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Claim-Evidence-Reasoning-Based Interactive Modules to Improve Students' Argumentation Skills on Salt Hydrolysis

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Abstract: Claim-Evidence-Reasoning-Based Interactive Modules to Improve Students' Argumentation Skills on Salt Hydrolysis. Scientific argumentation is a crucial element in chemistry education, enabling students to construct evidence-based explanations and engage in higher-order thinking. Nevertheless, students often struggle with abstract concepts such as salt hydrolysis, a topic that has received limited attention in the context of multimedia-based argumentation research. **Objective**: This study aims to develop and validate an interactive multimedia module designed to enhance students' scientific argumentation skills and conceptual understanding of the salt hydrolysis topic. **Methods:** A research and development (R&D) approach was employed, following a modified educational development model consisting of seven stages: needs analysis, design, development, expert validation, revision, limited field testing, and final evaluation. The interactive module integrated visual simulations, narrative explanations, and interactive prompts based on the Claim–Evidence–Reasoning (CER) framework. Validation was conducted by three categories of experts, consisting of media experts, subject matter experts, and chemistry teachers, to evaluate the module's pedagogical feasibility, content accuracy, and technical feasibility. **Findings:** Expert validation indicated high feasibility, with average scores of 92.3% from media experts, 90.6% from subject matter experts, and 88.7% from practitioner teachers. In a pilot study involving 32 students, the average argumentation score increased from 56.8 (pre-test) to 78.2 (post-test), reflecting a gain score of 21.4. Classroom observations noted the increase in student engagement and participation. In addition, student feedback emphasized that the multimedia was user-friendly, visually appealing, and effective in assisting them in understanding complex topics, such as salt hydrolysis. **Conclusion:** Interactive multimedia modules, when designed using structured reasoning models such as the CER framework, can effectively foster the development of scientific argumentation skills and conceptual understanding. This study contributes to the field of technology-enhanced learning by providing a validated approach for integrating CER into digital science instruction. Future research should investigate the scalability and effectiveness of this approach across different scientific disciplines and educational levels.

Keywords: interactive multimedia, salt hydrolysis, argumentation skills, chemistry education, claim–evidence–reasoning.

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INTRODUCTION

In today's knowledge-driven society, the ability to engage in reasoned discourse, evaluate claims, and construct well-founded arguments is a critical aspect of scientific literacy (Allioui et al., 2025). Scientific argumentation is not only a cognitive skill but also a communicative process that enhances conceptual understanding and empowers learners to participate meaningfully in scientific reasoning (Bidarra et al., 2015). In the context of science education, promoting argumentation is increasingly recognized as essential for cultivating higher-order thinking and informed decision-making (Osborne, 2010; Sampson et al., 2011). Despite this, empirical studies consistently report that many high school students face difficulties in constructing scientifically sound arguments, especially in abstract subjects such as chemistry, where connecting observable phenomena with molecular-level representations remains challenging (Sadler & Fowler, 2006; Morris et al., 2024).

Chemistry presents a distinct cognitive challenge due to its dependence on symbolic language, microscopic particles, macroscopic phenomena, and complex theoretical models. Research has shown that students often struggle to integrate the three levels of chemical representation (macroscopic, submicroscopic, and symbolic), resulting in fragmented or superficial understanding (Dewi et al., 2021; Dewi et al., 2022). This challenge becomes more pronounced in topics such as salt hydrolysis, where learners are required to simultaneously comprehend equilibrium processes, ionic interactions, and pH variations. As noted by Dewi et al. (2021), effective chemistry learning demands abstract reasoning and conceptual interpretation beyond memorization. Consequently, instructional approaches that focus solely on delivering factual content, without actively involving students in the construction of scientific arguments, often lead to limited conceptual gains and promote passive learning dispositions (Dewi et al., 2023; Febliza et al., 2023).

This theoretical concern is reflected in the findings from the needs analysis conducted at SMAN 1 Gunungsari. Classroom observations and teacher interviews revealed that students rarely articulated reasoning when discussing salt hydrolysis, and over 70% of students were unable to construct complete Claim–Evidence–Reasoning (CER) structures in diagnostic assessments. Teachers attributed this to students' fear of making mistakes, as well as the prevalence of teacher-centered instruction and static learning materials. These local findings ground the broader theoretical challenge in practical classroom realities, highlighting the urgent need for instructional innovations that explicitly scaffold scientific argumentation. However, prior studies have demonstrated that interactive multimedia can enhance student engagement and conceptual understanding in chemistry (Ayu et al., 2024; Liu et al., 2024). Most of these efforts have focused on general conceptual development or argumentation in topics such as acids and bases. A limited number of studies have specifically explored how argument scaffolding can be integrated into multimedia resources for complex topics, such as salt hydrolysis. Furthermore, existing studies rarely examine the connection between multimedia design, theoretical argumentation frameworks, and real-world classroom implementation, thereby limiting their pedagogical relevance and applicability (Podolefsky et al., 2013).

One widely proposed solution in science education research is the integration of technology-enhanced learning environments, particularly through the use of interactive multimedia. Multimedia that combines text, visuals, animations, and sound has been shown to enhance students' motivation, cognitive engagement, and conceptual understanding (Raviolo, 2019; Mayer, 2021; Anggraeni et al., 2021). When multimedia becomes interactive, enabling learners to control their learning paths, manipulate variables, and receive immediate feedback, it fosters active cognitive processing and supports learner autonomy (Kulatunga et al., 2011).

The present study addresses existing gaps by synthesizing three complementary theoretical frameworks: the Cognitive Theory of Multimedia Learning (CTML), the Claim–Evidence–Reasoning (CER) model, and Toulmin's Argument Pattern. CTML informs the visual and auditory design of the module by minimizing cognitive load and promoting meaningful learning through dual-channel processing (Mayer, 2021). The CER framework provided a structure for learning tasks that elicit scientific argumentation, while Toulmin's model was employed to assess the logical components of students' arguments. Together, these frameworks promote the development of a multimedia tool that is both cognitively accessible and pedagogically purposeful.

