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DEVELOPMENT AND EVALUATION OF ARTICULATE STORYLINE-BASED INTERACTIVE MEDIA: INTEGRATION OF SOCIO-SCIENTIFIC ISSUES IN HYDROCARBON LEARNING TO ENHANCE STUDENTS' CRITICAL THINKING SKILLS

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ABSTRACT

Critical thinking enables students to make informed decisions, resist misinformation, and construct deeper disciplinary understanding, yet it remains underdeveloped in many classrooms. This study developed and evaluated an interactive hydrocarbon learning medium created with Articulate Storyline and integrating socioscientific issues (SSI) within the ADDIE framework (Analysis, Design, Development, Implementation, Evaluation). The research was conducted at an Islamic boarding school in Banjarmasin with 61 students (individual try-outs: n = 5; small-group trials: n = 10). Instruments—questionnaires, observation sheets, and tests—were aligned to Facione's six critical-thinking indicators and used to assess validity, practicality, and effectiveness. Content and media validity were high (expert ratings: 0.89 and 0.88), internal consistency was acceptable (Cronbach's alpha = 0.86), and practicality was rated very good (mean = 4.59). Effectiveness analyses showed substantial learning gains (normalized gain, n-gain = 0.77 and 0.78) and statistically significant pre- to post-improvements (paired t-tests, $p < 0.001$), indicating the medium effectively enhances students' critical thinking in chemistry. Limitations include the focus on a single topic (hydrocarbons), a single site with a modest sample, and no assessment of other skills or long-term retention. Within these bounds, the media demonstrate strong quality and practical classroom value, supporting teachers to design engaging, student-centered instruction that cultivates deeper thinking.

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INTRODUCTION

Critical thinking is one of the most essential outcomes of education and is regarded as a key factor in improving the quality of human resources [1], [2]. It involves understanding and solving problems, evaluating alternative solutions, and making well-informed decisions. Critical thinking also requires self-evaluation and deep reflection before drawing conclusions, along with the ability to create, apply, analyze, synthesize, and evaluate information obtained through observation, experience, reflection, and communication [3], [4].In the context of school education, particularly in science, fostering critical thinking is a central goal that allows students to develop scientific attitudes and apply their knowledge to real-world problems [5].

Chemistry is one of the subjects that particularly demands critical thinking, as it requires not only memorization of theories, formulas, and reactions but also a conceptual understanding of abstract phenomena. Studies show that many students perceive chemistry as difficult due to its complexity and abstract nature, often leading to misconceptions, poor problem-solving abilities, and reduced cognitive achievement [6], [7]. Hydrocarbon compounds, for example, are commonly associated with misunderstandings related to the uniqueness of carbon atoms, bonding patterns, chain structures, and their fundamental properties and reactions. Such difficulties are exacerbated by traditional teaching practices that rely heavily on lectures, textbooks, and laboratory demonstrations, which often fail to promote meaningful engagement or active learning [8], [9].

eacher-centered approaches that focus primarily on rote learning and predetermined answers further limit students' ability to develop higher-order thinking skills. These methods often neglect the social, ethical, and value dimensions of contemporary science, thereby restricting opportunities for students to engage in evidence-based reasoning and reflective argumentation. Moreover, the lack of interactive discussions and critical exploration prevents learners from analyzing scientific assumptions from multiple perspectives [10], [11]. Consequently, conventional methods are inadequate for equipping students with the critical thinking skills needed to evaluate and apply chemistry concepts in real-world contexts. To overcome these limitations, teaching strategies must provide relevant contexts, encourage student participation, and create opportunities for reflection and meaningful knowledge construction [12], [13].

The integration of Socioscientific Issues (SSI) into chemistry learning has emerged as an effective way to address these challenges. SSI situates science learning in authentic, real-world contexts, prompting students to engage with controversial issues that require them to collect and evaluate data, analyze different perspectives, and make reasoned decisions [14], [15], [16]. Research consistently demonstrates the positive impact of SSI-based learning on students' argumentation, decision-making, motivation, environmental awareness, and critical thinking [17]. [18], [19]. By linking chemistry concepts with relevant societal issues, SSI not only makes learning more meaningful and engaging but also develops students' scientific literacy, informal reasoning, and reflective assessment. Therefore, integrating SSI into chemistry education offers a promising approach to improving students' critical thinking skills while simultaneously fostering their understanding of science in both conceptual and practical dimensions.

The use of appropriate learning media has been shown to improve students' critical thinking skills [20]. Previous studies, such as the development of an E-Worksheet based on the ExPRession Activities Learning Modelskills [21]. and Android-based interactive media using the Storyline application [22]. Previous research has improved students' critical thinking skills in science learning using various learning media, especially in chemistry learning, such as hydrocarbon material.

have reported positive effects on students' cognitive development. In chemistry education, especially in topics such as hydrocarbons, learning media plays a crucial role in addressing students' misconceptions and enhancing critical thinking. Among the available tools, Articulate Storyline is regarded as highly suitable due to its rich features—including quizzes, interactive buttons, URL and trigger links, as well as multimedia integration (audio, video, animations, and images). It is flexible for online and offline use, accessible via laptops and mobile devices, and capable of overcoming spatial and temporal constraints in learning [18], [23], [24].

Prior research has developed Articulate Storyline media based on different approaches, such as the case method to strengthen problem-solving skills [25]. gamification to deepen knowledge through engaging constructivist learning [26]. and Project-Based Learning (PjBL) with environmental issues to improve outcomes [27]. However, most of these studies have focused on enhancing problem-solving or content knowledge rather than explicitly targeting critical thinking. The novelty of this research lies in integrating Socioscientific Issues (SSI) into hydrocarbon teaching via Articulate Storyline. Unlike previous SSI implementations that typically relied on printed scenarios, linear modules, or teacher-led discussions, this study situates chemistry learning in interactive, branching narratives that require students to navigate real-world dilemmas, make evidence-based decisions, and engage in ethical reasoning.

