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Interactive Multimedia on Reaction Rates to Train Higher Order Thinking Skills of High School Students

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Abstract

The educational demands of the 21st century require students to develop Higher-Order Thinking Skills (HOTS). However, chemistry learning at the senior high school level is still dominated by conventional teaching approaches, which often limit students' understanding of abstract concepts such as reaction rates and reduce active cognitive engagement. To address this issue, this study aimed to develop HOTS-oriented interactive multimedia to enhance conceptual understanding and student engagement. This research employed a Research and Development (R&D) approach based on the Alessi and Trollip model, consisting of planning, design, and development phases. The planning phase included a needs analysis related to school facilities and curriculum requirements. In the design and development phases, flowcharts and storyboards were transformed into interactive multimedia in Genially, integrated with the Problem-Based Learning (PBL) model to support analytical, evaluative, and creative thinking. Product validity was assessed by four expert validators, resulting in high validity scores for media (97.1%), content (93.3%), language (84.6%), and instructional design (97.5%). Practicality testing through one-to-one and small-group trials yielded average scores of 93.33% and 98.33%, indicating that the multimedia is very practical to use. Effectiveness testing showed significant improvements in learning outcomes and HOTS, with average scores increasing from 50.60 on the pretest to 80.43 on the posttest, 96.92% of students achieving the Minimum Mastery Criteria, and an N-Gain of 0.60 (moderate). These results indicate that the developed interactive multimedia is valid, practical, and effective for teaching reaction rate material at the senior high school level.

Keywords: Interactive multimedia; Reaction rates; Higher order thinking skills; Chemistry learning.

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INTRODUCTION

The advancement of science and technology in the 21st century necessitates that the educational sector produces human resources equipped with Higher Order Thinking Skills (HOTS). These competencies encompass the abilities to analyze, evaluate, and create, as classified in the revised Bloom's Taxonomy (Pu et al., 2025). HOTS is considered an essential competency as it fosters individuals capable of problem-solving, critical thinking, logical argumentation, and effective decision-making across various life contexts (Zhou et al., 2023).

The national curriculum, known as Kurikulum Merdeka, emphasizes the importance of HOTS development through student-centered and activity-based learning approaches (Abdurrahman et al., 2023). However, field implementation reveals that instruction is still dominated by conventional lecture methods and informative media. Students remain largely engaged in lower-order cognitive activities, such as remembering and understanding, while opportunities to cultivate higher-order thinking remain limited (Purwati et al., 2025).

A significant factor contributing to the suboptimal development of HOTS is the scarcity of learning media capable of facilitating independent interaction, exploration, and reflection

(Kwangmuang et al., 2021). Current teacher-led media are often not systematically designed to guide students through problem analysis, conclusion drawing, or phenomenal evaluation (Daryanes et al., 2023). Consequently, the learning process has yet to optimally foster critical and creative thinking skills.

The utilization of interactive multimedia emerges as a relevant solution aligned with the characteristics of the digital generation, who are accustomed to technology, dynamic visuals, and rapid information access (Cromley & Chen, 2025). Interactive multimedia integrates diverse elements—such as text, audio, video, animation, simulation, and interactive quizzes—into a structured learning unit (Abdulrahaman et al., 2020). This integration allows students to experience richer, more contextual, and meaningful learning, enabling them to move beyond theoretical understanding to connecting concepts with real-world phenomena. Furthermore, interactive multimedia serves as a learning environment that encourages active engagement, facilitates concept formation, and provides immediate feedback, helping students monitor their own learning progress and outcomes (Dong et al., 2024).

Interactive multimedia designed to facilitate HOTS must be grounded in systematic instructional design principles integrated with meaningful learning activities (Pamungkas, 2026). The media should incorporate contextual problems, analytical tasks, open-ended questions, and simulations that challenge students to analyze, evaluate, and create (Sailer et al., 2021). Additionally, it must provide space for exploration, reflection, and decision-making, ensuring students are not merely passive recipients of information but active constructors of knowledge (Kalsum & Takda, 2024). Rigorous planning in multimedia development ensures that the media functions not just as a visual aid, but as an effective pedagogical tool to improve thinking quality and learner autonomy (AlShaikh et al., 2024).

The quality of interactive multimedia must be evaluated based on educational product standards, specifically validity and practicality (Hadi et al., 2025). Validity assesses the alignment of the media with content standards, learning objectives, student characteristics, and HOTS indicators; invalid media risk causing misconceptions and failing to achieve target competencies (Yi-Ming Kao & Ruan, 2022). Meanwhile, practicality pertains to ease of use, navigation clarity, linguistic comprehensibility, and time efficiency, as media that is valid but impractical remains difficult to implement and yields minimal impact on the learning process (Siregar, 2025).

Based on a needs analysis conducted at SMA N 2 Sungai Selan, chemistry instruction regarding reaction rates requires innovative and interactive media. Survey results indicate that 92.96% of students struggle to understand the material due to its abstract, microscopic nature and mathematical complexities. Conversely, 96.60% of students believe that learning media aids understanding, and 92.60% view visual media or animations as highly effective. Infrastructure readiness is strong: 100% of students possess digital devices, 86.80% are accustomed to using them for study, 92.00% have experience with interactive multimedia, and laboratory facilities and internet access are fully available. Teachers also expressed a high demand (80.00%) for media development, with 100% agreeing that interactive multimedia is necessary for this topic. Although 100% of teachers theoretically understand HOTS, only 60.00% of currently used media is HOTS-based, with a potential application rate of 72.50%. This finding highlights a gap between teacher understanding and the practical application of HOTS-based media (Anistasya et al., 2025).

Despite numerous studies on interactive multimedia and HOTS-oriented chemistry instruction, most prior research has emphasized visualization-based or standalone multimedia without integrating systematic pedagogical scaffolding to train higher-order thinking skills (Nowlan et al., 2023). Multimedia developed for reaction rate topics generally supports conceptual understanding but lacks structured inquiry stages, problem-based learning (PBL) integration, adaptive feedback, and learning analytics to monitor students' cognitive engagement (Zotou et al., 2020).

This study offers a novel contribution by integrating Genially-based interactive multimedia with a PBL framework, supported by HOTS-oriented simulations, digital student worksheets (LKPD), ChatGPT-assisted scaffolding, and a login-based learning analytics system. Simulations and contextual problems are designed to reduce cognitive load, while PBL and guided inquiry provide scaffolding for analysis, evaluation, and creation processes. The inclusion of ChatGPT and learning analytics supports reflection, self-regulated learning, and the systematic development of higher-order thinking skills (HOTS) in chemistry education by providing adaptive cognitive scaffolding, analytical questioning, and continuous feedback that promotes student reflection and self-regulation (Lee et al., 2024).

This situation justifies the urgent need for learning media that can present information while fostering active engagement and systematically training Higher Order Thinking Skills (HOTS). Interactive multimedia is selected as the solution by providing direct interaction through visualization, animation, simulation, and exploratory activities. The development of interactive multimedia for reaction rates is a strategic step to bridge abstract chemical concepts, enhance learning quality and engagement, and align the instructional process with the demands of Kurikulum Merdeka, 21st-century education, and the Industrial Revolution 4.0. The ultimate objective of this research is to develop valid and practical interactive multimedia to train the HOTS of high school students.

METHOD

This study employed a Research and Development (R&D) approach guided by the Alessi and Trollip model, which systematically integrates three core phases: planning, design, and development. The planning phase established a robust pedagogical foundation through a comprehensive needs analysis incorporating curriculum reviews, student characteristic assessments, and infrastructure evaluations to define learning objectives and HOTS-oriented content strategies for reaction rate material, while the subsequent design phase translated these requirements into structural frameworks involving flowcharts and storyboards that served as the blueprint for a Genially-based prototype integrated with the Problem-Based Learning (PBL) model to foster analytical, evaluative, and creative skills. The development phase then involved rigorous formative evaluations, starting with alpha testing by four expert validators specializing in media, content, linguistics, and instructional design, followed by beta testing through one-to-one and small-group student trials to ensure practical usability. To synthesize the findings, a mixed-methods data analysis approach was utilized, whereby qualitative feedback from open-ended responses informed iterative product refinements, while quantitative data from Likert-scale instruments were converted into percentages and interpreted against predetermined criteria to objectively categorize the level of validity and practicality of the developed interactive multimedia.

Interactive Multimedia Validity Test

The validity questionnaire results from media, content, linguistic, and instructional design experts will be calculated using the following formula.

$$X = \frac{Total\ Score}{Maximum\ Score} X\ 100\%$$

The average results obtained from these calculations are subsequently categorized based on the criteria presented in the following table (Dewati, 2024).