Beyond fostering general engagement, multimedia also holds significant potential for supporting the development of students' scientific argumentation. Interactive learning environments that incorporate structured prompts such as the Claim–Evidence–Reasoning (CER) framework or Toulmin's Argument Model have been shown to effectively assist students in organizing their thoughts, justifying conclusions, and evaluating alternative explanations (Herawati et al., 2022). These frameworks scaffold students' reasoning processes and provide structured opportunities for practicing scientific discourse. For example, studies by Walker et al. (2016) and Yulianti et al. (2023) demonstrated that the integration of Toulmin-based electronic worksheets into chemistry instruction significantly enhanced students' ability to construct evidence-based arguments, particularly in the context of acid–base topics.

Previous empirical studies further support the pedagogical potential of multimedia in chemistry education. Ayu et al. (2024) and Quílez (2019) demonstrated that interactive multimedia grounded in scientific approaches significantly enhanced student achievement and was validated as both feasible and effective by experts and learners. Schwarz and Baker (2017) found that multimedia designed on the topic of hydrocarbons improved students' critical thinking skills, with the most notable gains observed in question formulation and conceptual explanation. Similarly, Toth et al. (2020) reported that scientific inquiry-based multimedia successfully fostered essential science process skills such as observation, inference, and logical reasoning.

While multimedia-based instruction has been shown to support conceptual change, the explicit integration of structured argumentation scaffolding within digital media, particularly for complex topics such as salt hydrolysis, remains underexplored. This study addresses that gap by developing and validating an interactive multimedia module that embeds CER prompts and visual simulations within a topic-specific context. The findings suggest that when multimedia is purposefully aligned with pedagogical goals such as scientific argumentation , it can effectively mediate complex content and promote the development of higher-order thinking skills.

Despite these promising findings, much of the existing literature has focused either on general multimedia tools for conceptual understanding or on argumentation in topics such as acid–base equilibrium and redox reactions. Few studies have integrated multimedia design with structured argumentation scaffolds specifically within the topic of salt hydrolysis, which remains particularly challenging for students. Furthermore, limited empirical research has examined how expert validation and student perceptions can jointly inform the development process of such multimedia tools. As a result, a significant research gap persists regarding how multimedia resources tailored to salt hydrolysis can be effectively designed, validated, and implemented to foster scientific argumentation in authentic classroom contexts.

To address this gap, the present study aims to develop and evaluate an interactive multimedia module on salt hydrolysis that explicitly integrates elements designed to foster scientific argumentation skills among senior high school students. The novelty of this study lies in its dual focus: embedding scientific argumentation frameworks within multimedia content and validating its pedagogical feasibility through triangulated input from expert judgment and student feedback. By targeting salt hydrolysis, a topic that has seldom been addressed in prior argumentation-focused research, this study offers both theoretical and practical contributions to the advancement of chemistry education.

Therefore, this study is guided by the following research questions: (1) What are the characteristics of an effective interactive multimedia module that fosters students' argumentation skills on the topic of salt hydrolysis?; (2) To what extent are the developed multimedia products valid, practical, and effective in improving students' scientific argumentation skills?. The scope of the study is limited to a single senior high school and one specific topic within the chemistry curriculum. Nevertheless, the findings are expected to offer a replicable model for integrating argumentation-based digital tools into other science topics, thereby supporting educators in aligning instruction with the goals of 21st-century scientific literacy.

■ METHOD

Participants

The effectiveness evaluation involved 34 students (19 females, 15 males; mean age = 16.4 years) from Class XI IPA 4 at SMAN 1 Gunungsari during the 2024/2025 academic year. Based on academic records and teacher information, this class was categorized as a regular (middle-performing) group within the school's academic hierarchy. Although not part of an accelerated or high-achieving cohort, the students demonstrated an adequate baseline understanding of basic chemistry concepts and sufficient digital literacy to engage effectively with multimedia-based learning environments. The school itself represents a typical public senior high school in Indonesia, equipped with computer laboratories featuring Windows 10 PCs and stable internet connectivity.

All participants had completed prerequisite units on acid–base theory and chemical equilibrium, providing a conceptual foundation for engaging with the topic of salt hydrolysis. In light of the growing emphasis on global scientific literacy and the integration of English terminology in Indonesia's revised chemistry curriculum, the multimedia module adopted a bilingual approach. Instructional narration and user interface elements were primarily delivered in Bahasa Indonesia, while key scientific terms (e.g., "conjugate acid," "pH," "equilibrium") were presented in both English and Indonesian. This strategy was intended to support students' comprehension of fundamental concepts while simultaneously familiarizing them with international scientific vocabulary, thereby enhancing both conceptual understanding and alignment with curriculum standards that promote 21st-century competencies and scientific communication skills.

Research Design and Procedures

The used research design integrated two complementary strands: (a) a Research and Development (R&D) design to generate and refine the multimedia artifact, and (b) a one-group pretest–posttest format to evaluate its impact on students' argumentation skills (Sugiyono, 2016). Although limited in establishing causal relationships, the use of a single-group pretest–posttest design was deemed appropriate for this initial exploratory validation study. Due to practical constraints in the school setting, such as limited class sections and institutional policies, randomized group allocation was not feasible.

Nonetheless, the design enabled the researchers to obtain preliminary empirical evidence (proof of concept) regarding the effectiveness and usability of the developed multimedia module in an authentic classroom context. Ethical clearance for the study was obtained from the Institutional Review Board of Universitas Pendidikan Mandalika, and informed consent was secured from all participants and their guardians. The research was conducted over four months, from February to May 2024.

The procedure included the following stages: Needs Analysis: a convergent mixed-methods approach was employed, combining classroom observation, semi-structured teacher interviews, and curriculum mapping. Observations focused on student engagement and the occurrence of argumentation episodes during chemistry lessons, while interviews explored teachers' perceptions of conceptual bottlenecks related to the salt hydrolysis process. Converging evidence revealed low student participation, minimal use of Claim–Evidence–Reasoning (CER) language, and a predominant reliance on teacher-centered instruction.