Integrating SSI into hydrocarbon teaching through Articulate Storyline is a significant innovation beyond existing SSI or multimedia pedagogies. Unlike previous SSI implementations that predominantly use case-based discussions, printed scenarios, or linear digital modules, this study uses a highly interactive and branching narrative environment to situate hydrocarbon-related environmental and societal dilemmas. This design allows learners to make evidence-based decisions, engage in ethical reasoning, and navigate complex dilemmas within a multimedia platform [28].

Empirical evidence demonstrates the effectiveness of both SSI and Articulate Storyline when applied separately. SSI-based instruction enhances argumentation, decision-making, and scientific literacy [14]–[19], while Articulate Storyline supports critical thinking, self-regulated learning, and engagement in science education [7], [29]. However, there remains a clear research gap: no prior study has combined these two approaches in the context of hydrocarbon learning. This integration is significant because it synthesizes SSI pedagogy with interactive digital media, offering a personalized and engaging pathway that simultaneously develops conceptual understanding, critical thinking, and 21st-century competencies [30]. By combining the strengths of both methods, this study seeks to overcome the limitations of earlier works that addressed SSI or digital media in isolation.

Theoretically, SSI provides a strong foundation for promoting critical thinking by embedding chemistry within socially relevant issues. Facione's taxonomy highlights cognitive skills such as interpretation, analysis, evaluation, inference, explanation, and self-regulation, all of which align with the objectives of SSI-based chemistry learning [31]. Real-world issues related to hydrocarbons—such as fossil fuel consumption, environmental pollution, and climate change—serve as authentic contexts in which students apply chemical knowledge while considering social and environmental implications [32]. Through SSI, learners are encouraged to explore multiple perspectives, assess the credibility of claims, and justify their decisions, thereby strengthening both scientific literacy and critical thinking [33]. Against this background, the present study aims to develop and evaluate Articulate Storyline-based learning media integrated with SSI for teaching hydrocarbons, following the ADDIE model to test its validity, practicality, and effectiveness in supporting student–teacher interaction and improving critical thinking in chemistry education.

METHODS

1. Research Design

This type of research is development research (Research and Development). The model used is ADDIE, which consists of five main stages: Analysis, Design, Development, Implementation, and Evaluation [34]. The flow of research conducted is presented in Figure 1.

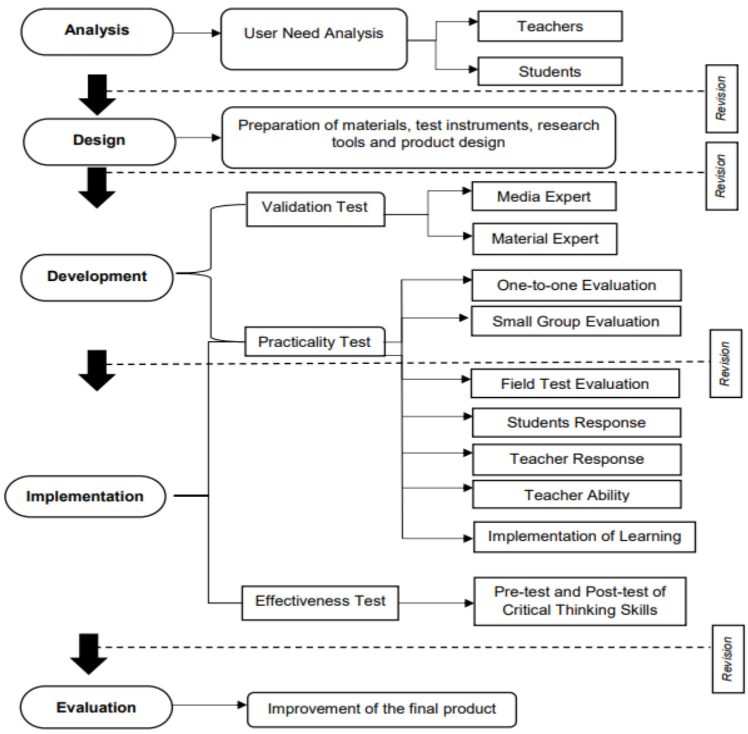


Figure 1. Research Flow Model ADDIE

2. Analysis Stage

The analysis stage was carried out to identify the needs and problems in the current learning environment as the basis for developing interactive learning media. This stage included two main activities. First, interviews with chemistry teachers were conducted to gather information regarding the teaching approaches, models, and learning resources commonly used in hydrocarbon instruction. The results showed that conventional methods, such as lectures and textbooks, were still dominant, while student engagement and opportunities for critical thinking remained limited.

Second, questionnaires were distributed to students to evaluate their initial critical thinking skills and their ability to relate chemistry concepts, particularly hydrocarbons, to real-life issues. The findings indicated that students had difficulty applying theoretical knowledge to authentic contexts and demonstrated limited skills in analysis, evaluation, and argumentation. This dual analysis provided the foundation for selecting hydrocarbon material as the focus of development and highlighted the importance of integrating the Socioscientific Issues (SSI) approach with interactive digital media to promote students' critical thinking.

3. Design Stage

The design stage focused on planning the framework and structure of the learning media to ensure that it aligned with the objectives of improving students' critical thinking skills. In this stage, several key components were determined. First, learning objectives were formulated based on curriculum standards and the six critical thinking indicators proposed by Facione, namely interpretation, analysis, evaluation, inference, explanation, and self-regulation.

Second, hydrocarbon material was selected as the primary content focus. This topic was chosen because previous analyses revealed frequent misconceptions among students, such as difficulties in understanding carbon bonding, hydrocarbon structures, and related reactions. Addressing these misconceptions required an approach that linked chemical concepts to real-world contexts. Third, the Socioscientific Issues (SSI) approach was integrated into the design to provide authentic and relevant contexts for learning. SSI was expected to stimulate discussion, argumentation, and decision-making, thereby fostering critical thinking.

