judged appropriate without major revision. The main revision was made to the reaction-rate equation section to clarify the determination of reaction order and its distinction from stoichiometric coefficients. Overall, the review confirmed that the selected concepts were suitable for inclusion in the developed e-book.

The third step involved developing content and pedagogical contexts linked to science process skills. Content context refers to the integration of phenomena, facts, data, and real-world applications into teaching materials (Anwar, 2024). One of the main contexts developed in the e-book was the production of liquid organic fertilizer (POC) from banana-peel waste, which was used to explain factors affecting reaction rates, particularly variations in banana-peel mass as a representation of substrate concentration and banana-peel particle size as a representation of surface area. Other reaction-rate phenomena, including fireworks and iron corrosion, were also incorporated into the e-book. The learning activities were aligned with the science process skill indicators represented in the developed e-book, particularly observing, classifying, and interpreting (Rustaman, 2005).

Table 6. Potential for Developing Science Process Skills in e-books

Real-World Context	Learning Activity in the E-Book	Assessment Prompt/Task	Science Process Skill
Fireworks, rusting of iron, and gas formation during banana-peel POC fermentation	Students observe changes and phenomena related to reaction rates.	Identify and describe the observable changes occurring in the presented phenomena.	Observing
Variation in banana-peel mass and particle size during POC fermentation	Students group gas-volume data based on variations in banana-peel mass and particle size.	Group the obtained data and identify which conditions produce the highest gas volume.	Classifying/ Grouping
Banana-peel POC fermentation with variations in mass and particle size	Students analyze fermentation data and construct a graph showing the relationship between CO_2 volume and time.	Interpret the data pattern and relate the results to collision theory and reaction-rate concepts.	Interpreting

Table 6 shows that the real-world contexts presented in the e-book were directly linked to learning activities, assessment tasks, and targeted science process skills. The activities particularly supported observing, classifying, and interpreting skills through reaction-rate phenomena and banana-peel POC fermentation data. Pedagogical contexts also need to be developed, as in this context, instructional materials will serve as tools or media to foster values, attitudes, and skills (Anwar, 2024). In this pedagogical context, one of the skills that is the focus of development is scientific process skills (Marhanita et al., 2026). Therefore, this e-book presents a laboratory experiment on the production of liquid organic fertilizer from banana peel waste to identify factors that can influence the reaction rate.

Result of the structuring phase

The e-book has been structured to prevent partial understanding (Anwar, 2024). In this stage, concept maps, macro structures, and three representative levels were developed. The results are as follows

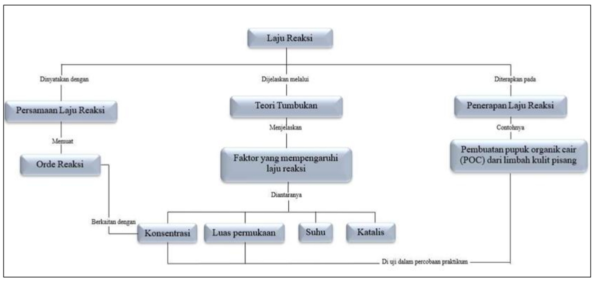

Figure 1. Concept Map of Reaction Rate

The concept map in Figure 1 was reviewed by a chemistry education expert using criteria that included the accuracy of relationships between concepts, the appropriateness of connecting words, hierarchical organization, meaningful cross-links, and the relevance of examples. The qualitative comments provided during the review were used to revise relationships, labels, and examples that required clarification. The revised concept map was then used as the structural basis for organizing the reaction-rate content in the e-book.

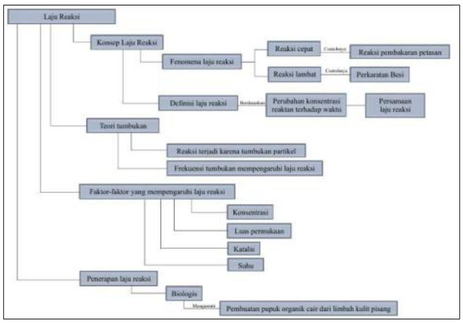

Figure 2. Macro Structure of Reaction Rate

As shown in Figure 2, the purpose of creating a macro structure is to demonstrate the coherence of the argumentation and validate the organization of the subject matter (Anwar, 2024).Thus, the macro structure developed by the author will serve as a guide in compiling the e-book. This macro structure was also reviewed by a lecturer specializing in chemistry education and has been confirmed to align in terms of the breadth and depth of its content with the referenced curriculum; the diagram format accurately represents the text, and the main and supplementary materials are arranged in the correct sequence.