Design Specification: design decisions were informed by three theoretical frameworks: the Cognitive Theory of Multimedia Learning (Mayer, 2021), Toulmin's Argument Pattern (Toulmin, 2003), and constructivist task analysis (Hake, 1998). Learning outcomes were defined to ensure that students would: (i) explain the ionic basis of salt hydrolysis, (ii) predict solution pH based on the strength of the parent acid and base, and (iii) construct Claim–Evidence–Reasoning (CER) arguments to justify their pH predictions. A detailed storyboard outlined the sequence of instructional screens, which included an introductory animation, exploratory simulation, guided worked examples, embedded CER prompts, and formative quizzes. Prototype Development: multimedia assets were developed using *Adobe Animate* for vector-based animations, *iSpring Suite* for creating interactive quizzes, and *Audacity* for recording audio narration. All components were integrated into a *SCORM*-compliant *HTML5* package to ensure compatibility and portability across various learning management systems. The prototype incorporated key principles of multimedia learning by applying dual-coding (onscreen text with synchronized narration), segmenting (breaking content into manageable chunks), and learner-controlled navigation, thus operationalizing core multimedia learning strategies (Mayer, 2021).

Expert Validation: Three independent validators assessed the prototype, including a media specialist with an M.Ed. in Educational Technology, a Ph.D.-level chemistry educator, and a practicing senior chemistry teacher. A four-point Likert-scale rubric was used to evaluate four key dimensions: (i) content accuracy, (ii) pedagogical coherence, (iii) technical usability, and (iv) aesthetic appeal. The validation process aimed to meet an eligibility threshold of 75% or higher in each domain, in line with criteria used in previous R&D studies (Ayu et al., 2024; Taber, 2013).

Product Revision: items receiving scores below the 75% threshold were revised accordingly. For example, the color scheme was modified to improve contrast ratios following feedback from the media expert regarding accessibility concerns. Additionally, an example contrasting strong-acid/weak-base salts was added based on the content expert's recommendation to enhance conceptual clarity. Pilot Testing: The revised module was pilot-tested with a convenience sample of 34 Grade XI science students. The testing sessions were conducted in the school's computer laboratory under the supervision of both the researcher and the classroom teacher. To capture real-time cognitive processing and usability challenges, think-aloud protocols were employed. Students were encouraged to verbalize their thoughts, decision-making processes, and any confusion while navigating the module. These verbalizations, along with students' on-screen activity, were recorded using screen-capture software (*Camtasia Studio*). The recordings were subsequently transcribed and thematically analyzed to identify usability issues, conceptual misunderstandings, and the extent to which students engaged with the embedded argumentation scaffolds.

Implementation: The finalized multimedia module was implemented with the full sample over two 90-minute classroom sessions, facilitated by the subject teacher. Prior to the intervention, students completed the Argumentation Test (AT-pre) under standard classroom conditions within a 40-minute time frame. To minimize expectancy effects, the researcher provided only general instructions and did not disclose that the study specifically focused on argumentation skills. During the two instructional sessions, students engaged individually with the multimedia module. Each session was supplemented by brief whole-class debriefings conducted at the beginning and end to contextualize the learning and reinforce key concepts. The teacher primarily acted as a facilitator, introducing the session by outlining the learning objectives and demonstrating how to navigate the module's features. Throughout the lessons, the teacher observed student interactions in class, using embedded CER prompts, and offered assistance when necessary.

Facilitation involved the use of guiding questions when students experienced difficulty in constructing claims or justifying their reasoning. Prompts such as "What does the simulation show you?" or "Why does that ion affect the pH?" were employed to encourage reflection and evidence-based reasoning. Across both sessions, the teacher made approximately 4–6 interventions per session, typically in response to visible signs of confusion, hesitation, or direct requests for clarification. During spontaneous peer discussions, the teacher occasionally joined group interactions to stimulate deeper reasoning. Rather than providing direct answers, the teacher prompted students to engage more critically with the available simulation evidence. This facilitative role was intended to balance instructional support with the promotion of student autonomy, while reinforcing the core components of the argumentation process. Immediately following the second lesson, students completed the Argumentation Test (AT-post) and the Perception Questionnaire to assess learning outcomes and gather feedback on the multimedia experience.

Instruments

The instruments used in this study included expert validation rubrics and an argumentation skill test. The expert-review rubric consisted of 28 items, distributed across four evaluation domains: content accuracy, pedagogical coherence, technical usability, and aesthetic appeal. Inter-rater reliability, measured using Cohen's ê, averaged 0.84, indicating substantial agreement among the validators. The argumentation skill test consisted of 15 items: 10 multiple-choice questions assessing students' conceptual understanding of salt hydrolysis, and five open-ended items requiring the construction of scientific arguments using the Claim–Evidence–Reasoning (CER) framework. The open-ended items were adapted from Marco-Bujosa et al. (2017) and validated through expert review for relevance and clarity. Each CER item was scored using a Toulmin-based rubric, with a maximum score of 12 points per item. The internal consistency reliability of the rubric, as measured by Cronbach's alpha, was 0.79, indicating acceptable reliability.

Sample CER-Based Essay Item:

"A solution of NH,, Cl is tested with litmus paper and turns red. Explain why the solution is acidic using the CER framework."

Table 1. Scoring rubric of argumentation skill test

Component	Criteria Description	Score Range
Claim	Clearly states a scientifically accurate claim (e.g., "NH_4Cl solution is acidic.")	0–2
Evidence	Provides relevant evidence from the context or data (e.g., "NH_4^+ ion hydrolyzes to produce H^+.")	0–4
Reasoning	Links evidence to the claim using appropriate scientific principles (e.g., "Because NH_4^+ is the conjugate acid of a weak base, it donates protons, lowering pH.")	0–6

The scoring rubric of argumentation skill test is presented in Table 1. The scores for the open-ended CER items were summed, with a maximum score of 12 points per item, to reflect students' overall quality of scientific argumentation. This scoring structure enabled a diagnostic assessment of students' ability to articulate and justify scientific reasoning within the context of salt hydrolysis. The Student Perception Questionnaire consisted of 20 Likert-scale items (1 = strongly disagree to 5 = strongly agree) designed to measure perceived ease of use, engagement, and perceived usefulness of the multimedia module. Validity indices for the questionnaire exceeded 0.80, as determined through exploratory factor analysis, indicating strong construct validity.