Articulate Storyline was chosen as the development platform due to its interactive features, including animations, quizzes, hyperlinks, audio-visual integration, and branching scenarios. These features were designed to create engaging, student-centered learning media that supports independent exploration and encourages deeper reflection. The outcomes of the design stage included detailed blueprints for the learning objectives, material selection, SSI-based learning scenarios, and the structure of the interactive media to be developed

4. Development Stage

The development stage transformed the design outputs into concrete instructional products. Several activities were carried out systematically. First, learning materials on hydrocarbons were prepared and contextualized with Socioscientific Issues (SSI), ensuring that the content addressed both conceptual understanding and real-world applications.

Second, interactive media was developed using *Articulate Storyline*. The media incorporated multiple features—such as animations, quizzes, branching narratives, and audio-visual elements—that supported active learning and encouraged students to practice critical thinking skills in simulated decision-making scenarios.

Third, assessment instruments were created based on Facione's six critical thinking indicators. These instruments included pre-test and post-test items, as well as observation sheets and questionnaires for collecting student responses and teacher evaluations.

Fourth, validation procedures were conducted to ensure the quality of the developed products. Validation involved content experts, media experts, and a pedagogy expert. The instruments were assessed for validity, practicality, and effectiveness using structured rubrics. The results of these validations are summarized in Table 1, which shows that all instruments achieved scores in the valid category.

Product feasibility and readability tests were carried out in three phases: (1) individual trials with five students, (2) small-group trials with ten students, and (3) limited classroom trials. Feedback obtained from these stages was used to refine the media before its classroom implementation

Table 1. Research instrument validation results.

Data	Instruments	Score	Category
Valid	Media validation	0.88	Valid
	Content validation	0.89	Valid
	Teaching module validation	0.95	Valid
Practical	Teacher response questionnaire	0.95	Valid
	Learner response questionnaire	0.95	Valid
	Implementation observation sheet	0.96	Valid
	Teacher ability observation sheet	0.97	Valid
Effective	Test instrument	0.93	Valid

Measurement in the use of research instruments uses a Likert scale. For each question, an answer choice is given with a score range of 1-5: score 1 "very poor," score 2 "poor," score 3 "moderate," score 4 "good," and score 5 "very good." The data analysis used in this research is a descriptive metrics analysis of validity, practicality, and effectiveness, which aims to determine the increase in students' critical thinking.

Validity analysis involved both media experts and experts in related fields using instruments consisting of 17 items for media experts and 10 items for experts in related fields, with sample items shown in Table 2.

Table 2. Sample items.

Experts	Sample items
Media	Interesting image animation
Content	Material in line with learning outcomes and objectives

Validators 1 and 2 were content experts, 3 and 4 were media experts, and Validator 5 was a specialist in pedagogy. The assessment was carried out using Aiken's V formula.

$$V = \frac{\Sigma n_1}{[\, n\,(c - lo)]} \qquad (1)$$

Description:

Σn_1 = Total score
r = Number of experts
c = The highest number of scores
lo = The lowest score

5. Sample and Research Site

The study involved a total of 61 students enrolled in Grade XII of the Science stream. Participants were selected through purposive sampling at an Islamic boarding school located in Banjarmasin, Indonesia. The choice of sample was based on the consideration that students at this level had already received formal instruction on hydrocarbon materials as part of the national chemistry curriculum.

The school's environment is situated in a mixed residential area, near public facilities, and represents a typical learning context for secondary education in the region. This setting provided a relevant background for evaluating the practicality and effectiveness of the developed instructional media in an authentic classroom environment.

Prior to the research, ethical approval was obtained from the Ministry of Religious Affairs of Banjarmasin and the school principal. Permission was granted under the condition that the study would not disrupt regular learning activities, and student data would remain confidential. All participants provided informed consent, and anonymity was maintained throughout the research process

6. Implementation Stage

The implementation stage consisted of applying the developed instructional media in a classroom setting to evaluate its practicality and effectiveness. The interactive media, created using Articulate Storyline and integrated with Socioscientific Issues (SSI), was used to deliver lessons on hydrocarbons.

The implementation was carried out in two Grade XII Science classes with a total of 61 students at the selected Islamic boarding school in Banjarmasin. The lessons were conducted during regular class hours to ensure that the learning process was consistent with the school's existing curriculum. Teachers acted as facilitators, while students engaged with the media through a combination of interactive modules, quizzes, and problem-based activities contextualized with SSI scenarios.

During the implementation, observers monitored the learning activities using structured observation sheets to evaluate the fidelity of implementation, teacher facilitation, and student engagement. In addition, teachers and students were asked to complete response questionnaires to provide feedback on the practicality and usability of the developed media.

To assess effectiveness, students were given pre-tests and post-tests designed around Facione's six critical thinking indicators. The tests were administered separately to minimize recall bias. Learning outcomes were then analyzed by comparing pre-test and post-test scores, supported by statistical tests (paired t-test, n-gain analysis) to determine whether significant improvements in critical thinking had occurred.

7. Data Collection and Analysis

Data collection was conducted using four primary instruments: (1) validation sheets completed by experts, (2) observation sheets used during classroom implementation, (3) teacher and student questionnaires, and (4) critical thinking tests based on Facione's six indicators. Each instrument provided complementary information that supported the analysis of validity, practicality, reliability, and effectiveness of the developed media[35]

a. Practicality Assessment

The practicality of the developed media was evaluated through teacher and student questionnaires, focusing on three main aspects: clarity of content, ease of use, and overall feasibility in classroom implementation. The questionnaire items were rated on a five-point Likert scale, where 1 = very poor and 5 = very good.

To interpret the average scores obtained from teachers and students, the scale was categorized into five levels of practicality, as summarized in Table 3.

Table 3. Practicallity score [36].