Table 7. Results of the Three-Level Representation

Concept/Material	Macroscopic	Submicroscopic	Symbolic
Definition of Reaction Rate – Fireworks	Fireworks produce light, smoke, heat, and gases within a short time, representing a fast reaction.	Fuel and oxidizer particles undergo effective collisions with sufficient energy to form products.	$2KClO_3(s) \rightarrow 2KCl(s) + 3O_2(g)$; $C(s) + O_2(g) \rightarrow CO_2(g)$
Definition of Reaction Rate – Vitamin C and Betadine	The brown color of Betadine gradually fades after reacting with vitamin C.	Ascorbic acid particles react with iodine molecules, producing iodide ions.	Chemical representation of ascorbic acid and iodine reaction

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Reaction-Rate Equation	The bromine solution gradually becomes colorless during its reaction with formic acid.	The number of Br_2 molecules decreases as the reaction proceeds.	$Br_2(aq) + HCOOH(aq) \rightarrow 2H^+(aq) + 2Br^-(aq) + CO_2(g)$; v=−Δ[Br2]/Δtv=-\Delta[Br_2]/\Delta t
Collision Theory	Iron exposed to seawater gradually forms rust.	Fe, O_2, and H_2O particles interact, while dissolved ions facilitate electron transfer.	$Fe(s) \rightarrow Fe^{2+}(aq) + 2e^-$; formation of hydrated iron oxide
Effect of Concentration	Different banana-peel masses during POC fermentation produce different volumes of CO_2.	Higher substrate concentration increases substrate–enzyme interactions until saturation occurs.	$(C_6H_{10}O_5)_n + nH_2O \rightarrow nC_6H_{12}O_6$; $C_6H_{12}O_6 \rightarrow 2CO_2 + 2C_2H_5OH$

Table 7 summarizes the integration of macroscopic, submicroscopic, and symbolic representations used to explain reaction-rate concepts in the developed e-book. The complete visual representations and detailed explanations are presented in the e-book. The following figures present visual examples of the contextual phenomena incorporated into the developed e-book to support the explanation of reaction-rate concepts. The selected examples include fireworks, the reaction between vitamin C and Betadine, the reaction between bromine and formic acid, corrosion, and banana-peel POC fermentation. These visual representations were used to connect macroscopic observations with submicroscopic explanations and symbolic representations in the learning material.

Figure 3. Colors Of A Firecracker's Flame Source: Wikipedia, 2025

As shown in Figure 3, the fireworks phenomenon was used as a macroscopic example to introduce the concept of reaction rate. The rapid production of light, smoke, and heat helps students recognize that chemical reactions can occur at different speeds. This phenomenon was then connected to submicroscopic explanations involving effective collisions between fuel and oxidizer particles and to symbolic representations in the form of chemical equations.

Figure 4. Reaction of A Vitamin C Tablet with Betadine

As shown in Figure 4, the reaction between vitamin C and Betadine was used to illustrate the definition of reaction rate through a visible color change. The gradual fading of the solution helped students observe that chemical change occurs over time. This phenomenon was linked to particle-level interactions between ascorbic acid and iodine and supported by symbolic representation.

Figure 5. The decrease in Bromine Concentration Over Time is Visible As The Solution's Color Fades (From Left to Rght).

As shown in Figure 5, the reaction between bromine and formic acid was used to explain the reaction-rate equation. The gradual fading of the bromine solution provided observable evidence of decreasing reactant concentration over time. This context was connected to the submicroscopic decrease in bromine particles and to the symbolic form of the reaction-rate equation.