Table 1. Validity Categories

Average Percentage	Category
0%–20%	Very Low Validity
21%–40%	Low Validity
41%–60%	Moderate Validity
61%–80%	Valid
81%–100%	Very Valid

Average percentage scores obtained from the expert validation process were rounded to the nearest whole number using standard rounding rules. The rounded scores were then interpreted based on predetermined decision thresholds to determine the level of product validity. An average percentage score of 61% or higher indicated that the product was categorized as valid, while scores exceeding 80% indicated that the product was very valid. Scores below 61% suggested that the product did not yet meet the validity criteria and required revision prior to further use.

Multimedia Interactive Practical Test

The practicality questionnaire results obtained from student responses will be calculated using the following formula:

$$X = \frac{\text{Total Score}}{\text{Maximum Score}} X\ 100\%$$

The average results obtained from these calculations are subsequently categorized according to the criteria presented in the table below (Dewati, 2024).

Table 2. Practicality Categories for One-to-One and small group Testing

Average Percentage	Category
0%–20%	Very Impractical
21%–40%	Impractical
41%–60%	Moderately Practical
61%–80%	Practical
81%–100%	Very Practical

Average percentage scores were rounded to the nearest whole number using standard rounding rules. Decision thresholds were applied to determine product practicality, with scores ≥ 61% indicating a practical product and scores > 80% indicating a very practical product. The categorization criteria proposed by Dewati (2024) were adopted due to their suitability for interpreting user responses in educational product validation, particularly in one-to-one testing contexts.

Testing the Effectiveness of Multimedia Interactive

The effectiveness of interactive multimedia was examined using a pre-experimental design, specifically a one-group pretest–posttest design, to determine differences in students' higher-order thinking skills (HOTS) before and after the implementation. The study population consisted of all 11th-grade chemistry students at the selected high school, with 65 students purposively selected as the sample. The instrument used in this study was a HOTS test comprising items that assess cognitive levels C4 (analyzing), C5 (evaluating), and C6 (creating). The questions were adapted from previous research and have established validity and reliability. The instrument consisted of 18 items designed to evaluate students' understanding of the Reaction Rate material. Effectiveness was analyzed using pretest results (administered at the beginning of the lesson) and posttest results (administered at the end of the lesson). In addition to calculating N-gain to determine the average score improvement, the analysis also considered individual changes in students' HOTS abilities. These changes were examined by analyzing shifts in responses across the C4 (analyzing), C5 (evaluating), and C6 (creating) indicators, allowing an assessment of how interactive multimedia enhanced students' analytical, evaluative, and creative thinking skills (Nurhikmah et al., 2023).

The pretest and posttest HOTS items were developed based on the same test blueprint aligned with higher-order thinking skills indicators (C4–C6).

Table 3. HOTS Test Blueprint for Pretest and Posttest on Reaction Rate Material

Learning Objectives	Item Indicators	Question Type	Item Number	Cognitive Level
Students are able to analyze the concept of reaction rate by relating it to real-life examples.	Given a narrative and phenomenon, students are able to analyze the concept of reaction rate based on the narrative or phenomenon.	MC	1	C4
	Given a narrative and phenomenon, students are able to analyze the concept of reaction rate based on the narrative or phenomenon.	MC	2	C4
Students are able to compare effective and ineffective collision theory based on simulations/images.	Given a narrative and images, students are able to analyze effective and ineffective collision theory based on the narrative, phenomenon, or images.	MC	3	C4
	Given a narrative and images, students are able to analyze effective and ineffective collision theory based on the narrative, phenomenon, or images.	MC	4	C4
Students are able to analyze zero-order reactions based on experimental data.	Given a narrative and experimental data, students are able to analyze the data to determine a zero-order reaction.	MC	5	C4
Students are able to analyze first-order reactions based on experimental data.	Given a narrative and experimental data, students are able to analyze a first-order reaction.	MC	6	C4
Students are able to analyze second-order reactions based on experimental data.	Given a narrative and experimental data, students are able to analyze the data to determine a second-order reaction.	MC	7	C4
Students are able to conclude the rate law equation based on experimental data.	Given an experimental data table, students are able to process and analyze the data to determine the rate law equation.	MC	8	C5
Students are able to conclude the rate law equation based on experimental data.	Given a narrative, students are able to process and analyze experimental data to determine the rate law equation.	MC	9	C4
	Given experimental data consisting of reactions, reactant concentrations, and reaction rates, students are able to determine the rate law equation.	MC	10	C5
	Given experimental data, students are able to analyze the relationship between changes in reactant concentration and reaction rate.	MC	11	C4
Students are able to conclude the effect of concentration on reaction rate based on experimental narratives and images.	Given a narrative, students are able to design a simple experiment to prove the effect of concentration on reaction rate.	MC	12	C6
Students are able to conclude the effect of	Given a narrative and experimental data, students are able to analyze the	MC	13	C4

Learning Objectives	Item Indicators	Question Type	Item Number	Cognitive Level
temperature on reaction rate based on experimental narratives and images.	effect of temperature based on the narrative and data. Given a word problem describing a student testing the effect of temperature on reaction rate, students are asked to design experimental steps.	MC	14	C6
Students are able to conclude the effect of surface area on reaction rate based on experimental narratives and images.	Given experimental data, students are able to analyze the effect of surface area on reaction rate.	MC	15	C5
	Given experimental data, students are able to analyze the effect of surface area on reaction rate.	MC	16	C5
Students are able to conclude the effect of a catalyst on reaction rate based on experimental narratives and images.	Given experimental images, students are able to analyze the effect of a catalyst based on the narrative and images.	MC	17	C5
	Given a word problem describing a student testing the effect of a catalyst on reaction rate, students are asked to design experimental steps.	MC	18	C6

After the pretest and posttest were completed, students' scores were calculated and converted into percentages. The percentage scores were then used to categorize students' higher-order thinking skills (HOTS) levels. This categorization aimed to determine the improvement in students' HOTS after the implementation of interactive multimedia by comparing the pretest and posttest results.

Table 4. Categories of Higher-Order Thinking Skills

Interval (%)	Category
86–100	Very High
76–85	High
60–75	Medium
55–59	Low
≤54	Very Low

The normalized gain score (N-Gain) provides an overview of the increase in students' Geometry thinking skills before and after treatment. The formula used is Hake has developed through the equation 1 below (Hake, 1998).

$$NGain = \frac{Skor\ Posttest - Skor\ Pretest}{Skor\ Maksium - Skor\ Pretest}$$

The N-gain results were then categorized according to predefined gain-level criteria, as shown in the following table (Hake, 1998):

Table 5. N-gain Score Categories

N-gain Interval	Category
N-gain > 0.70	High
0.40 < N-gain ≤ 0.70	Medium
N-gain ≤ 0.40	Low

RESULTS AND DISCUSSION

Planning

The planning phase established the foundation for developing HOTS-oriented interactive multimedia aligned with the Kurikulum Merdeka. This phase included defining the content scope, analyzing learner and user characteristics, identifying development constraints, formulating design guidelines, and collecting relevant resources. The multimedia was designed for eleventh-grade (Class XI) students and focused on reaction rate topics, targeting cognitive levels C4–C6 through the Problem-Based Learning (PBL) model. Learner analysis indicated adequate technological infrastructure, positive student attitudes toward digital media, and challenges in the mathematical aspects of reaction rate concepts, which informed content and interaction design. Development considerations emphasized cross-device accessibility, visual consistency, accurate chemical terminology, responsive navigation, and the integration of interactive features such as simulations, quizzes, and web-based learning tools, providing a structured basis for the subsequent design and development stages.

Design

The design stage involves developing web based instructional multimedia for reaction rate materials through concept development, task analysis, and the creation of flowcharts and storyboards. In collaboration with supervisors, the initial concept was aligned with Kurikulum Merdeka to determine content depth and interactivity forms. The Problem Based Learning model is implemented with a HOTS orientation to cultivate critical and creative thinking. Task and concept analysis maps the knowledge structure, emphasizing relationships between collision theory and reaction rate factors to ensure systematic learning. The program description integrates instructional strategies into concept maps, enabling students to analyze and evaluate contextual problems. All learning steps follow the PBL syntax and are structured to meet high level cognitive objectives.