Practicality Scale	Category
$4.20 < P \leq 5.00$	Very Practical
$3.40 < P \leq 4.20$	Practical
$2.60 < P \leq 3.40$	Enough Practical
$1.80 < P \leq 2.60$	Less Practical
$1.00 \leq P \leq 1.80$	Impractical

Based on this classification, scores above 4.20 indicate that the media is very practical, while scores between 3.40–4.20 suggest that the media is practical. Lower scores reflect decreasing levels of practicality. This stage of analysis ensured that the developed learning media was not only theoretically valid but also functionally appropriate for classroom use. By combining teacher and student perspectives, the assessment provided a balanced measure of practicality that accounted for both instructional delivery and learner experience

b. Reliability Testing

The reliability of the critical thinking test instrument was measured using Cronbach's Alpha, which evaluates the internal consistency of test items. A high Cronbach's Alpha value indicates that the test items measure the same construct consistently and reliably. The formula used to calculate Cronbach's Alpha is presented in Equation (2).

$$r_{11} = \left[\frac{k}{(k-1)}\right]\left[1 - \frac{\Sigma\sigma b^2}{\sigma t^2}\right] \qquad (2)$$

Description:
r11 = instrument reliability
k = number of question items
Σσb2 = the sum of the variance of the scores of each question item
σt2 = variance of total score

The criteria for interpreting the results of calculating the reliability of the test instrument are in Table 4.

Table 4. Reliability of the test instrument [37].

Reliability Coefficient	Category
$r \geq 0.90$	Very High
$0.70 \leq r < 0.89$	High
$0.50 \leq r < 0.69$	Medium
$r < 0.50$	Low

c. Critical Thinking Assessment

Students' critical thinking performance was assessed based on Facione's six indicators, namely: interpretation, analysis, evaluation, inference, explanation, and self-regulation. Each indicator was represented by one test item, allowing for a comprehensive evaluation of students' reasoning and problem-solving abilities. A sample of these test items is presented in Table 5.

Table 5. Sample indiactor items.

Indicator	Sample items
Self-regulation	What role can you play as a member of the community affected by forest fires to prevent air pollution from getting worse?

Student responses to the test were evaluated using a rubric that classified their performance into categories of high, medium, or low, as outlined in Table 6.

Table 6. Critical thinking assessment criteria [38].

Critical Thinking Ability Score	Category
76-100	High
60-75	Medium
0-59	Low

This rubric ensured that students' performance was measured not only in terms of numerical scores but also in relation to their ability to demonstrate higher-order thinking. Students who achieved scores in the high category were able to interpret, analyze, and evaluate information effectively while also demonstrating strong reasoning and self-regulation skills. Conversely, those in the low category showed limited ability to connect concepts, evaluate arguments, or provide reflective responses. Through this structured assessment, the research was able to capture a clear picture of how the developed media supported the enhancement of students' critical thinking skills across multiple dimensions.

d. Effectiveness Analysis

The effectiveness of the developed interactive learning media was evaluated by measuring the improvement in students' critical thinking skills before and after implementation. This was done through a pre-test and post-test design, using identical instruments administered at different times during the learning process. The improvement in learning outcomes was calculated using the N-gain formula, as presented in Equation (3).

$$\text{N-gain} = \frac{S_{post} - S_{pre}}{S_{maks} - S_{pre}} \qquad (3)$$

Description:
N-gain = gain normality test value
S_{post} = score post-test
S_{pre} = score pre-test
S_{max} = score max

The criteria for assessing the n-gain score can be seen in Table 7.

Table 7. Criteria N-gain [39].

N-gain	Category
n > 0.7	High
0.3 ≤ n ≤ 0.7	Medium
n < 0.3	Low

Data calculation using the Excel Office software 2019 version dan SPSS version 26.

RESULT AND DISCUSSION

This development research was conducted using the ADDIE development model, which consists of five stages: Analysis, Design, Development, Implementation, and Evaluation. Each stage produced several outcomes, including the development of interactive hydrocarbon learning media based on Articulate Storyline integrated with socio-scientific issues (AS-SSI). The results are presented in terms of the validity, practicality, and effectiveness of the developed media.

1. Analysis Stage

The The analysis stage was carried out to identify the needs of both teachers and students in chemistry learning. Data were collected using questionnaires distributed via Google Forms for students and questionnaire sheets for teachers. This stage served as the foundation for determining the appropriate media and materials to be developed.The results of the initial needs analysis from three chemistry teachers and 25 students are presented in Figures 2 and 3.

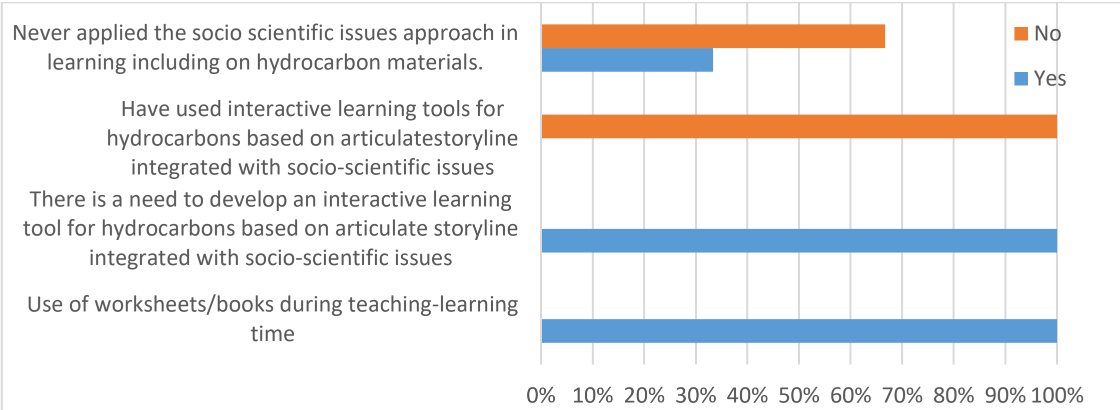


Figure 2. Initial teachers need analysis.