Figure 6. Shipwreck Source: Wikipedia, 2025

As shown in Figure 6, the corrosion of a shipwreck was used to explain collision theory. The rusting phenomenon provided a contextual example of a slow reaction influenced by environmental conditions. This phenomenon was related to particle interactions among iron, oxygen, and water and reinforced by symbolic oxidation and rust-formation equations.

Figure 7. The Fermentation Process of Liquid Organic Fertilizer from Banana Peel Waste

As shown in Figure 7, the fermentation of banana-peel waste into liquid organic fertilizer (POC) was used as the main contextual example for explaining the effect of concentration on reaction rate. The observed production of CO_2 gas helped students relate differences in banana-peel mass to reaction-rate changes. This context was further explained through submicroscopic interactions between substrates and enzymes and supported by symbolic fermentation equations.

Table 8. Text Package Distribution for the Characterization Test

Package	Texts	Number of students	Grade
1	1-15	20	8 students in Class XI-1 at the first school and 12 students in Class XI-1 at the second school.
2	16-30	20	
3	31-45	20	

Table 8 shows that the 45 texts were divided equally into three packages, with 15 texts and 20 students in each package. This distribution ensured that each text received the same number of student responses while reducing the reading load for individual participants. The 60 Grade 11 students from two senior high schools were assigned to three groups of 20 students. Each group received one of three text packages, with each package containing 15 of the 45 texts tested. Thus, each text was evaluated by 20 students. This allocation was used to keep the number of texts assessed by each student manageable while ensuring that all 45 texts were evaluated. Students from both schools were included in each package; for example, Package 1 consisted of 8 students from the first school and 12 students from the second school. The distribution of students across the packages was arranged to reduce potential differences in school composition among the groups. Nevertheless, because the participants were drawn from two different schools, possible school-level differences in prior learning experiences may have influenced students' responses and should be considered when interpreting the characterization and comprehensibility results.

The text characterization data were collected using a text characterization test sheet consisting of 45 reaction rate texts. Each student was asked to identify the main idea of the assigned text. If a student considered a text difficult, they were also asked to provide the reason for the difficulty. The data were analyzed descriptively by calculating the percentage of students who correctly identified the main idea of each text. Texts with more than 50% correct responses were categorized as easy, whereas texts with 50% or fewer correct responses were classified as difficult (Anwar, 2024). Figure 3 presents the results of the text characterization.

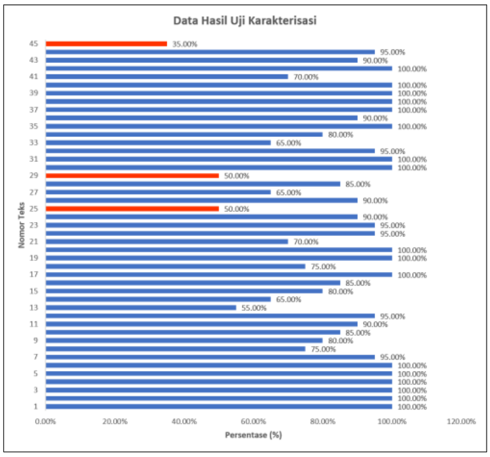

Figure 8. Characterization Test Result

Figure 8 shows that most of the tested texts were categorized as easy, with comprehension scores above 50%. Only three texts, namely Texts 25, 29, and 45, were classified as difficult, with scores of 50%, 50%, and 35%, respectively. These three texts were therefore selected for further analysis and didactic reduction. The difficult texts were classified based on students' reported reasons: abstract texts contained concepts that were difficult to observe or visualize, complex texts required connections among several concepts, and complicated texts involved difficult language or sentence structure. Based on these criteria, Texts 25 and 29 were classified as abstract, while Text 45 was classified as complex. The didactic reduction strategies were adapted to each difficulty type through visual support, analogies, sentence reformulation, familiar terminology, and omission of unnecessary information. The revised texts were reviewed by a chemistry education expert and retested using the same main-idea identification criterion.