During the implementation phase, a structured 9-item observation checklist was employed to document student engagement in argumentation-related behaviors. The checklist focused on three core indicators, each operationally defined to ensure consistency in data recording: Spontaneous Claims: statements in which a student independently asserts a position or conclusion without direct prompting from the teacher or multimedia interface (e.g., "This solution is acidic."). Requests for Evidence: questions posed by students that explicitly seek supporting data or justification, either from peers or from the multimedia content (e.g., "What is the proof that it produces Hz ?" or "Where in the simulation does it show that?"). This category excluded generic or procedural inquiries, such as "What do I click next?" or "I do not get this." Reasoning Statements: utterances that connect a claim to evidence by invoking relevant scientific principles (e.g., "Because NH,, z is a weak acid, it releases Hz ions, making the solution acidic."). This observational tool was designed to provide real-time insights into the degree to which students engaged with the argumentation process during multimedia-based instruction.

Observations were conducted by a trained research assistant with a background in chemistry education. Prior to data collection, the observer participated in a two-hour calibration session with the lead researcher. This session involved reviewing operational definitions, analyzing ambiguous cases using video exemplars, and conducting inter-rater reliability trials on pilot data. Inter-rater reliability, calculated using Cohen's ê, reached 0.81 during the trial phase, indicating substantial agreement. To minimize subjectivity in recording, the observer maintained timestampe d field notes, which were cross-referenced with audio-visual recordings obtained from the think-aloud sessions. This triangulation strategy enhanced the trustworthiness of the observational data and facilitated qualitative coding aligned with Claim–Evidence–Reasoning (CER) framework.

Data Analysis

Quantitative data were analyzed using both descriptive and inferential statistical methods. For validation data, expert scores were converted into percentages and interpreted using Sugiyono's (2016) feasibility criteria: 0–50% (not feasible), 51–75% (feasible with revision), and 76–100% (highly feasible). In addition to numerical ratings, open-ended comments from expert validators were subjected to thematic coding to identify recurring domains for improvement. Verbal data obtained from think-aloud protocols and classroom observations were transcribed verbatim and analyzed using a deductive thematic coding approach grounded in the Claim–Evidence–Reasoning (CER) framework. This framework informed the development of an initial codebook with predefined categories, including: claim identification, evidence reference, causal reasoning, misconception, and non-task-related talk. The initial coding was conducted by the lead researcher, who possesses formal training in qualitative analysis and science education research.

To enhance the reliability of the analysis, a second independent coder, also trained in CER-based pedagogy, coded 25% of the transcripts. Prior to independent coding, a calibration session was held to ensure consistency in the interpretation of code definitions. Following the independent coding process, results were compared, and any discrepancies were resolved through consensus. Inter-coder agreement was calculated using Cohen's kappa (ê), yielding a value of 0.83, which indicates substantial agreement. Emergent themes that fell outside the CER framework, such as affective responses and metacognitive remarks, were documented and categorized separately for descriptive reporting. This process ensured that both expected and unexpected patterns in students' reasoning were captured, while maintaining fidelity to the study's theoretical orientation.

Multiple-choice items were scored dichotomously (correct = 1, incorrect = 0), while CER items were evaluated using a holistic rubric with a maximum score of 12 points per item. Total argumentation scores were normalized and analyzed using a paired-samples t-test (á = 0.05) to assess statistically significant differences between pre- and post-test performance. Effect size was calculated using Hake's normalized gain formula to determine the magnitude of learning gains attributable to the intervention. Qualitative observation notes were used to triangulate the quantitative findings by capturing real-time argumentation episodes and student engagement patterns during implementation. Responses from the student perception questionnaire were analyzed using descriptive statistics. Data distributions across key dimensions (ease of use, engagement, perceived usefulness) were visualized using box plots to examine score dispersion. Additionally, Spearman's rank-order correlation was employed to explore potential associations between students' perception scores and their post-test argumentation performance.

■ RESULT AND DISCUSSION

Product Features and User Experience

During the development process, the interactive multimedia module was designed to include five main components: (1) introduction, (2) concept exploration, (3) visual simulation, (4) CER-based argumentation tasks, and (5) evaluative quizzes. Each section was structured sequentially to ensure that students not only developed an understanding of the concept of salt hydrolysis but also gained the ability to construct scientific arguments based on relevant data and principles. For instance, in the visual simulation section, students could select different types of salts and observe the resulting pH changes. This was followed by a series of prompts that required them to formulate claims, identify supporting evidence, and provide justifications, thereby engaging them in the complete argumentation cycle. In this way, scientific thinking was not merely delivered through teacher explanation but was actively experienced by students through interactive exploration. Initial responses from students indicated that the multimedia module helped them better understand previously confusing chemical processes, mainly due to the combination of animations and concise narration. Students also reported that the visual and interactive design increased their sense of engagement compared to conventional lecture-based instruction.

Expert Validation Outcomes

Three experts evaluated the feasibility of the multimedia module based on four key aspects: content accuracy, media design, pedagogical suitability, and technical usability. The results were generally positive, indicating strong potential for classroom implementation. The media expert assigned a feasibility score of 88%, noting that the module's navigation was intuitive and the visual elements effectively supported conceptual understanding. However, they suggested minor improvements, such as adjusting the color contrast to be more accessible for students with mild visual impairments. The chemistry content expert rated the module at 86%, commending the scientific accuracy and the logical progression of material from basic to more complex concepts. Nonetheless, they recommended the inclusion of additional examples involving polyatomic salts and a more detailed explanation of acid–base equilibrium constants (Ka and Kb).

The chemistry teacher provided a feasibility rating of 83%, affirming that the module is well-suited for classroom use as a supplementary tool to face-to-face instruction. However, they suggested the development of a printable version or accompanying worksheet to accommodate students with limited access to digital devices. Overall, all three experts concluded that the multimedia module is highly feasible for educational use, both in terms of content quality and technical design. Their suggestions were incorporated into subsequent revisions and were validated by the results of the classroom pilot, during which many students showed marked improvement in constructing scientific arguments, particularly in formulating claims and identifying supporting evidence.