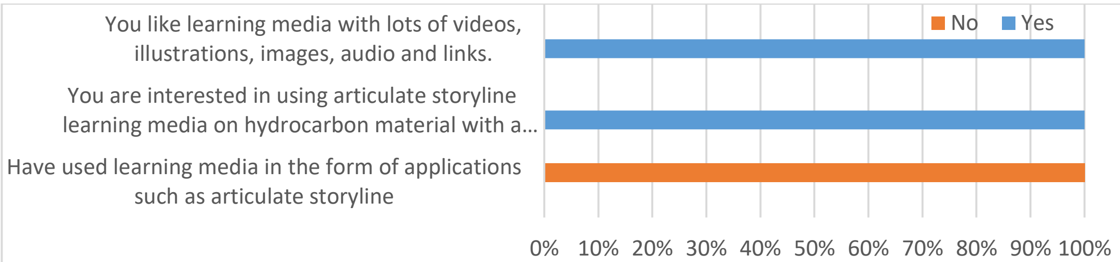


Figure 3. Initial students need analysis.

The teacher responses indicated that printed textbooks are still the primary learning resource, with limited use of electronic-based media. None of the teachers had previously used Articulate Storyline as a learning medium, and the socio-scientific issues (SSI) approach was rarely applied in classroom practice. Teachers also expressed agreement on the need to develop interactive media to improve student engagement and critical thinking.

Similarly, the student responses revealed that they had never used Articulate Storyline as a learning medium but showed strong interest in media containing videos, illustrations, images, audio, and interactive links. These findings confirm the relevance and necessity of developing AS-SSI–based interactive media for hydrocarbon learning.

2. Design Stage

During the design stage, interactive learning media on hydrocarbons were developed along with the supporting research instruments. The outcomes of this stage are presented in Figures 4–7.

Figure 4. Cover media

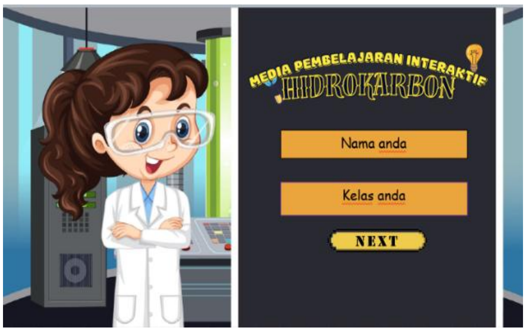


Figure 5. Identity filling

As shown in Figure 4 , the cover page includes several essential elements such as the institutional logo, subject matter and class descriptions, a chemistry laboratory–themed visual, and a login button. The use of laboratory imagery was intended to establish a direct connection with chemistry as the subject of study. In addition, the use of an attractive and professional design was expected to enhance students' motivation and interest in engaging with the learning material.

Figure 5 illustrates the identity/login page, where students are required to input their name and class before accessing the media. This page was designed to create a structured entry point and to provide a positive initial impression, thereby encouraging learners' enthusiasm for exploring the hydrocarbon content integrated with socio-scientific issues (SSI).

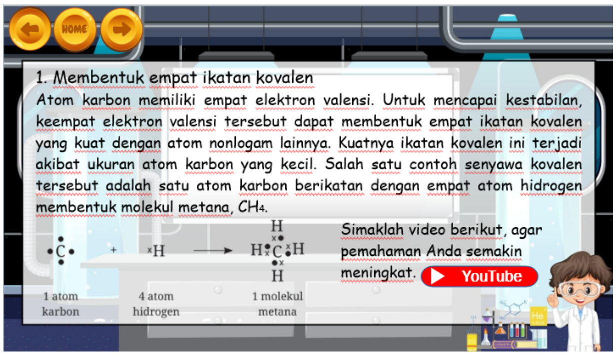


Figure 6. Material.

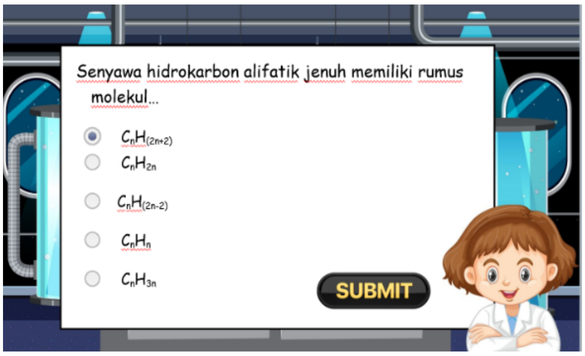


Figure 7. Question.

Figures 6 and 7 display examples of the instructional content and practice questions embedded in the AS-SSI–based learning media. The content covered several key topics, including the uniqueness of carbon atoms, the classification of hydrocarbons, nomenclature, and isomerism. To support independent learning, the material was presented with videos, illustrations, and interactive activities. The inclusion of practice questions was intended to foster student engagement by stimulating active participation and problem-solving related to socio-scientific issues in hydrocarbon chemistry [40].

3. Development Stage

At the development stage, product validation is carried out using AS-SSI-based hydrocarbon interactive learning media. It is done to improve the shortcomings of the interactive learning media developed before testing. After validation, improvements will be made to the interactive learning media developed, after which individual and small group trials will be carried out.

Five validators carried out validity testing to determine the validity and feasibility of hydrocarbon interactive learning media. According to material experts, Table 9 presents the following results of the validator's assessment of interactive learning media.

Table 8. The results of the learning media validation assessment according to the material expert.

Assessment aspect	Validator					Validation score	Description
	I	II	III	IV	V		
Material suitability	25	22	25	20	22	0.89	Valid
Affective impact	10	9	9	10	8	0.90	Valid
Usability	15	13	15	14	12	0.90	Valid

Source: Data processing results.

As shown in Table 8, all assessment aspects—material suitability, affective impact, and usability—fall within the "valid" category. The slightly lower score in material suitability indicates the need for stronger alignment with learning objectives, while higher scores in affective impact and usability suggest that the media was engaging, contextually relevant, and tailored to student needs. These features contributed to enhanced student interest in learning [41]. The results of the validator's assessment of interactive learning media according to media experts are presented in Table 9.