Table 6. Integration of PBL, HOTS, and Interactive Multimedia

Learning Phase	Integration of PBL, HOTS, and Interactive Multimedia	Teacher's Role	Student's Role
Problem Orientation	Students analyze contextual problem cards in multimedia to identify problems and formulate scientific questions (C4).	Communicate objectives, motivate, present problems.	Listen, analyze problems, take notes.
Organizing Learning	Students work in small heterogeneous groups to discuss problem cards, interpret data, and propose hypotheses.	Form groups, explain problem-solving steps.	Work in groups, observe and discuss problems.
Guiding Investigation	Multimedia features (simulations, LKPD, ChatGPT, YouTube, Google) support data analysis, evaluation, and solution development (C4–C6).	Guide inquiry, facilitate data search, moderate discussion, request LKPD documentation.	Write hypotheses, collect data, record results in LKPD.
Developing & Presenting Results	Students compile reports and present findings using interactive LKPD, training evaluation and creation skills (C5–C6).	Facilitate reporting and presentation, give feedback.	Prepare reports, present results, answer questions.
Analyzing & Evaluating Process	Automatic feedback in LKPD supports reflection, evaluation, and conclusion making (C5–C6).	Provide feedback, request conclusions.	Evaluate group solutions, present conclusions.

The integration of Problem Based Learning (PBL) and HOTS within the multimedia is demonstrated through contextual problem orientation and collaborative investigations. Students engage in analyzing (C4) by interpreting data, simulations, and problem cards to

formulate hypotheses. HOTS development is further reinforced during the evaluation and creation phases (C5–C6), where students utilize ChatGPT, simulations, and digital worksheets to assess findings and compile reports. Supported by automated feedback, this structured sequence ensures the multimedia acts as a vital tool for reinforcing analytical skills and mastering abstract chemistry concepts.

In this multimedia, ChatGPT is provided as a supplementary information resource to support Higher Order Thinking Skills (HOTS), accessible only after students demonstrate foundational conceptual understanding, with its use governed by structured prompts, content boundaries, teacher supervision, and basic privacy safeguards to ensure ethical, controlled, and pedagogically meaningful engagement, while the digital LKPD collects only essential learning data (e.g., student identity, task responses, and reports), does not store ChatGPT conversation histories, requires instructional consent, protects underage learners through teacher-controlled access, and securely stores all data using a login-based system accessible exclusively to authorized teachers..

The flowchart illustrates the navigational flow from the home page to material topics, worksheets, simulations, and supporting features such as ChatGPT, Google, YouTube, and quizzes. The storyboard details the page layout, visual elements, text, navigation, and screen interactions. Both the flowchart and storyboard serve as media production guides and documentation tools for design evaluation prior to full-scale development.

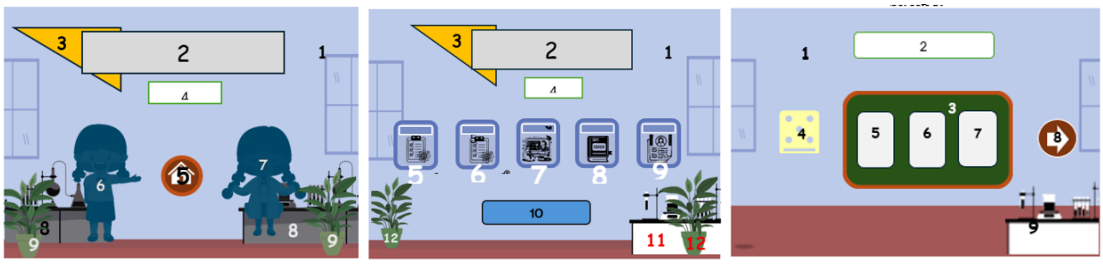


Figure 1. Interactive multimedia storyboard

The prototype was developed to evaluate core functionalities, including the login system, digital worksheets, ChatGPT integration, and interactive simulations. Visual assets were designed in Canva and programmed using HTML, CSS, and JavaScript. These elements were integrated via iframes to establish the structural framework for the web based learning media.

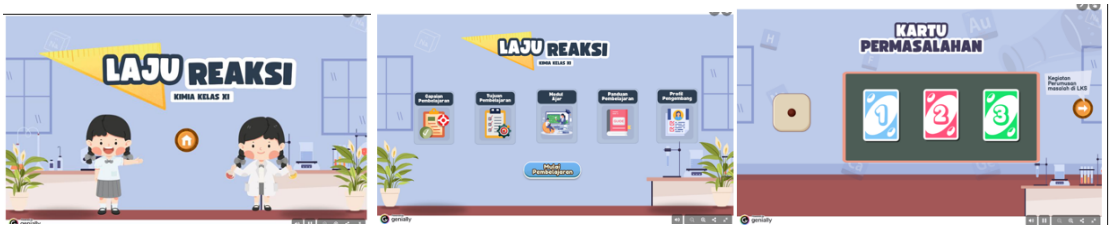


Figure 2. Interactive multimedia prototype

Audio and video scripts were systematically developed using Google Docs to ensure clear and communicative material delivery. These scripts provided essential narrative text and visual cues, facilitating team collaboration and seamless integration across all multimedia components.

Development

The development phase involved a systematic transformation of conceptual designs into an interactive multimedia product aligned with the Grade XI Kurikulum Merdeka and general chemistry references, covering reaction rates, collision theory, reaction orders, rate equations, and factors affecting reaction rates, with contextual content designed to support higher order thinking skills. The multimedia was developed using HTML, CSS, and JavaScript and integrated interactive features such as simulations, variable manipulation, automatic timing,

and data storage through Google Apps Script and Firebase, with preliminary testing conducted using JSFiddle before deployment through Netlify. Audio narration and video materials were produced using AI based voice tools and edited with CapCut, then combined with visual assets designed using Canva. All components including text, code, graphics, audio, and video were unified into a single interactive program using the Genially platform, followed by expert validation, student practicality testing, and a field test using a pretest and posttest design to evaluate the effectiveness of the multimedia in improving conceptual understanding, learning outcomes, and students higher order thinking skills on reaction rate material.

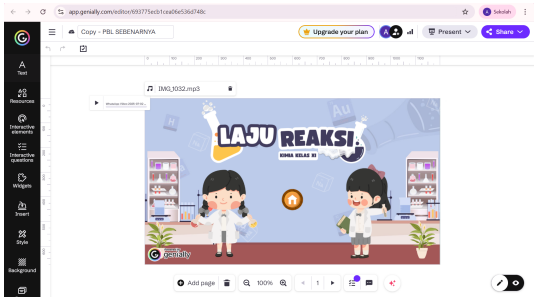


Figure 3. Genially use as the main platform

The sixth stage, preparing supporting materials, is carried out by preparing user guides, instructional videos, lesson plans (RPP) for meetings, as well as pretest and posttest based on HOTS indicators to measure students' higher-order thinking skills before and after the use of interactive multimedia, so that the utilization of the media can run optimally.

Validity of Interactive Multimedia

The next step is alpha testing to assess the validity of the developed product, namely the interactive multimedia. Validity assessment was conducted by four experts, specifically in the fields of media, material, linguistics, and instructional design.

Media Expert

The media expert validation aims to assess the visual quality, format, and attractiveness of the reaction rate interactive multimedia developed using Genially. The assessment was conducted using a validation sheet and written feedback from the validator, which served as the basis for product refinement.

Table 7. Overall Scores of Media Expert Validation Aspects

Aspect	Achieved Score	Ideal Score	Percentage	Criteria
Media Display	18	20	90%	Very Valid
Text	20	20	100%	Very Valid
Graphics	20	20	100%	Very Valid
Audio	10	10	100%	Very Valid
Total	68	70	97.1%	Very Valid

The media achieved an overall validity score of 97.1%, classifying it as highly feasible, with the interface aspect scoring 90% after minor revisions to strengthen chemical visual identity and clarify ChatGPT instructions. Textual, graphical, and audio aspects each reached 100%, indicating optimal readability, high-resolution visualization, effective sound synchronization, and an ergonomic layout that supports autonomous learning. Overall media validation confirms the multimedia as highly valid, attractive, and intuitive, in line with findings that consistent interactive design enhances motivation and focus (Gerbaudo-González et al., 2024), clear and structured text supports conceptual understanding (Saputra et al., 2025), appropriate visualization improves comprehension and higher-order thinking skills Dong et al., (2024), balanced audio facilitates information retention (Choirudin et al., 2025), and interactive multimedia integration enhances understanding and HOTS development (Katona et al., 2025)

Subject Matter Expert

Subject matter expert validation was conducted to assess the accuracy, appropriateness, and quality of the reaction rate material within the interactive multimedia. The assessment was carried out by a chemistry expert using a validation questionnaire accompanied by written suggestions as a basis for revision, ensuring that the content facilitates student understanding and cultivates HOTS.