The expert validation results provide strong evidence that the multimedia module was pedagogically sound. Feasibility ratings from both media and subject-matter experts exceeded 85%, with particular praise for the module's clarity, usability, and visual design. These findings are consistent with previous research by Ayu et al. (2024), which demonstrated that interactive multimedia grounded in scientific learning principles can achieve high validation scores and yield measurable learning gains. A distinctive pedagogical feature of the present module is the integration of the Claim–Evidence–Reasoning (CER) framework into the content structure. Unlike conventional approaches that treat argumentation as a peripheral skill, this module embeds argumentation tasks directly within the explanation of chemical phenomena. This design aligns with the principles of argument-driven inquiry (Sampson et al., 2016), ensuring that students are continuously prompted to articulate their reasoning throughout the instructional process, not only during summative assessments. As a result, argumentation becomes an integral part of knowledge construction, rather than an add-on activity.

Implementation

Pilot testing was conducted with a sample of 34 Grade XI science students to evaluate the practical usability, student engagement, and cognitive impact of the multimedia module. Data were triangulated through classroom observations and pre- and post-assessment results. During the 90-minute implementation session, students exhibited high levels of engagement. Most participants navigated the module independently, interacted with the simulations without teacher prompting, and actively engaged in completing the embedded CER tasks. Notably, spontaneous peer discussions emerged in response to argumentation prompts, indicating collaborative cognitive processing. Although the module was designed to support student-centered learning, the teacher's role as a facilitator remained crucial. In addition to assisting with navigation and technical aspects, the teacher actively stimulated reasoning by posing guiding questions when students encountered conceptual difficulties. For instance, when a student struggled with a CER prompt, the teacher might ask, "What does the simulation show?" or "What principle explains that effect?", thus redirecting attention to the embedded evidence and encouraging scientific reasoning. This facilitative interaction supported deeper engagement with the argumentation process and reinforced the alignment between multimedia design and pedagogical intent.

These facilitative interventions were not frequent but were strategically timed, typically occurring 4–6 times per session. They often coincided with moments of cognitive hesitation or conceptual impasse, when students struggled to articulate or justify their reasoning. In several observed instances, teacher prompts clarified misconceptions or encouraged students to revisit and refine their initial claims based on the data presented in the simulation. Additionally, the teacher occasionally joined spontaneous group discussions, helping to sustain meaningful dialogue without dominating the conversation. This approach maintained the student-centered nature of the learning environment while providing just-in-time scaffolding to support deeper engagement with scientific argumentation.

These findings highlight that while the multimedia module offers robust scaffolding through visual simulations and CER prompts, the presence of a knowledgeable facilitator remains critical, particularly when students encounter a complex topic or require conceptual redirection. Although the module was well-received and students demonstrated independent engagement, the quality of scientific argumentation improved markedly when teacher facilitation complemented the multimedia experience. It remains an open question whether the module can function effectively as a fully self-directed learning tool in the absence of teacher support. Based on current findings, its effectiveness appears to be maximized when paired with responsive facilitation that prompts deeper reasoning and supports real-time conceptual clarification. Further research is warranted to evaluate the module's standalone efficacy in minimally guided settings, such as flipped classrooms or asynchronous online environments. Transcripts from classroom dialogues revealed that students were actively formulating and revising claims in response to simulation outcomes, indicating genuine cognitive engagement with the argumentation process.

For Example, In One Exchange: One illustrative dialogue occurred when two students discussed the effect of CH*f* COONa on solution pH: **Student A:** "*So CHf COONa makes the solution basic because it gives OH{ , right?*" **Student B:** "*Yeah, because the acetate ion pulls Hz from water. That is why OH{ increases.*"

At first glance, the dialogue demonstrates a basic level of conceptual understanding: Student B correctly identifies the behavior of CH*f* COO{ as a conjugate base and links it to the production of OH{ ions in solution. However, a closer analysis reveals a more complex cognitive process involving peer negotiation of meaning and self-correction. Student A's initial question reflects a degree of uncertainty and functions as a tentative claim, inviting clarification. Student B's response not only affirms the idea but also elaborates on it by referencing the underlying mechanism of proton abstraction. This exchange exemplifies the dynamic nature of collaborative reasoning, in which students test, adjust, and validate their ideas through dialogic interaction. It illustrates how argumentation in a peer context can promote deeper engagement with scientific principles, enabling learners to refine their understanding in real time through socially mediated discourse.

Importantly, the simulation feature of the multimedia module played a pivotal role in anchoring the students' dialogue. Prior to the exchange, both students had interacted with a visual model depicting acetate ions in water, where animated molecular interactions illustrated the attraction of Hz ions and the subsequent increase in OH{ concentration, accompanied by a pH scale shifting toward the basic range. This shared visual evidence served as a common epistemic reference point, enabling both students to construct and negotiate their claims using a mutually accessible representation. The combination of dynamic visualization and interactive control provided students with immediate, interpretable data to support or revise their reasoning, an essential condition for productive scientific argumentation. Consequently, the dialogue not only reflects a developing understanding of acid–base behavior but also demonstrates how well-designed multimedia can mediate scientific discourse by grounding abstract chemical concepts in concrete, observable phenomena. These moments suggest that carefully constructed visual simulations do more than enhance individual cognitive processing; they also facilitate socially distributed reasoning within classroom settings. This finding underscores the pedagogical value of multimedia as a catalyst for collaborative meaning-making and dialogic engagement in science education.

Pre- and Post-Test Argumentation Scores

Quantitative data revealed a statistically significant improvement in students' scientific argumentation skills following the intervention. The average pre-test score was 42.3%, which increased to 68.7% on the post-test. The normalized gain, calculated using Hake's formula, was $g = 0.46$, placing it within the "moderate" category of learning gains according to Hake's classification. While the results indicate meaningful progress in students' ability to construct scientific arguments, the magnitude of the gain did not reach the "high" category. Several factors may account for this outcome, including students' varying levels of prior knowledge, limited instructional time, and the novelty of engaging in structured argumentation tasks. Further exploration of these factors is warranted to optimize the module's impact and better support higher levels of argumentation proficiency.