Table 9. The results of the learning media validation assessment according to media experts

Assessment aspect	Validator					Validation score	Description
	I	II	III	IV	V		
Design	30	24	30	25	24	0.86	Valid
Languange	25	23	25	22	20	0.90	Valid
Ilustration	10	9	10	9	8	0.90	Valid
Typography	20	19	20	19	14	0.90	Valid

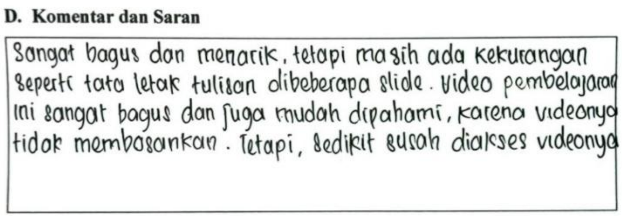
Based on Table 10, the design aspect received a slightly lower score, indicating that improvements were needed to enhance animation quality and attract student attention. In contrast, higher scores were obtained for language, illustration, and typography, which reflects the consistent use of colors, clarity of text, and neat layout. Overall, the media was deemed valid for classroom use [42].

The combined results of material and media expert validation confirm that the interactive learning media is in the "valid" category. This indicates that the product is accurate, pedagogically sound, and suitable for implementation in the classroom. Furthermore, the findings align with prior studies on Articulate Storyline–based learning media, which also reported high validation scores (≥0.90) and concluded that such media were effective for enhancing student engagement and critical thinking skills [43], [44].

4. Trials and Revisions

a. Individual Trial

The individual trial phase was conducted with five students to evaluate the readability, usability, and practicality of the developed interactive learning media. During this stage, students were asked to provide feedback, including suggestions for improvement. One example of a student's comment is presented in Figure 8.


D. Komentar dan Saran

Sangat bagus dan menarik, tetapi masih ada kekurangan seperti tata letak tulisan dibeberapa slide. Video pembelajaran ini sangat bagus dan juga mudah dipahami, karena videonya tidak membosankan. Tetapi, sedikit susah diakses videonya

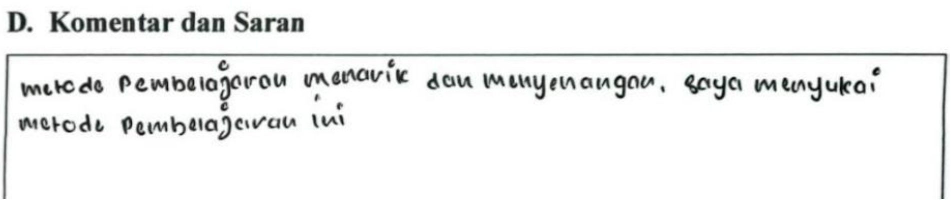
Figure 8. One student's comment

The comments obtained in this phase highlighted the need for minor revisions, particularly in enhancing the clarity of some instructions and improving the navigation buttons. Based on these suggestions, the interactive learning media was revised accordingly. The results of the individual trial indicated that the media was categorized as *very practical*.

b. Small group trial

Following the revisions, a small group trial was conducted with 10 students. At this stage, the students used the revised interactive learning media and provided feedback through questionnaires. The results showed that the media continued to fall within the *very practical* category. Students commented that the media was engaging, easy to use, and effective as a learning resource for hydrocarbon material. An example of student feedback is shown in Figure 9.

The positive responses from both individual and small group trials demonstrate that the interactive learning media was not only valid but also highly practical in supporting classroom learning.


D. Komentar dan Saran

metode pembelajaran menarik dan menyenangkan, saya menyukai metode pembelajaran ini

Figure 9. One student's comment

5. Implementation Stage

At this stage, the AS-SSI-based interactive learning media, which had been validated and revised based on expert input as well as individual and small-group trials, was implemented in limited classroom settings. The implementation focused on testing both the practicality and effectiveness of the developed media.

a. Practicality test

The practicality test was conducted using questionnaires and observation sheets, which included five main instruments: (1) readability questionnaire, (2) learner response questionnaire, (3) teacher response questionnaire, (4) observation sheet of teacher ability to use the media, and (5) observation sheet of classroom implementation.

Table 10. Recapitulation of practicality test results.

Component	Science Class A		Science Class B	
	Score	**Std. Deviation**	**Score**	**Std. Deviation**
Readability	4.43	0.09	4.30	0.15
Learner response	4.45	0.37	4.38	0.42
Teacher response	4.90	0.32	4.90	0.32
Teacher skills	4.61	0.15	4.69	0.12
Implementation of learning	4.55	0.17	4.69	0.15
Average Score	**4.59**	**-**	**4.59**	**-**

Description: 1) very poor; 2) poor; 3) moderate; 4) good; 5) very good.

The results in Table 10 indicate that all components of the practicality test achieved a high average score of 4.59, which falls within the *very practical* category. The highest score was obtained from the teacher response component (4.90 in both classes), suggesting that teachers found the media very easy to use, aligned with instructional needs, and supportive of effective classroom implementation.

The lowest score was observed in the readability component, with values of 4.43 (XII IPA 1) and 4.30 (XII IPA 2). Although these scores still fall within the *good* category, they indicate that a small number of students may have experienced minor difficulties in reading or interpreting the text presented in the media.

Overall, the results demonstrate that the interactive learning media is highly practical, flexible, and easy to use in the teaching and learning process. Both students and teachers consistently confirmed its usefulness and relevance, highlighting its potential as a sustainable learning tool for hydrocarbon topics in chemistry.

b. Effectiveness test

Before the learning activity began, students took a preliminary test to determine their initial understanding of hydrocarbon material prior to using the interactive learning media. After completing the lesson with the developed media, students were given a final test to measure the improvement in their understanding of hydrocarbons and their critical thinking skills. The maximum score obtained was 100. The results of the pre-test and post-test for Science Class A and Science Class B are presented in Table 11.

Table 11. Pre-test, post-test and n-gain results.