Table 8. Overall Scores of Content Expert Validation Aspects

Aspect	Achieved Score	Ideal Score	Percentage	Criteria
Curriculum	24	25	96%	Very Valid
Text	47	50	94%	Very Valid
Language	13	15	86.7%	Very Valid
Total	84	90	93.3%	Very Valid

Subject matter validation achieved an overall validity score of 93.3%, categorizing the multimedia as highly feasible, with the curriculum aspect scoring 96%, content 94%, and linguistics 86.7%. Revisions focused on standardizing chemical terminology, reaction rate symbols (v), concentration notation ([S]), and adopting formal IUPAC nomenclature, such as *reactant*, while refining animations and chemical diction to enhance scientific accuracy and alignment with HOTS-oriented learning outcomes. These improvements ensure curriculum consistency and symbol accuracy essential for conceptual understanding (Mashami et al., 2025), support logical and comprehensive material structure for abstract concepts and higher-order thinking skills (Wu et al., 2025), and promote precise language use to minimize misconceptions and facilitate effective learning (Darling-hammond et al., 2020).

Linguistic Expert

The linguistic expert validation aims to assess the clarity, precision, and appropriateness of language usage to ensure that the material is easily understood by students. The assessment was conducted by a linguist through an online validation questionnaire via WhatsApp, and the feedback provided served as the basis for product refinement.

Table 9. Overall Scores of Language Expert Validation Aspects

Aspect	Achieved Score	Ideal Score	Percentage	Criteria
Language Presentation	17	20	85%	Very Valid
Sentence Presentation	18	20	90%	Very Valid
Language Consistency	20	25	80%	Valid
Total	55	65	84.6%	Very Valid

Linguistic validation achieved an overall validity score of 84.6%, classifying the multimedia as highly feasible, with language presentation scoring 85%, sentence structure 90%, and linguistic consistency 80%. Revisions focused on standardizing spelling, punctuation, numbering formats, and italicization of foreign terms, as well as streamlining instructional sentences to improve brevity, clarity, and communicative flow. These refinements ensure linguistic coherence and eliminate comprehension barriers, in line with evidence that clear and contextual language enhances student engagement and understanding (Jannah et al. 2025), linguistic precision reduces misconceptions (Fiedler et al., 2026), concise sentence structure supports conceptual understanding in multimedia learning (Tuzcu-Eken and Tuzcu 2026), and consistency in terminology and formatting facilitates cognitive processing and knowledge integration (Mahmudah et al., 2026).

Instructional Design Expert

Validation by instructional design experts was conducted to assess the alignment between learning objectives, materials, strategies, and evaluation in the lesson plan/module. The process utilized an evaluation sheet accompanied by written feedback as a basis for product improvement.

Table 10. Overall Scores of Instructional Design Expert Validation

Aspect	Achieved Score	Ideal Score	Percentage	Criteria
Curriculum	24	25	96%	Very Valid
Learning Strategy	44	45	97.7%	Very Valid
Learning Evaluation	10	10	100%	Valid
Total	78	80	97.5%	Very Valid

Instructional design validation showed high feasibility across all aspects, with the curriculum component scoring 96% (Highly Valid), confirming alignment with Kurikulum Merdeka through complete ABCD components oriented toward HOTS development, including refinement of instructional terminology from LKS to LKPD to ensure policy relevance. The instructional strategy aspect achieved 97.7% (Highly Valid), indicating systematic implementation of Problem Based Learning syntax that supports structured knowledge construction and cognitive engagement. The learning evaluation aspect reached 100% validity, demonstrating strong alignment between HOTS-oriented assessment instruments and learning objectives. Overall, the multimedia is highly feasible for implementation, supported by evidence that curriculum alignment and HOTS-based instructional strategies and assessments are essential for mastering abstract chemistry concepts (Sivakumar & Boon, 2026)

The validation process involves four experts: media, material, linguistics, and instructional design experts.

Table 11. Validity Test Results

Validity Test	Obtained Score	Maximum Score	Percentage	Category
Media Expert	68	70	97.1%	Very Valid
Subject Matter Expert	88	90	93.3%	Very Valid
Language Expert	55	65	84.6%	Very Valid
Instructional Design Expert	78	80	97.5%	Very Valid

The validation results indicate that the interactive multimedia achieved an average validity score of 94.75%, categorizing it as very valid and highly feasible for implementation. Media expert validation scored 97.1%, confirming engaging, consistent, and proportional interface, format, and visual elements that support readability and audio quality; content expert validation reached 93.3%, demonstrating accurate, systematic, and logically structured reaction rate material that stimulates Higher Order Thinking Skills (HOTS); linguistic expert validation achieved 84.6%, reflecting communicative and standard-compliant language use; and instructional design expert validation scored 97.5%, indicating strong alignment among instructional design, learning strategies, evaluation instruments, and learning objectives. Minor revisions were implemented by refining the interface, adding user instructions, standardizing chemical terminology, and strengthening reaction rate equation structures, in line with findings that emphasize the importance of visual design and navigation in instructional media (Alamsyah & Yusuf, 2025), clarity of terminology and conceptual accuracy in multimedia learning (Sundari & Fatonah, 2025), and the critical role of comprehensive expert validation in enhancing multimedia quality through targeted revisions (Adnyani et al., 2025).

Practicality of Interactive Multimedia

The subsequent stage is beta testing, an evaluation phase aimed at assessing the practicality and user experience (UX) of the interactive multimedia before its large-scale implementation. This stage comprises two types of testing: one-to-one and small-group trials. The one-to-one trial involved three students with varying academic performance levels (high, medium, and low) to identify initial difficulties, evaluate navigational ease, and ensure that every program segment functions correctly for individual users. Subsequently, the small-group trial was conducted with six students to assess the consistency of program functions, visual interface, and user comfort when the multimedia is utilized within a small group setting.

One to One Test

Table 12. Results of One to One Test

Name	Total Score	Max Score	%	Category
RA	74	80	92.5%	Very Practical
FF	75	80	93.75%	Very Practical
NCK	75	80	93.75%	Very Practical
Avarage	224	240	93.33%	Very Practical

The one-to-one trial involved three eleventh-grade students representing low, medium, and high cognitive levels (RA, FF, and NCK) to assess the practicality of the interactive multimedia on reaction rates, yielding a mean practicality score of 93.33% and a "very practical" category. Students reported that the text, images, animations, videos, and laptop-based access were clear and engaging, with reaction rate simulations identified as the most effective feature for supporting conceptual understanding. Minor suggestions included adjusting text size for mobile devices, replacing the magnifying glass icon with a book icon, simplifying technical terminology, and numbering the learning flow to improve navigation clarity. Content was perceived as concise, interactive, and motivating, while virtual laboratory simulations facilitated observation of particle motion and supported problem formulation using inquiry-based question prompts. These findings align with studies emphasizing the importance of usability and audiovisual design in shaping user experience (Kishabale, 2021), proportional integration of visual and verbal elements for stronger mental model construction (Anam et al., 2024), the positive impact of virtual laboratory simulations on student interest (Dodevska et al., 2025), communicative language for enhancing conceptual mastery and motivation (Bahrudin & Yogihati, 2022), and the need for simplified terminology to support lower-achieving students (Rybicki et al., 2024).

Small Group Test

Table 13. Results of the Small Group Test

Name	Total Score	Max Score	%	Category
RP	79	80	98.75%	Very Practical
CA	80	80	100%	Very Practical
SO	78	80	97.5%	Very Practical
PAW	79	80	98.75%	Very Practical
HNA	78	80	97.5%	Very Practical
FI	78	80	97.5%	Very Practical
Avarage	472	480	98.33%	Very Practical

The small group trial results show a very high level of practicality of the interactive multimedia across all student ability levels, with an overall mean score of 98.33%, indicating strong suitability for classroom implementation. Students positively evaluated text readability, visual quality, and aesthetic design, while minor suggestions related to navigation clarity, audio quality, and simplified diction were addressed through revisions to improve usability and independent operation. These findings support the view of **(**Monazam-Tabrizi et al., 2025) that instructional media with simple navigation and a clear presentation flow reduce cognitive load and enhance conceptual focus.

From the content perspective, all ability groups rated the multimedia very highly, stating that the engaging presentation of reaction rate material facilitated conceptual understanding and increased learning motivation. This result aligns with **(**Cromley & Chen, 2025), who report that visually appealing instructional media effectively enhance student attention and engagement. In addition, the interactive and non-monotonous content structure supports efficient information processing without overloading cognitive capacity, as emphasized by

(Bali et al., 2025). Consistently, Singh et al., (2025)found that learning materials enriched with interactive features significantly improve student motivation and learning outcomes.