Several factors may explain why the observed improvement in argumentation skills did not reach the "high" category. First, the short duration of the intervention, that limited to two 90-minute sessions, may have been insufficient for cultivating a complex, higher-order competency such as scientific argumentation. Unlike factual recall, argumentation requires metacognitive regulation, epistemic justification, and iterative refinement of ideas, all of which typically develop through sustained practice over time. Second, the inherent conceptual difficulty of salt hydrolysis likely posed an additional barrier. To fully grasp this topic, students must integrate multiple levels of representation: symbolic (chemical equations and ionization), submicroscopic (molecular and ionic interactions), and macroscopic (observable pH changes). Simultaneously, they are expected to apply abstract reasoning to interpret cause-and-effect relationships between these layers. Prior research (Taber, 2013; Dewi et al., 2021) has consistently shown that even advanced students often struggle to coordinate these representations, particularly in topics involving chemical equilibrium, where misconceptions are persistent and the conceptual load is high.

Third, although the multimedia module was positively received by students, certain design aspects may still benefit from further optimization. For instance, while CER prompts were embedded throughout the module, their effectiveness could be enhanced by increasing scaffolding or incorporating adaptive feedback mechanisms.

The current version of the module assumes a linear progression of reasoning, which may not adequately support students entering the learning task with diverse cognitive backgrounds or levels of prior knowledge. Incorporating more personali zed supports, such as branching pathways or differentiated prompts based on students' respons es, could promote deeper engagement and allow learners to progress at a pace aligned with their individual needs. Similarly, interactive guidance that responds dynamically to common misconceptions could foster more robust argument construction. These design refinements may improve the module's capacity to support differentiated instruction and maximize its pedagogi impact across a wider range of learners.

These reflections point to several directions for future research. Extended interventions over multiple sessions, the inclusion of follow-up activities, or the integration of teacher-led discussion around CER tasks may yield stronger gains. Students used these types of multimedia resources to work on various topics; their performance would surely improve. Additionally, iterative refinement of the multimedia based on learning analytics and student navigation patterns could help tailor the experience more closely to learners' needs. Overall, the moderate gain should not be seen as a limitation, but rather as an invitation for further pedagogical and design innovation to support complex reasoning in chemistry education.

A paired-samples t-test confirmed the statistical significance of this difference ($t = 6.47$, $p < 0.01$), indicating that students' ability to construct CER-based arguments improved after engaging with the multimedia module. Table 2 summarises the pre- and post-test results.

Table 2. Pre- and post-test argumentation performance

Measure	Pre-Test Mean (%)	Post-Test Mean (%)	Normalized Gain (g)
Claim	65.0	95.0	0.86
Evidence	27.5	70.0	0.59
Reasoning	13.3	35.0	0.25
Total Score	42.3	68.7	0.46

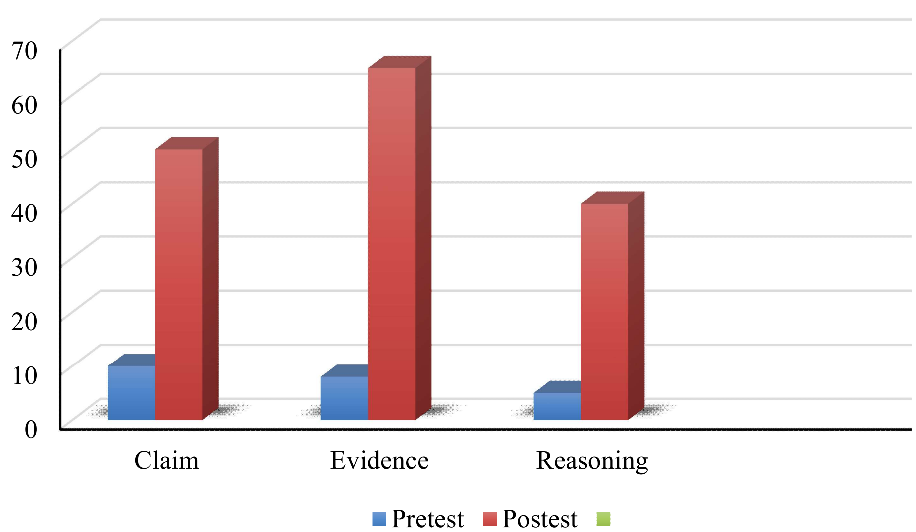

Figure 1. Student performance in the argumentation component

The qualitative analysis of students' open-ended responses also indicated notable improvement in the structure and depth of their scientific arguments. Prior to the intervention, most responses were limited to a Claim only (e.g., "The solution is acidic"), with minimal or no inclusion of supporting Evidence or Reasoning. Post-intervention, however, student responses more frequently incorporated relevant data (e.g., "NH,, z reacts with water to produce Hz ") and explicit reasoning (e.g., "Because NH,, z is the conjugate acid of a weak base, the solution becomes acidic"), demonstrating a more complete alignment with the Toulmin Argumentation Model. This shift suggests that the multimedia module, particularly through its embedded CER prompts, contributed to students' ability to construct more comprehensive and logically connected scientific arguments.

Quantitative findings demonstrated differentiated improvements across the three components of the CER framework. The mean score for the Claim component increased from 1.3 to 1.9 (on a 0–2 scale), indicating that more students were able to formulate accurate and complete scientific claims. The Evidence component showed the most substantial improvement, with mean scores rising from 1.1 to 2.8 (on a 0–4 scale). This suggests that the interactive simulations and visual cues were particularly effective in helping students identify and reference relevant scientific data to support their claims. In contrast, the Reasoning component, which requires students to logically connect evidence to claims using appropriate scientific principles, remained the most challenging. Although the mean score increased from 0.8 to 2.1 (on a 0–6 scale), many students continued to struggle with articulating coherent justifications that connect empirical observations and conceptual understanding. These results highlight the importance of ongoing instructional support and targeted scaffolding, particularly in developing students' reasoning abilities, which are essential for constructing robust scientific arguments.