Class	Pre-test	Post-test	n-gain
Science A	41.80	86.02	0.78
Science B	40.14	86.94	0.77

The post-test results presented in Table 11 show that scores increased compared to the pre-test results. The average post-test scores of students in both Science Class A and Science Class B are in the high category. This increase demonstrates that learning with the assistance of AS-SSI-based hydrocarbon interactive learning media significantly improved students' critical thinking skills. Thus, the developed media proved effective in supporting the achievement of learning objective.

The n-gain results of students in Science Class A and Science Class B presented in Figure 10 are in the high category. This shows that the consistent use of interactive learning media in each class successfully improved students' post-test results. This finding is reinforced by previous research, which reported that the use of learning media is effective in improving students' critical thinking skills, with an average n-gain score of 0.72, categorized as high [45].

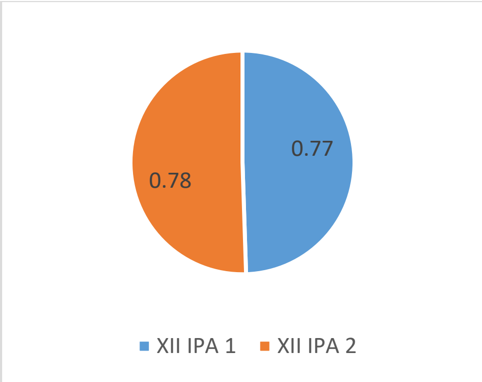


Figure 10. Average post-test n-gain

Table 12. Paired samples test.

Class	Mean	Std. Deviation	Sig. (2-tailed)
Science A	44.22	8.24	0.000
Science B	46.81	8.94	0.000

Based on the data in 12, it can be concluded that there was a significant difference between the two classes after the pre-test and post-test were conducted.

The following presents data on the results of the critical thinking skills test of students in Table 13.

Table 13. Critical thinking skills test results.

Indicators	Science Class A		Science Class B	
	N-gain	Category	N-gain	Category
Interpretation	0.79	High	0.76	High
Analysis	0.71	High	0.77	High
Indicators	**Science Class A**		**Science Class B**	
	N-gain	**Category**	**N-gain**	**Category**
Evaluation	0.77	High	0.73	High
Inference	0,72	High	0.86	High
Explanation	0,80	High	0.83	High
Self-regulation	0,77	High	0.72	High

Table 13 shows that the highest n-gain score in Science Class A was achieved in the explanation indicator, while in Science Class B it was in the inference indicator. The n-gain results in both classes show that the use of interactive learning media was categorized as high, meaning that it was effective in improving students' critical thinking skills.

The resulting interactive learning media was tested for effectiveness through the students' critical thinking skills test. The effectiveness of the interactive learning media was analyzed in two categories, namely based on the overall performance of students and based on individual critical thinking skill indicators.

The developed hydrocarbon interactive learning media was proven to improve students' critical thinking skills. The media presented engaging content with images, audio, and video, and applied the socio-scientific issues approach, enabling students to more easily understand the material and access it anytime.

The improvement in students' critical thinking skills obtained from both classes confirms that the developed learning media was effective. The interactive learning media successfully improved students' abilities across the six Facione indicators—interpretation, analysis, evaluation, inference, explanation, and self-regulation. In addition, it helped achieve learning objectives, encouraged meaningful and applicable learning, and facilitated student interaction with the material through attractive and accessible technology.

These findings are consistent with research using Articulate Storyline 3 learning, which obtained an n-gain value of 0.76, categorized as effective [43]. Similarly, other research on Articulate Storyline-based media demonstrated improvements in learning outcomes, with an n-gain value of 0.70, also categorized as high[46].

The critical thinking skills test was constructed based on Facione's indicators, which were translated into specific question items. According to Facione, the indicators of critical thinking skills include interpretation, analysis, evaluation, inference, explanation, and self-regulation[47]. The n-gain results of students based on these critical thinking ability indicators are presented in Figure 11.

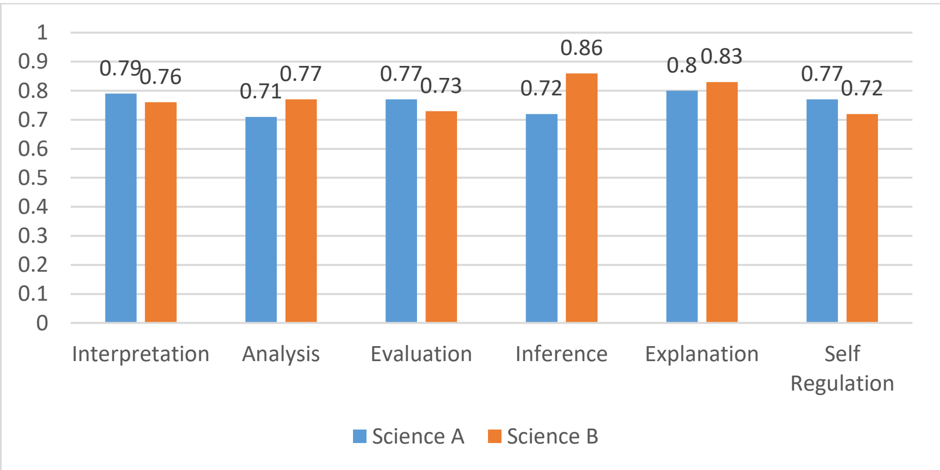


Figure 11. Average n-gain result of each indicator

Based on the n-gain results, the interpretation indicator increased to the high category. During the pre-test, students were unable to classify compounds into groups that affect the human respiratory system and irritate the throat. However, in the post-test, students successfully grouped compounds according to their impacts on the respiratory system and throat. An example of a student's post-test response is shown in Figure 12.

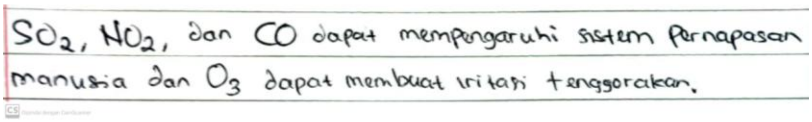

SO_2, NO_2, dan CO dapat mempengaruhi sistem Pernapasan manusia dan O_3 dapat membuat iritasi tenggorokan.