Effectiveness of Interactive Multimedia

The table below summarizes the pretest and posttest results for all 65 students, showing the development of Higher-Order Thinking Skills (HOTS) in the topic of Reaction Rate following the implementation of interactive multimedia.

Table 14. Summary of Students' Pretest and Posttest Results

Pretest			Postest		
Score Total	**Avarage**	**Categories of HOTS**	**Score Total**	**Avarage**	**Categories of HOTS**
592	3288,89	-	941	5227,78	-
9,11	50,60	Very Low	14,47	80,43	High

Based on the pretest and posttest data presented above, it is evident that students' initial HOTS abilities before using interactive multimedia were still in the very low to medium category. The average pretest score of 50.60 indicates that students' initial understanding of Reaction Rate concepts and their higher-order thinking skills were limited. After participating in interactive multimedia learning activities, a significant improvement was observed in the posttest results, with an average score of 80.43, placing it in the high category. This indicates that, on average, students experienced notable progress in understanding Reaction Rate material and developing their HOTS.

Referring to the Minimum Competency Criteria (KKM), the pretest results show that all students (65 participants) did not meet the competency threshold, with the KKM for 11th-grade Chemistry set at 70. The class average of 50.60 falls into the not-achieved category, with HOTS at a very low level. These findings indicate that students' initial abilities were below the expected learning standards and insufficient to meet the demands of HOTS-based learning.

The posttest results demonstrate a significant improvement in learning achievement. The class average increased to 80.43, surpassing the KKM and reaching the achieved category with a high HOTS level. A total of 63 out of 65 students met the competency criteria. However, 2 students had not yet achieved the standard. These results indicate that the implemented learning approach effectively improved students' academic achievement in terms of KKM mastery. A comparison of students' scores based on KKM criteria from pretest and posttest is presented in Figure 1.

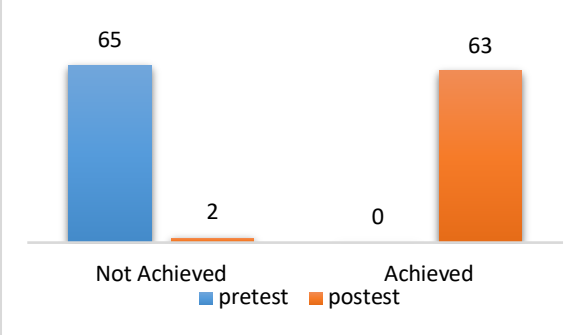


Figure 4. Comparison Diagram of Students' KKM Achievement through Pretest and Posttest

Based on the analysis of Minimum Competency Criteria (KKM) achievement, all students (65 participants) were in the not-achieved category during the pretest. No students reached the achievement category, indicating that their initial abilities did not meet the established competency standards.

Posttest results revealed a substantial improvement in Minimum Competency Criteria (KKM) achievement, with 63 students reaching the achieved category and only 2 remaining not achieved, indicating a clear shift from non-mastery to mastery after the learning process.

This improvement reflects enhanced academic performance and student mastery of reaction rate material following the implementation of interactive multimedia. Such findings are consistent with Haleem et al., (2022), who report that interactive multimedia significantly improves learning outcomes and supports mastery learning. Similarly, Abdulrahaman et al., (2020) emphasize that visually rich and contextual multimedia enhances conceptual understanding and facilitates achievement of Minimum Competency Criteria. Consequently, the improved KKM attainment in this study confirms the effectiveness of interactive multimedia-based learning in meeting established mastery standards (Mulyono et al., 2025)

Table 15. Summary of Pretest and Posttest Results Based on KKM Categories

Interval Value	Total Pretest	Total Posttest	% Pretest	% Posttest	Category
>70	0	63	-	96.92%	Achieved
<70	65	2	100%	3.08%	Not Achieved

Based on the recapitulation of pretest and posttest results according to KKM categories, a very clear improvement in learning achievement can be observed after the learning process. During the pretest, all students were in the not-achieved category (100%), with no students reaching the achieved category. This indicates that students' initial abilities were below the required competency standards.

The posttest results after interactive multimedia learning show a highly significant increase in KKM achievement. A total of 96.92% of students reached the achieved category, while only 3.08% remained in the not-achieved category. The shift in the distribution of learning outcomes from all students not achieving the standard in the pretest to almost all students achieving it in the posttest demonstrates that the implemented learning significantly improved students' mastery of the material. The decrease in the number of students in the not-achieved category from 100% in the pretest to 3.08% in the posttest provides strong evidence of improved learning quality through the use of interactive multimedia.

The Minimum Mastery Criteria (KKM) achievement also serves as a basis for reflecting on individual students' ability to utilize interactive multimedia. The findings indicate that the use of interactive multimedia can transform student learning outcomes, shifting them from a dominance of non-mastery categories to a dominance of mastery categories. Nevertheless, a small proportion of students still remain in the low category. This suggests that students exhibit individual differences in learning speed, learning styles, and cognitive backgrounds. These findings are consistent with Bloom's Mastery Learning theory, which states that each student requires different amounts of time and learning experiences to achieve mastery Winget & Persky (2022). In addition, Lengetti et al. (2020) emphasize that competency improvement is a gradual process strongly influenced by the duration of concept internalization and the intensity of students' learning interactions. Therefore, although interactive multimedia is generally effective, additional guidance is needed for certain students so that all learners can achieve optimal mastery.

The pretest and posttest results also allow for interpreting changes in students' Higher-Order Thinking Skills (HOTS) before and after the use of interactive multimedia. The comparison of students' HOTS can be seen in Figure 2.

Based on the pretest and posttest data of 65 students, the distribution of students' higher-order thinking skills (HOTS) before and after using interactive multimedia is as follows. In the pretest, the majority of students were in the very low category, totaling 33 students, indicating that their HOTS abilities were still weak and only capable of solving questions requiring minimal analytical thinking. Twelve students were in the low category, 20 in the medium category, and none in the high or very high categories. This indicates that prior to the learning process, most students were not yet accustomed to thinking critically, evaluatively, and creatively in understanding reaction rate material.

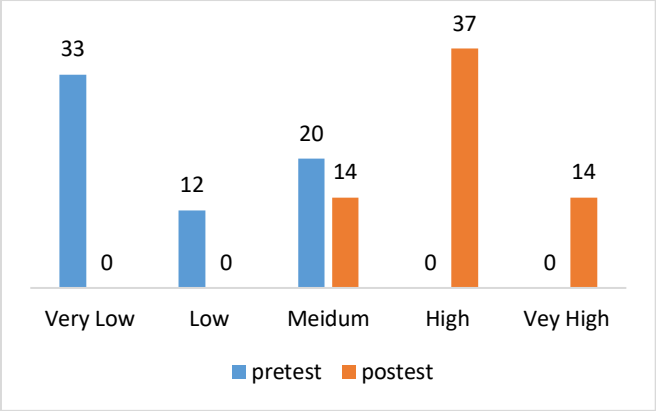


Figure 15. Comparison Diagram of Students' HOTS Categories in Pretest and Posttest

After learning through interactive multimedia, students' HOTS improved significantly. No students remained in the very low or low categories, indicating that all students reached at least a minimal understanding and could apply concepts more critically. Fourteen students were in the medium category, 37 in the high category, and 14 in the very high category. These results show that interactive multimedia effectively enhanced students' analytical, evaluative, and creative abilities through simulation features, quizzes, and Problem-Based Learning (PBL) activities that encourage higher-order thinking. Overall, this improvement indicates the effectiveness of interactive multimedia in supporting the development of HOTS in reaction rate material.

Table 16. Summary of Students' Pretest and Posttest Based on HOTS Categories

Score Interval	Number of Students Pretest	Number of Students Posttest	% Pretest	% Posttest	Category
86-100	0	14	-	21,54%	Very High
76-85	0	37	-	56,92%	High
60-75	20	14	30,77%	21,54%	Medium
55-59	12	0	20%	-	Low
<54	33	0	50,77%	-	Very Low

The pretest and posttest recapitulation based on HOTS categories shows a very significant increase. The pretest results indicate that no students achieved the very high or high categories. About 30.77% of students were in the medium category, 20% in the low category, and 50.77% in the very low category. This shows that most students had low higher-order thinking skills before instruction.