Tabel 7. Didactic Reduction Grid for Difficult Texts

Explanation of Material (Text)	Characteristics			Type of Reduction
	Abstract	Complex	Complicated	
Teks 25 Meanwhile, at the maximum point of the potential energy curve, the reactant molecules have combined to form an activated complex. When this activated complex breaks down into products, the products have a lower potential energy (2 kJ/mol), thereby gaining greater kinetic energy. This reaction is classified as endothermic because the energy of the products is higher than that of the reactants, so the energy difference equals the heat of reaction (ΔH). Since energy increases, ΔH is positive.	✓			Qualitative text presentation, use of explanatory images, and reformulation of sentences using familiar terminology.

Based on the results of the didactic reduction presented in Table 7, Text 25 exhibits abstract text characteristics because it explains concepts that cannot be directly observed by students, such as potential energy, and is presented solely through lengthy sentences without visual aids, making it difficult for students to understand. This is evident from the many students who stated they struggled to grasp the text's content and found the explanation—without the inclusion of a curve—difficult to comprehend. Based on this, didactic reduction was carried out by presenting the text in a qualitative manner, using visual explanations, as well as reformulating sentences and using familiar terminology.

Tabel 8. Didactic Reduction Grid for Difficult Texts

Explanation of Material (Text)	Characteristics			Type of Reduction
	Abstract	Complex	Complicated	
Teks 29 In the reaction between acetic acid and sodium bicarbonate, carbon dioxide gas is produced, as shown in the reaction equation below: $\boldsymbol{CH_3COOH(aq) + NaHCO_3 \rightarrow CH_3COONa\ (aq) + H_2O\ (l) + CO_2(g)}$ In this context, a balloon containing sodium bicarbonate is attached to the mouth of an Erlenmeyer flask containing vinegar solution for the subsequent reaction. The amount or mass of sodium bicarbonate is kept constant, and the reaction is carried out by varying the vinegar concentration concentrated. from dilute to Variations in vinegar concentration result in differences in the number of acetic acid particles in the different containers, even though the volume to be reacted is the same.	✓			Use of analogies & sentence reformulation.

As presented in Table 8, Text 29 has the characteristics of an abstract text because it explains the reaction between acetic acid and sodium bicarbonate at the particle level, which cannot be directly observed by students. Furthermore, the effect of concentration variations on the number of acetic acid particles is also a concept that is difficult for students to visualize. This is evident from students stating they do not understand and finding the language used in the text difficult to comprehend. Based on this, didactic reduction was carried out by presenting the text in a qualitative manner, using illustrations, reformulating sentences, and employing familiar terminology to make abstract concepts easier for students to grasp.

Tabel 9. Didactic Reduction Grid for Difficult Texts

Explanation of Material (Text)	Characteristics			Type of Reduction
	Abstract	Complex	Complicated	
Teks 45 The activation energy in the starch breakdown reaction of cassava will decrease due to the presence of enzymes produced by yeast. Starch will be broken down into simpler sugar molecules through a reaction that occurs more easily. Because enzymes are present, the effective collisions between particles will increase, so the fermentation reaction will proceed faster compared to fermentation without yeast. The following is the reaction equation for the cassava tape fermentation process: $(C_6H_{10}O_5)_n \rightarrow C_6H_{12}O_6$ Starch, with the help of yeast, becomes glucose. $C_6H_{12}O_6 \rightarrow C_2H_5OH + CO_2$ Glucose, with the help of yeast, becomes ethanol.		✓		Qualitative text presentation, use of analogies, & sentence reformulation.

As presented in Table 9, Text 45 had complex characteristics because it explained the cassava tape fermentation process, which simultaneously involved enzymes, effective collisions between particles, and activation energy. Consequently, students were required to connect multiple concepts at once. This difficulty was reflected in students' responses, which indicated limited understanding of the text content and confusion in identifying the main idea, particularly regarding the role of enzymes in the fermentation process. Therefore, didactic reduction was carried out through omission of unnecessary information, the use of analogies, sentence reformulation, and familiar terminology.

The results of the didactic reduction of the three texts classified as difficult were reviewed by a chemistry education expert and used to improve the developed e-book. The revised texts were subsequently incorporated into the e-book, resulting in the second draft of the teaching material. This second draft was then reviewed again by a chemistry education expert to ensure the clarity and appropriateness of the revised content.