This discrepancy suggests that although students became more confident in identifying relevant evidence, many still lacked the deeper conceptual schema required to integrate that evidence into robust scientific reasoning. For instance, several responses simply restated the evidence without explaining how or why it supports the claim (e.g., "NH,, z produces Hz "), without further elaboration on underlying acid–base equilibrium principles. These findings underscore the need for additional instructional scaffolding and metacognitive prompts that specifically target the reasoning component of scientific argumentation. Future iterations of the module could incorporate guided examples or reflective questions such as "Why does this process affect the pH?" to help students internalize the causal logic that underpins chemical phenomena. A more granular scaffolding approach, including step-by-step feedback, reasoning modeling, and differentiated prompts, may be necessary to support students in moving from descriptive to explanatory argumentation. Such design enhancements could help bridge the gap between recognizing scientific facts and constructing logically coherent explanations grounded in disciplinary knowledge.

Student Perceptions

The questionnaire results indicated that students found the multimedia module easy to use (92%), engaging (88%), and helpful to their understanding (87%). Qualitative comments further supported these findings, with students noting that "learning is not boring" and that they "understand better because [they] can see the effects firsthand". Interestingly, Spearman's correlation revealed a moderately strong and statistically significant relationship between students' perception of the usefulness of the multimedia and their argumentation performance (r› = 0.54, $p < 0.01$). This suggests that students who perceived the module as beneficial were also more likely to demonstrate higher learning gains. However, correlations for the ease of use and engagement dimensions were not statistically significant, indicating that appealing interfaces alone may not be sufficient to enhance learning outcomes unless they are accompanied by substantive, cognitively meaningful content. These results align with the affective, cognitive feedback loop proposed in multimedia learning research, in which positive emotional responses enhance cognitive engagement, but only when instructional design effectively supports deeper learning processes (Mayer, 2021).

Correlations with the other two perception dimensions include ease of use (r› = 0.33, p = 0.06) and engagement (r› = 0.29, p = 0.08), which were positive but did not reach statistical significance at the $p < 0.05$ level. These findings suggest that while usability and engagement may enhance the overall learning experience, the students' perceived instructional value of the module is the factor that most strongly correlates with measurable improvements in learning outcomes. This interpretation is consistent with prior research indicating that perceived instructional relevance is a key motivational factor influencing cognitive investment and achievement (Fredricks et al., 2004; Mayer, 2021). In the context of this study, students who believed that the multimedia module helped them better understand complex chemistry content were more likely to engage meaningfully with the argumentation tasks and perform better on the post-intervention assessments. Figure 2 presents a radar chart showing the mean scores across the three measured dimensions: ease of use, engagement, and perceived usefulness.

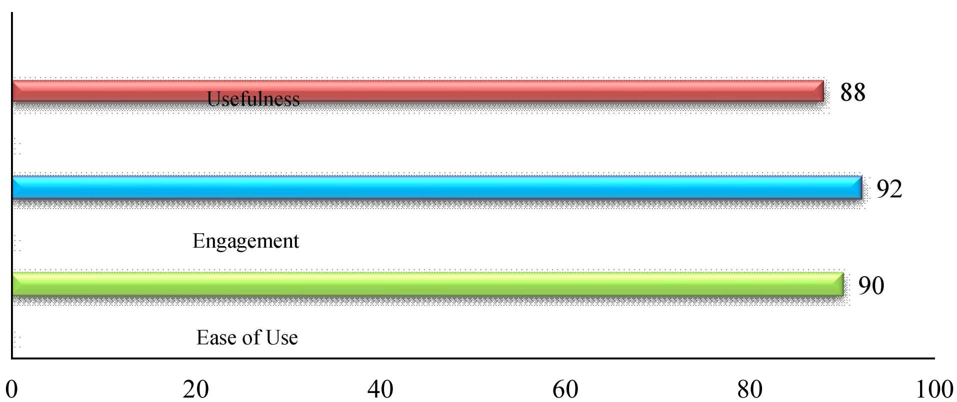

Figure 2. Student perception scores

Another dimension of effectiveness pertains to students' affective and cognitive engagement with the multimedia module. Responses to the perception questionnaire indicated high levels of satisfaction across three domains: ease of use, engagement, and perceived usefulness. Mean ratings ranged from 4.4 to 4.6 on a 5-point Likert scale, reflecting a uniformly positive reception among participants. These results align with previous findings by Sa'adah et al. (2020), who reported that multimedia-enhanced instruction can increase learner motivation and reduce anxiety in science learning contexts. Similarly, Toth et al. (2020) found that multimedia tools embedded within scientific inquiry environments foster high levels of enthusiasm and sustained attention among students. Taken together, these findings suggest that well-designed interactive multimedia not only support conceptual understanding but also contribute to a more engaging and emotionally supportive learning experience.

Students' open-ended responses provided additional nuance to the Likert-scale data. Many students expressed appreciation for the module's visual animations, interactive tasks, and immediate feedback, noting that these features made it easier to grasp abstract concepts such as hydrolysis reactions and ionic interactions. These reflections reinforce Mayer's (2021) assertion that dynamic visualization, when paired with narrative explanation, enhances the accessibility of complex scientific content, particularly for novice learners. Moreover, the high perception scores were consistent with the observed improvements in argumentation skills, suggesting that engagement and cognitive achievement may be mutually reinforcing. As previous studies have emphasized, affective engagement plays a crucial mediating role between instructional design and learning outcomes (Fredricks et al., 2004). In the context of this study, the multimedia module's intuitive interface and curricular relevance likely contributed to deeper cognitive processing and sustained learner effort, thus promoting both understanding and performance.

Implications, Limitations, and Recommendations

The findings of this study carry several important implications for science educators, instructional designers, and education researchers. First, the successful integration of argumentation structures into a topic-specific multimedia module represents a promising pedagogical strategy. While argumentation has been extensively promoted in science education policy, its classroom implementation remains inconsistent. This study demonstrates that argumentation need not be confined to writing tasks or debates but can be woven into digital instruction through design features such as embedded prompts, simulations, and scaffolded explanations. Educators seeking to foster both conceptual understanding and reasoning can draw on this model as a blueprint for other challenging chemistry topics. Second, the study supports the feasibility of using multimedia in resource-constrained contexts, provided the materials are designed with accessibility in mind. The use of low-bandwidth technologies, printable support sheets, and offline compatibility makes this approach adaptable to diverse school environments across Indonesia and beyond.