In the posttest, a shift to higher HOTS categories was observed. 21.54% of students reached the very high category, 56.92% in the high category, 21.54% in the medium category, and no students remained in the low or very low categories. This distribution shift indicates that the implemented learning effectively enhanced students' higher-order thinking skills comprehensively.

Improvements in students' Higher Order Thinking Skills are also evident from the comparison of average pretest and posttest scores. The average score increased from 50.60 on the pretest (very low HOTS) to 80.53 on the posttest (high HOTS). This improvement indicates that interactive multimedia not only enhances conceptual mastery but also significantly trains students' higher-order thinking skills. These results are supported by Rogti (2024), who stated that interactive multimedia is effective in improving critical thinking skills as part of HOTS. Additionally, Wibawanto et al. (2022) found that simulation-based interactive multimedia promotes students' HOTS through exploratory activities and problem-solving, thereby directly contributing to the development of higher-order thinking skills in understanding chemical

concepts. The study by Sinaga et al. (2022) also showed that the use of an interactive medium enhances learning outcomes and HOTS through engaging visual presentations and by encouraging independent exploration.

Table 17. Summary Based on HOTS Categories

HOTS	Pretest Score	Max Score	%	Category	Posttest Score	Max Score	%	Category
C4 (Analyze)	337	650	51.81	Low	533	650	82.00	High
C5 (Evaluate)	161	325	49.54	Very Low	264	325	81.23	High
C6 (Create)	94	195	48.21	Very Low	144	195	73.85	Medium
Total	592	1170	50.60	Very Low	941	1170	80.43	High

The pretest-posttest analysis shows a very significant increase in students' HOTS at the C4, C5, and C6 levels after participating in interactive multimedia-based Problem-Based Learning. For C4 (analyzing), the score increased from 337 to 533, with a percentage rise from 51.81% (low) to 82.00% (high). For C5 (evaluating), the score improved from 161 (49.54%; very low) to 264 (81.23%; high). For C6 (creating), the score increased from 94 to 144, with a percentage rise from 48.21% (very low) to 73.85% (medium). Overall, total HOTS scores increased from 592 to 941, with percentages rising from 50.60% (very low) to 80.43% (high). This demonstrates that interactive multimedia effectively facilitates higher-order thinking processes, enabling students to analyze, evaluate, and create solutions more effectively after instruction.

Further analysis indicates that students' higher-order thinking skills in the domains of analyzing (C4), evaluating (C5), and creating (C6) showed clear improvement after the implementation of interactive multimedia. This improvement demonstrates that interactive multimedia can progressively facilitate higher-order thinking processes, from analysis to creation. These findings are consistent with the research by Shanti et al., (2022), which shows that integrating interactive learning media significantly enhances students' HOTS. Moreover, the analysis reveals that improvements in analytical skills show a higher percentage increase than those in evaluating and creating skills. This finding aligns with Boom-Cárcamo et al., (2024), who state that analytical ability is the HOTS aspect that develops most readily through interactive multimedia-based learning, particularly when integrated with a Problem-Based Learning (PBL) approach. Al Farisi et al., (2023) also reported that analytical skills demonstrate the highest achievement percentage in learning using interactive media because students are more frequently trained to observe, compare, and interpret information.

Table 18. Recapitulation of Students' N-Gain Categories

	Total	Avarage	N-gain	Category
Pretest	592	50,60	0,60	Medium
Postetst	941	80,43		

The N-Gain analysis resulted in an average value of 0.60, categorized as moderate, indicating that interactive multimedia provides a meaningful improvement in students' learning outcomes and Higher-Order Thinking Skills (HOTS). This finding suggests that interactive multimedia effectively supports students' understanding of reaction rate concepts, particularly of abstract and complex chemical material. A moderate N-Gain reflects not only quantitative improvement but also cognitive development, as students are better able to construct conceptual understanding through interactive learning experiences. These results are consistent with by Asysyura et al., (2023), who reported that interactive multimedia enhances conceptual understanding and learning outcomes through visualizations, animations, and interactivity that support analytical thinking (Fauziah et al., 2025). In addition, Komariyeh and Mariono (2025) emphasize that interactive multimedia fosters meaningful learning by actively engaging students rather than positioning them as passive learners (Khalid et al., 2024). The systematic and accessible presentation of content also facilitates independent and collaborative learning

(Chen et al., 2025). Similarly, Kwangmuang et al., (2026) found that integrating visual elements and digital activities into interactive media significantly improves learning outcomes and student engagement. Overall, these findings confirm that interactive multimedia is an effective learning medium for enhancing conceptual understanding and HOTS in 11th-grade students.

CONCLUSION

The results of this study indicate that: (1) the interactive multimedia developed based on the Alessi & Trollip framework achieved a very high level of validity, with an average score of 94.75%, as evaluated by media, content, language, and instructional design experts; minor revisions were implemented to refine the interface, user instructions, chemical terminology accuracy, table formatting, reaction rate equation presentation, and grammatical consistency; (2) practicality testing through one-to-one and small group trials yielded scores of 93.33% and 98.33%, respectively, indicating that the multimedia is easy to use, features clear navigation, an attractive interface, and functions effectively across learning contexts; and (3) effectiveness testing demonstrated significant improvements in students' learning outcomes and Higher-Order Thinking Skills (HOTS), with mean scores increasing from 50.60 to 80.43, 96.92% of students achieving the Minimum Mastery Criteria, and an N-Gain value of 0.60, confirming a meaningful learning impact in Grade 11 chemistry.

RECOMMENDATION

Future research could enhance the development of interactive multimedia by expanding its scope to include other relevant chemistry topics. Specifically, subsequent studies should incorporate more sophisticated collision theory animations to better visualize particle dynamics across various reaction rate factors, with a particular emphasis on refining the representation of catalytic processes. However, several limitations of the current study must be acknowledged. First, the practicality testing was conducted with a relatively small sample size and within the context of a single school, which may limit the generalizability of the findings to broader educational settings. Additionally, while the multimedia demonstrated high validity and practicality, this study focused primarily on initial engagement and conceptual clarity without assessing long-term knowledge retention. Future investigations should therefore employ longitudinal designs and larger, more diverse cohorts to rigorously evaluate the sustained impact of this multimedia tool on student learning outcomes.

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AUTHOR CONTRIBUTIONS STATEMENT

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Anistasya	✓	✓	✓			✓		✓	✓	✓	✓			
Hartono	✓	✓		✓		✓	✓			✓		✓		
Sofia							✓				✓			

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no conflicts of interest related to the research, authorship, or publication of this manuscript.

INFORMED CONSENT

Informed consent was obtained from the research participants in accordance with applicable institutional and school procedures.

ETHICAL APPROVAL

The research was conducted in accordance with applicable ethical principles for educational research involving high-school students. Institutional and school permissions were obtained before implementing the multimedia trials and classroom-based assessments. Participation was voluntary, and measures were implemented to protect students' privacy, confidentiality, and learning data.

DATA AVAILABILITY

The data supporting the findings of this study, including anonymized pretest and posttest results, expert validation scores, practicality assessment data, and relevant research instruments, are available from the corresponding author upon reasonable request.

REFERENCES

Abdulrahaman, M. D., Faruk, N., Oloyede, A. A., Surajudeen-Bakinde, N. T., Olawoyin, L. A., Mejabi, O. V, Imam-Fulani, Y. O., Fahm, A. O., & Azeez, A. L. (2020). Multimedia tools in the teaching and learning processes: A systematic review. *Heliyon*, *6*(11), e05312. https://doi.org/10.1016/j.heliyon.2020.e05312

Abdurrahman, A., Maulina, H., Nurulsari, N., Sukamto, I., Umam, A. N., & Mulyana, K. M. (2023). Impacts of integrating engineering design process into STEM makerspace on renewable energy unit to foster students' system thinking skills. *Heliyon*, *9*(4), e15100. https://doi.org/10.1016/j.heliyon.2023.e15100

Adnyani, N. K., Mahartini, K. T., & Primayana, K. H. (2025). Pengembangan Multimedia Interaktif untuk Materi Keragaman Budaya dan Kearifan Lokal pada Mata Pelajaran IPAS Siswa Kelas IV Sekolah Dasar. *Jurnal Pendidikan Guru Sekolah Dasar*, *2*(4), 15. https://doi.org/10.47134/pgsd.v2i4.1672

Al Farisi, F. R., Yulianti, E., HR, N. H., Hidayah, F., & Hidayat, D. H. Z. (2023). Enhancing student higher order thinking skills through problem-based learning media integration. *Jurnal Pendidikan Progresif*, *13*(3), 1121–1134. https://doi.org/10.23960/jpp.v13.i3.202317

Alamsyah, N., & Yusuf, D. U. (2025). Pengembangan Media Pembelajaran Interaktif Berbasis PowerPoint pada Mata Pelajaran Dasar Desain Grafis di SMK Negeri Kota Makassar. *Education and Information Technologies*, *1*(1), 22–28.