The didactic reduction process not only simplified the difficult texts but also improved the clarity and accessibility of the e-book content. Revised explanations, visual supports, and more familiar terminology were incorporated to facilitate students' understanding of abstract and complex reaction-rate concepts.

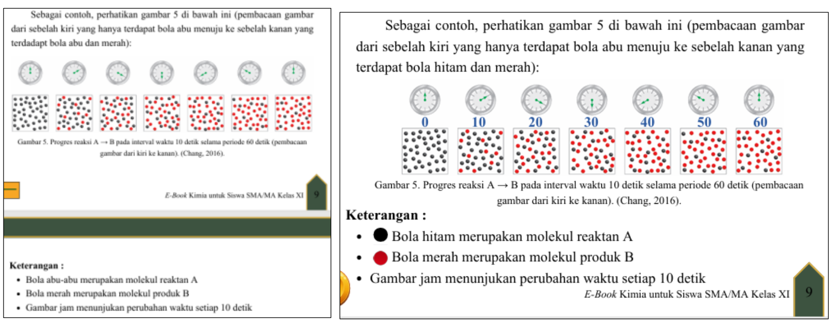

Figure 9. (a) before (b) after improvements

As shown in Figure 9, the initial image on the left included captions on a separate page. To improve clarity and help students understand the content more easily, the image was revised by placing the captions on the same page, adding colored circles corresponding to the observed elements, and providing time labels.

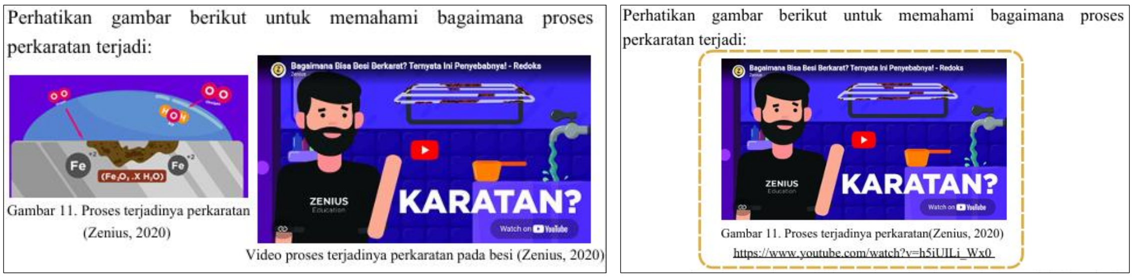

Figure 10. (a) before (b) after improvements

As shown in Figure 10, the explanation in Figure 5(a) was initially supported only by images, which could make the content difficult for students to understand. Therefore, Figure 5(b) was improved by adding an explanatory video that could be accessed directly through the e-book. This feature illustrates one of the advantages of e-books, namely their ability to integrate multimedia elements such as sound, images, animations, and educational videos, thereby making the presentation of information more engaging and helping students understand abstract concepts more easily (Hanikah et al., 2022).

E-Book Evaluation

E-Book Feasibility Test

A feasibility test was conducted on the developed e-book by three senior high school chemistry teachers serving as subject-matter evaluators. The assessment aimed to determine the suitability of the contextual reaction-rate e-book across five dimensions: content, presentation, design, graphics, and science process skills. The first four dimensions were based on the applicable national standards for instructional materials, while the science process skills dimension was included to assess the extent to which the e-book provided opportunities for students to engage in scientific activities (Kementerian Pendidikan, Kebudayaan, Riset, dan Teknologi & Badan Standar, Kurikulum, 2022). The feasibility results were analyzed for each assessment dimension and summarized across the three evaluators. Because the assessment involved only three teacher raters, the resulting feasibility percentages were interpreted as preliminary evidence of the e-book's suitability for limited use or further testing rather than as evidence of effectiveness or generalizability across different school contexts. The feasibility results are presented in Table 10.