Pedagogical Implications for Teachers: Based on the findings, it is recommended that teachers integrate the multimedia module not as a replacement for direct instruction, but as a supplemental learning tool that supports and extends students' conceptual understanding. The module is particularly effective when introduced after a foundational review of acid–base theory and equilibrium concepts, serving as a conceptual bridge to the more complex topic of salt hydrolysis. Teachers are encouraged to incorporate the module into guided classroom activities, allowing students to interact with the simulations and CER prompts in small groups. These sessions can be followed by structured whole-class discussions to reinforce scientific reasoning and clarify misconceptions. Alternatively, the module can be assigned for individual exploration or used within a flipped-classroom model, where students engage with the multimedia content at home and later participate in in-class argumentation tasks. However, the study underscores that teacher facilitation remains essential, particularly in supporting students' ability to elaborate and justify their reasoning. Thus, the most effective use of the module involves a blended instructional approach, combining self-directed multimedia learning with teacher-guided reflection, feedback, and scaffolding.

Design Implications for Multimedia Developers: This study offers several important insights for educational multimedia developers, particularly in the context of science education. A key finding is the importance of integrating pedagogical scaffolding directly into the learning flow, rather than positioning assessment as a separate endpoint. The effectiveness of the module was primarily attributed to the strategic placement of CER prompts at critical stages within the simulation, which encouraged students to actively construct explanations rather than passively consume visual content. Developers are encouraged to consider the timing, positioning, and interactivity of scaffolding elements to ensure optimal user experience. For example, prompts that appear after each simulation step can elicit immediate reflection, while branching responses that adapt to learners' input can personalize the learning experience. Additionally, feedback mechanisms should move beyond binary correct/incorrect responses and instead promote metacognitive engagement through reflective prompts such as, "Why do you think this happened?" or "What principle supports your answer?". Such feedback fosters deeper reasoning and supports the development of argumentation skills. The study also underscores the importance of designing multimedia for dialogic use, that is, supporting not only individual exploration but also peer discussion and teacher facilitation. Features such as visual clarity, conceptual sequencing, and cognitive load management, as outlined in the Cognitive Theory of Multimedia Learning (CTML), should be thoughtfully aligned with opportunities for reasoning and discourse. This is particularly critical in cognitively demanding domains, such as chemistry, where abstract concepts often challenge novice learners.

However, several limitations must be acknowledged. The sample size, particularly for the pilot study (n = 34), was small, which limited the generalizability of the results. While statistical analyses were valid for preliminary inference, broader implementation and replication are needed to confirm the findings across multiple schools and demographics. Additionally, the study employed a one-group pre-post design without a control group, which limits the ability to draw causal conclusions. While the findings indicate a measurable improvement in students' argumentation scores following the implementation of the multimedia module, the one-group pretest-posttest design limits the ability to attribute causality exclusively to the intervention. Several alternative explanations must be considered when interpreting the results. First, the Hawthorne Effect may have contributed to the observed gains. Students were aware that they were participating in a study and that their responses were being evaluated, which may have increased their motivation, attentiveness, and effort during learning activities and assessments. Second, the Testing Effect could also have influenced the results. Completing the pre-test may have familiarized students with the argumentation format and prompted them to reflect on the content, thereby enhancing their performance on the post-test regardless of the multimedia intervention. Third, the possibility of a Maturation Effect cannot be ruled out. Since the study was conducted over several weeks, some improvement in cognitive processing and academic performance could be attributed to students' natural developmental progression or exposure to related content in other lessons. Nevertheless, future studies employing control-group designs or randomized trials are recommended to strengthen causal claims. Incorporating delayed post-tests or alternative versions of the assessment may also help differentiate actual learning gains from testing artifacts. These methodological refinements will provide a more robust foundation for evaluating the long-term impact and generalizability of argumentation-based multimedia in science education.

Another limitation concerns the short duration of the intervention. While immediate post-tests showed improvement, the study did not assess long-term retention of argumentation skills or conceptual knowledge. Follow-up testing after several weeks or months would provide valuable insights into the durability of learning gains. Finally, the multimedia module focused specifically on salt hydrolysis, a topic that, while representative of abstract chemistry content, is limited in scope. Further research is recommended to adapt the argumentation-based multimedia model to other chemistry topics (e.g., chemical equilibrium, thermodynamics) and other science disciplines (e.g., biology, physics).

CONCLUSION

This study was initiated in response to a well-documented challenge in chemistry education: students' persistent difficulties in constructing scientific arguments, particularly when engaging with abstract topics such as salt hydrolysis. To address this issue, an interactive multimedia module embedded with Claim–Evidence–Reasoning (CER) scaffolds was developed and evaluated to support students' conceptual understanding and argumentation skills. The findings suggest that the multimedia module shows considerable pedagogical potential. Students demonstrated measurable improvement in constructing CER-based arguments, alongside positive perceptions regarding usability and learning support. However, the interpretation of these outcomes must be tempered by the study's limitations, including its single-group design, short intervention duration, and implementation within a single school context. While the results provide preliminary evidence that multimedia enriched with argumentation scaffolds can enhance student engagement and reasoning, further validation is required to establish generalizability. From an instructional perspective, the module is best utilized as a complementary resource that facilitates guided exploration, rather than as a fully self-directed learning tool. The role of teacher facilitation emerged as particularly significant in supporting deeper reasoning, especially when students encountered conceptual challenges. Future research should explore the comparative effectiveness of different argument scaffolding frameworks, for example, examining CER in relation to more elaborated models such as Toulmin's Argument Pattern, to identify which structures provide optimal support for students with diverse prior knowledge and reasoning capabilities. Additionally, longitudinal studies with control-group designs are recommended to assess long-term learning outcomes, transferability across topics and disciplines, and the potential for integration into standard science curricula.

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