AlShaikh, R., Al-Malki, N., & Almasre, M. (2024). The implementation of the cognitive theory of multimedia learning in the design and evaluation of an AI educational video assistant utilizing large language models. *Heliyon*, *10*(3), e25361. https://doi.org/10.1016/j.heliyon.2024.e25361

Anam, R. S., Gumilar, S., & Widodo, A. (2024). The use of the constructivist teaching sequence (CTS) to facilitate changes in the visual representations of fifth-grade elementary school students: A case study on teaching heat convection concepts. *International Journal of Science and Mathematics Education*, *22*(1), 73–99.

Anistasya, Hartono, & Sofia. (2025). Interactive Multimedia as An Innovative Strategy to Train HOTS in Reaction Rate Material : A Need Analysis. *Dinasti International Journal of Education Management and Social Science*, *7*(2), 1981–1993. https://doi.org/10.38035/dijemss.v7i2.5785

Asysyura, F., Adnan, A., & Faisal, F. (2023). The Effect of Interactive Multimedia on Students' Cognitive Learning Outcomes on System Materials. *Biodidaktika : Jurnal Biologi Dan Pembelajarannya*, *18*, 9. https://doi.org/10.30870/biodidaktika.v18i1.17808

Bahrudin, A. D., & Yogihati, C. I. (2022). Development of interactive learning media as an alternative to improve students' conceptual understanding and motivation on the temperature and heat topics. *International Journal of Education and Teaching Zone*, *1*(2), 132–145. https://doi.org/10.57092/ijetz.v1i2.37

Bali, C., Várkonyi, G., Szabó, M., & Zsidó, A. N. (2025). The impact of visual cues on reducing cognitive load in interactive storybooks for children. *Journal of Experimental Child Psychology*, *260*, 106320. https://doi.org/10.1016/j.jecp.2025.106320

Boom-Cárcamo, E., Buelvas-Gutiérrez, L., Acosta-Oñate, L., & Boom-Cárcamo, D. (2024).

Gamification and problem-based learning (PBL): Development of creativity in the teaching-learning process of mathematics in university students. *Thinking Skills and Creativity*, *53*, 101614. https://doi.org/10.1016/j.tsc.2024.101614

Chen, -Zhi, Chen, L.-A., Tseng, C.-C., Pai, C. H., Tsai, K.-E., Liang, E.-C., Chen, Y.-F., Chen, T.-L., Liu, S.-Y., Lee, P.-C., Lai, K.-C., Liu, B. R., Fouad, K. E., & Chen, C.-W. (2025). Enhancing student engagement and learning outcomes in life sciences: implementing interactive learning environments and flipped classroom models. *Discover Education*, *4*(1), 102. https://doi.org/10.1007/s44217-025-00501-x

Choirudin, C., Lubis, M., & Masuwd, M. A. (2025). Enhancing High School Students' Mathematical Problem-Solving Skills through Interactive Media: A Classroom Action Research Approach. *Journal of Teaching and Learning Mathematics*, *2*(2), 104–121. https://doi.org/10.22219/jtlm.v2i2.31685

Cromley, J. G., & Chen, R. (2025). A meta-analysis of Richard Mayer's multimedia learning research: Searching for boundary conditions of design principles across multiple media types. *Educational Research Review*, *49*, 100730. https://doi.org/10.1016/j.edurev.2025.100730

Darling-hammond, L., Flook, L., Cook-harvey, C., Barron, B., Flook, L., Cook-harvey, C., Darling-hammond, L., Flook, L., Cook-harvey, C., & Barron, B. (2020). Implications for educational practice of the science of learning and development. *Applied Developmental Science*, *24*(2), 97–140. https://doi.org/10.1080/10888691.2018.1537791

Daryanes, F., Darmadi, D., Fikri, K., Sayuti, I., Rusandi, M. A., & Situmorang, D. D. B. (2023). The development of articulate storyline interactive learning media based on case methods to train student's problem-solving ability. *Heliyon*, *9*(4), e15082. https://doi.org/10.1016/j.heliyon.2023.e15082

Dodevska, M., Zdravevski, E., Chorbev, I., Kostoska, M., Branco, F., Coelho, P. J., Pires, I. M., & Lameski, P. (2025). Virtual reality as a learning tool: Evaluating the use and effectiveness of simulation laboratories in educational settings. *Social Sciences & Humanities Open*, *12*, 101742. https://doi.org/10.1016/j.ssaho.2025.101742

Dong, H., Qu, H., Liu, P., & Apuke, O. D. (2024). The effectiveness of using interactive visual multimedia technology intervention in improving the literacy skills of children in rural China. *Learning and Motivation*, *86*, 101964. https://doi.org/10.1016/j.lmot.2024.101964

Fauziah, R., Ghufron, A., Muhtadi, A., & Fauzi, M. (2025). Effectivenes of Animated Simulation Video Media in Promoting Higher-Order Thinking Skills in Grade 10 High School Physics Material. *Salud, Ciencia y Tecnología*, *5*, 1905. https://doi.org/10.56294/saludcyt20251905

Fiedler, D., Schönle, D., Reich, C., & Harms, U. (2026). Supporting Pre-Service Teachers' Diagnostic Skills: Analysing Judgement Accuracy and Chatbot Impact in a Biology Classroom Simulation. *Journal of Computer Assisted Learning*, *42*(1), e70161. https://doi.org/10.1002/jcal.70161

Gerbaudo-González, N., Rodríguez-González, R., Facal-Mayo, D., & Gandoy-Crego, M. (2024). Personalized interactive multimedia systems to support meaningful activities in dementia care: A systematic review. *Archives of Gerontology and Geriatrics*, *127*, 105575. https://doi.org/10.1016/j.archger.2024.105575

Hadi, A. S., Rahayu, S. E., & Saputro, B. (2025). Validity and Practicality : Development of an Interactive Flipbook to Enhance Students Knowledge and Digital Literacy. *Journal of Natural Scient and Integration*, *8*(1), 111–129. https://doi.org/10.24014/jnsi.v8i1.34901

Hake, R. (1998). Interactive-Engagement Versus Traditional Methods: A Six-Thousand-Student Survey of Mechanics Test Data for Introductory Physics Courses. *American Journal of Physics - AMER J PHYS*, *66*. https://doi.org/10.1119/1.18809

Haleem, A., Javaid, M., Qadri, M. A., & Suman, R. (2022). Understanding the role of digital

technologies in education: A review. *Sustainable Operations and Computers*, *3*, 275–285. https://doi.org/10.1016/j.susoc.2022.05.004

Jannah, R., Lukman, I. R., Choiruddin, F., Izzah, N. N., Zahra, U., & Sakdiah, H. (2025). *Development of HOTS Assessment Tools to Measure Achievement in Acid-Base Learning Outcomes*. *6*(2), 2–7.

Kalsum, U., & Takda, A. (2024). Pengembangan Media Pembelajaran Berbasis HOTS Berbantuan iSpring Suite 10 pada Materi Getaran, Gelombang dan Bunyi. *Jurnal Penelitian Pendidikan Fisika*, *9*(2), 67–74. https://doi.org/10.36709/jipfi.v9i2.91

Katona, J., Ida, K., & Gyonyoru, K. (2025). Integrating AI-based adaptive learning into the flipped classroom model to enhance engagement and learning outcomes. *Computers and Education: Artificial Intelligence*, *8*, 100392. https://doi.org/10.1016/j.caeai.2025.100392

Khalid, N., Zapparrata, N., & Phillips, B. C. (2024). Theoretical underpinnings of technology-based interactive instruction. *Teaching and Learning in Nursing*, *19*(1), e145–e149. https://doi.org/10.1016/j.teln.2023.10.004

Kishabale, B. (2021). Theorising and Modeling Interface Design Quality and Its Predictive Influence on Learners' Post Adoption Behaviour in E-Learning Course Environments. *International Journal of Education and Development Using Information and Communication Technology*, *17*(1), 100–122.