Table 10. Results of the Feasibility Test for E-Book Teaching Materials

No	Aspect	Assessment		Criteria
		Appropriate	Not Appropriate	
1	Content Feasibility	98.89%	1.11%	Very Feasible
2	Presentation Feasibility	95.45%	4.55%	Very Feasible
3	Design Feasibility	100%	0.00%	Very Feasible
4	Graphic Feasibility	100%	0.00%	Very Feasible
5	KPS Feasibility	100%	0.00%	Very Feasible
Average		98.87%	1.13%	Very Feasible

Based on the results presented in Table 10, the developed e-book obtained an average feasibility score of 98.87% and was therefore rated very feasible for limited use or further testing.

The highest scores were obtained for design, graphics, and science process skills, each reaching 100%, while content and presentation feasibility reached 98.89% and 95.45%, respectively. However, these feasibility ratings should be interpreted as preliminary evidence of product suitability and do not by themselves establish the e-book's effectiveness, scalability, or applicability across different school contexts.

E-Book Comprehensibility Test Result

Texts classified as difficult during the characterization phase and which underwent didactic reduction were retested with students to determine whether the didactically reduced texts had become easier to understand or remained difficult. The comprehensibility test was conducted with 60 Grade 11 students from the same two schools, using 45 texts divided into three sets, as in the characterization stage. The main difference was that Texts 25, 29, and 45 had undergone didactic reduction before the comprehensibility test. The results were interpreted cautiously because prior exposure to similar texts may have introduced familiarity or recall effects that could influence the post-reduction comprehension scores. The comprehensibility test of the teaching materials aims to assess students' understanding of the texts in the developed teaching materials. The following table shows the scores from the comprehensibility test of students' understanding of the texts in the e book teaching materials.

Table 11. Recapitulation of the Results for E-Book Teaching Materials Comprehension Test

Package	Texts	Number of students	Grade	Average Comprehension Percentage	Average Comprehension
1	1-15	20	8 students in Class XI-1 at the first school and 12 students in Class XI-1 at the second school.	95 %	97 %
2	16-30	20		98 %	
3	31-45	20		97 %	

Based on the comprehensibility test results presented in Table 11, Texts 25, 29, and 45, which had previously been classified as difficult and subsequently underwent didactic reduction, showed higher proportions of correct main-idea identification. Text 25 increased from 7 of 20 students (35%) to 18 of 20 students (90%), Text 29 increased from 10 of 20 students (50%) to 20 of 20 students (100%), and Text 45 increased from 10 of 20 students (50%) to 19 of 20 students (95%). These changes were evaluated descriptively by comparing the number and percentage of correct responses before and after didactic reduction. Therefore, the results indicate improved text comprehensibility but should not be interpreted as evidence of a causal effect because no control condition was used and prior exposure to the texts may have influenced the retest results. Overall, the developed e-book obtained an average comprehensibility score of 97%, indicating a high level of text comprehensibility. This result suggests that the e-book content was generally understandable to students; however, it should not be interpreted as sufficient evidence that the e-book can function independently as self-study material without additional evaluation of students' learning performance and independent learning ability.

Conclusion

The study developed a contextual e-book on reaction rates using the 4STMD method, consisting of selection, structuring, characterization, and didactic reduction. The resulting e-book demonstrated distinct characteristics at each development stage and obtained an average feasibility rating of 98.87% from three senior high school chemistry teachers. The comprehensibility test produced an average score of 97%, indicating that the tested texts were highly comprehensible to the participating students. The e-book also incorporated contextual learning activities and science process skill indicators; however, this study did not evaluate whether its use improves students' science process skills, learning outcomes, or independent learning. Therefore, such potential effects should be examined through subsequent classroom implementation studies.

Several limitations should be considered when interpreting these findings. The feasibility assessment involved only three teacher evaluators and used a binary Yes/No scoring format, which may provide limited discrimination among ratings. The student sample was restricted to 60 Grade 11 students from two schools in Bandung City, limiting the generalizability of the findings. In addition, each of the 45 texts was assessed by only a subset of 20 students rather than by the entire sample. The re-evaluation of difficult texts may also have been affected by students' prior exposure and familiarity with the materials. Furthermore, the e-book was evaluated only in terms of product characteristics, feasibility, and text comprehensibility, without classroom implementation or effectiveness testing. Future research should therefore involve broader and more diverse samples and examine the e-book's effects on science process skills and learning outcomes through controlled classroom implementation.

Acknowledgment

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