Kwangmuang, P., Jarutkamolpong, S., Sangboonraung, W., & Daungtod, S. (2021). Heliyon The development of learning innovation to enhance higher order thinking skills for students in Thailand junior high schools. *Heliyon*, *7*(6), e07309. https://doi.org/10.1016/j.heliyon.2021.e07309

Kwangmuang, P., Kosum, S., Sarakan, P., & Nguyen, L. T. (2026). Innovative learning approaches to develop students' Design thinking skills through digital technology and local wisdom in border patrol police schools. *Thinking Skills and Creativity*, *60*, 102047. https://doi.org/10.1016/j.tsc.2025.102047

Lee, H.-Y., Chen, P.-H., Wang, W.-S., Huang, Y.-M., & Wu, T.-T. (2024). Empowering ChatGPT with guidance mechanism in blended learning: effect of self-regulated learning, higher-order thinking skills, and knowledge construction. *International Journal of Educational Technology in Higher Education*, *21*(1), 16. https://doi.org/10.1186/s41239-024-00447-4

Lengetti, E., Kronk, R., & Cantrell, M. A. (2020). A theory analysis of Mastery Learning and Self-Regulation. *Nurse Education in Practice*, *49*, 102911. https://doi.org/10.1016/j.nepr.2020.102911

Mahmudah, M., Mahliatussikah, H., Solehudin, M., & Batrisya, N. A. (2026). A Multimodal Instructional Design Model: Integrating Infographics and Interactive Videos in Arabic Language Learning. *International Journal of Arabic Language Teaching*, *8*(01), 1–15. https://doi.org/10.32332/ijalt.v8i01.11671

Mashami, R. A., Ahmadi, & Pahriah. (2025). Green chemistry and cultural wisdom: A pathway to improving scientific literacy among high school students. *Social Sciences & Humanities Open*, *11*, 101653. https://doi.org/10.1016/j.ssaho.2025.101653

Monazam-Tabrizi, N., Kurt, Y., & Kang, W. il-K. (2025). Navigating Learning Disruptions: The Role of Digital Learning Platforms in Student Motivation, Feedback and Emotion. *Computers & Education*, 105534. https://doi.org/10.1016/j.compedu.2025.105534

Mulyono, Slamet, S., & Chumdari. (2025). The Effectiveness of Interactive Learning Media in Improving Students' Understanding of the Food Chain Concept in Elementary Schools. *Jurnal Penelitian Pendidikan IPA*, *11*, 340–348. https://doi.org/10.29303/jppipa.v11i6.11099

Nowlan, N., Arya, A., Qorbani, H. S., & Abdinejad, M. (2023). Higher-order thinking skills assessment in 3D virtual learning environments using motifs and expert data. *Computers*

& Education: X Reality, *2*, 100012. https://doi.org/10.1016/j.cexr.2023.100012

Nurhikmah, M., Nahry Yarza, H., Setyaningsih, M., Annisa, R., Akbar, B., & Anugrah, D. (2023). Analisis Kemampuan Berpikir Tingkat Tinngi Siswa Terkait Pembelajaran Biologi Materi Sel. *Bionatural*, *10*(2), 06–11. https://doi.org/10.61290/bio.v10i2.506

Pamungkas, B. K. (2026). Improving Elementary School Students' Critical Thinking Skills Through Wordwall-Based Learning Integrated with Banyumas Local Wisdom. *Journal of Innovation and Research in Primary Education*, *5*(1), 298–311. https://doi.org/10.56916/jirpe.v5i1.2857

Pu, J., Safian, A. R. Bin, Nasrifan, M. N. Bin, & Saidon, Z. L. Bin. (2025). Need analysis on developing Students' higher order thinking skills one-to-one Western classical instrumental music lessons in higher education. *Acta Psychologica*, *254*, 104759. https://doi.org/10.1016/j.actpsy.2025.104759

Purwati, P., Sari, I. N., Pratama, R. A., Nikmah, F. K., & Gumintang, B. (2025). Uncovering Competitive Behavior: How Critical Thinking, Self-Efficacy, and Social Comparison Shape College Students in Central Java, Indonesia. *The Open Psychology Journal*, *18*. https://doi.org/10.2174/0118743501383616250425105109

Rogti, M. (2024). The Effect of Mobile-based Interactive Multimedia on Thinking Engagement and Cooperation. *International Journal of Instruction*, *17*(1), 673–696. https://doi.org/https://doi.org/10.29333/iji.2024.17135a

Rybicki, J.-M., Hämäläinen, W., Pitkänen, K. K., & Malmi, L. (2024). Why students fail to revise? Analysis of written metalinguistic feedback and cognitive effort on revision success. *Ampersand*, *13*, 100211. https://doi.org/10.1016/j.amper.2024.100211

Sailer, M., Schultz-Pernice, F., & Fischer, F. (2021). Contextual facilitators for learning activities involving technology in higher education: The Cь-model. *Computers in Human Behavior*, *121*, 106794. https://doi.org/10.1016/j.chb.2021.106794

Saputra, A. R., Murti, R. C., & Hastuti, W. S. (2025). The effect of web-based interactive learning media on critical thinking skills of elementary school students. *Jurnal Prima Edukasia*, *13*(1), 159–168. https://doi.org/10.21831/jpe.v13i1.75228

Shanti, M., Istiyono, E., & Munadi, S. (2022). The effectiveness of learning to improve students' higher-order thinking skills. *Cypriot Journal of Educational Sciences*, *17*, 1576–1587. https://doi.org/10.18844/cjes.v17i5.7220

Sinaga, P., Setiawan, W., & liana, M. (2022). The impact of electronic interactive teaching materials (EITMs) in e-learning on junior high school students' critical thinking skills. *Thinking Skills and Creativity*, *46*, 101066. https://doi.org/10.1016/j.tsc.2022.101066

Singh, M., Sun, D., & Yang, Y. (2025). Design and implementation of Math City: An inquiry-based metaverse platform for mathematics education. *Computers and Education: Artificial Intelligence*, *9*, 100462. https://doi.org/10.1016/j.caeai.2025.100462

Siregar, T. (2025). An Analysis of Lecturers' Pedagogical Practices: Balancing Higher-and Lower-Order Thinking Skills in Higher Education. *Preprint. Https://Doi. Org/10.20944/Preprints202510*, *1231*, v1.

Sivakumar, K., & Boon, M. (2026). A preliminary higher order thinking skills (HOTS) framework for interdisciplinary problem solving and scientific research (IDPSSR) in engineering science education. *European Journal of Engineering Education*, 1–34. https://doi.org/10.1080/03043797.2025.2609749

Sundari, S., & Fatonah, K. (2025). Pengembangan Media Flipbook Interaktif dalam Pembelajaran Bahasa Indonesia Materi Teks Prosedur di Sekolah Dasar. *Jurnal BELAINDIKA (Pembelajaran Dan Inovasi Pendidikan)*, *7*(3), 570–585. https://doi.org/10.52005/belaindika.v7i3.455

Tuzcu-Eken, D., & Tuzcu, A. (2026). Enhancing technical vocabulary learning: A comparative study of a mobile multimedia app and a word list. *System*, *138*, 103962. https://doi.org/10.1016/j.system.2025.103962

Wibawanto, H., Roemintoyo, R., & Rejekiningsih, T. (2022). Simulation-based interactive multimedia to improve vocational students' learning outcomes. *World Journal on Educational Technology: Current Issues*, *14*, 1927–1942. https://doi.org/10.18844/wjet.v14i6.8363

Winget, M., & Persky, A. M. (2022). A Practical Review of Mastery Learning. *American Journal of Pharmaceutical Education*, *86*(10), ajpe8906. https://doi.org/10.5688/ajpe8906

Wu, T., Lee, H., Chen, P., Wang, W., & Huang, Y. (2025). Integrating computational thinking diagnostic mechanism and reflective learning: An innovative approach to enhance learning outcomes in introductory programming. *Journal of Computer Assisted Learning*, *41*(5), e70121. https://doi.org/10.1111/jcal.70121Digital Object Identifier (DOI)

Yi-Ming Kao, G., & Ruan, C.-A. (2022). Designing and evaluating a high interactive augmented reality system for programming learning. *Computers in Human Behavior*, *132*, 107245. https://doi.org/10.1016/j.chb.2022.107245

Zhou, Y., Gan, L., Chen, J., Wijaya, T. T., & Li, Y. (2023). Development and validation of a higher-order thinking skills assessment scale for pre-service teachers. *Thinking Skills and Creativity*, *48*, 101272. https://doi.org/10.1016/j.tsc.2023.101272

Zotou, M., Tambouris, E., & Tarabanis, K. (2020). Data-driven problem based learning: enhancing problem based learning with learning analytics. *Educational Technology Research and Development*, *68*(6), 3393–3424. https://doi.org/10.1007/s11423-020-09828-8