Figure 12. Post-test answer interpretation indicators.

Interpretation refers to the ability to understand and explain the meaning of information or data. This indicator emphasizes how students can summarize the essence of the reading or material they encounter and convey these ideas clearly to others. It tests both deep comprehension and effective communication skills [48].

The analysis indicator also improved to the high category. Students engaged in analysis by examining problems presented in the form of two articles. They were asked to determine the correct answer based on the facts provided. An example of a student's post-test response is shown in Figure 13.

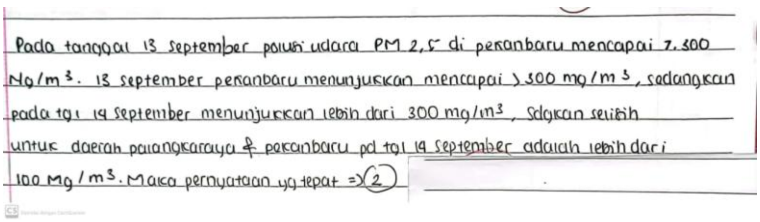

Pada tanggal 13 september polusi udara PM 2,5 di pekanbaru mencapai 7.300 Mg/m³. 13 september pekanbaru menunjukkan mencapai > 300 mg/m³, sedangkan pada tgl 14 september menunjukkan lebih dari 300 mg/m³, sdgkan selisih untuk daerah palangkaraya & pekanbaru pd tgl 14 september adalah lebih dari 100 Mg/m³. Maka pernyataan yg tepat => 2

Figure 13. Post-test answer evaluate indicators.

During the pre-test, one student provided an answer that was not based on the article, showing limited criticality. The response identified characteristics of safe areas for cardiopulmonary patients instead of selecting an area based on the article. However, in the post-test, the student correctly identified the appropriate area using facts from the article. This improvement indicates growth in students' analytical skills, which include distinguishing concepts, taking a stance on claims, and identifying the intent of a conclusion [49].

The n-gain results also showed an increase to the high category. Students were asked to evaluate three statements derived from a data graph and select the statement most consistent with the evidence. An example of a student's post-test response is shown in Figure 14.

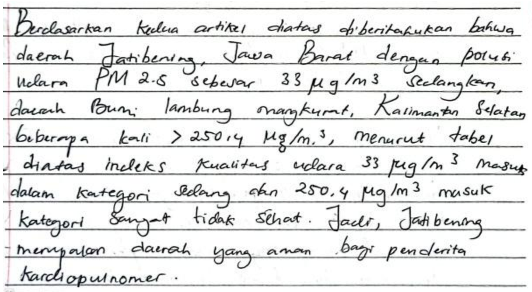


Figure 14. Post-test answer analysis indicators.

During the pre-test, a student incorrectly selected statement number 3, which did not align with the graph, indicating poor data interpretation. In the post-test, the same student chose statement number 2, demonstrating improved ability to read and interpret the graph. This improvement shows that students became capable of evaluating data and drawing rational conclusions [50].

The inference indicator also increased to the high category. Students were asked to explain the contents of a graph and draw logical conclusions. An example of a student's post-test response is presented in Figure 15.

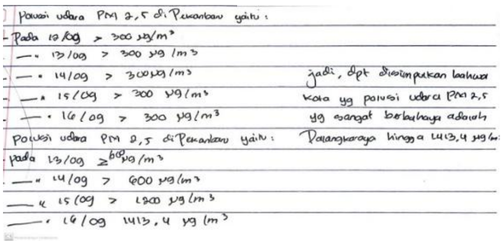


Figure 15. Post-test answer inference indicators.

In the pre-test, a student concluded correctly that cities experiencing air pollution were hazardous but failed to provide supporting explanations from the graph. In the post-test, the same student gave a more complete answer, explaining the data in the graph, drawing conclusions based on it, and answering the question comprehensively. Inference involves the ability to derive implicit meanings, make predictions, or form hypotheses based on evidence, which requires both deductive and inductive reasoning [48].

The explanation indicator also showed a high n-gain value. Students were tasked with selecting the correct response from graph-based data and providing a supporting explanation. An example of a student's post-test response is shown in Figure 16.

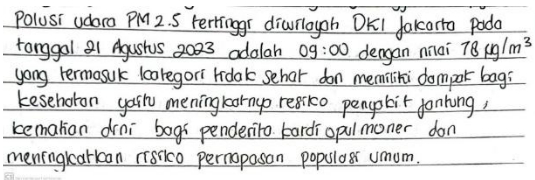
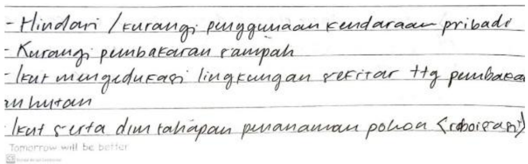


Figure 16. Post-test answer explanation indicators.

During the pre-test, one student provided an incorrect response due to errors in interpreting the graph, reflecting low criticality. By contrast, in the post-test, the student answered correctly and provided a strong, evidence-based explanation aligned with the data. High n-gain values in the explanation indicator indicate that students were able to justify their reasoning with clear explanations and evidence, and relate their conclusions to relevant theories [51], [52].

The self-regulation indicator also improved to the high category. Students were asked to propose solutions to minimize the impact of forest fires on air pollution. An example of a student's post-test response is shown in Figure 17.


- Hindari / kurangi penggunaan kendaraan pribadi
- Kurangi pembakaran sampah
- Ikut mengedukasi lingkungan sekitar ttg pembakaran hutan
- Ikut serta dlm tahapan penanaman pohon (reboisasi)

Tomorrow will be better

Figure 17. Post-test answer self-regulation indicators.

During the pre-test, one student provided a correct but incomplete answer. By the post-test, the response was more complete and demonstrated improved critical thinking skills in self-regulation. This included the ability to organize oneself in problem-solving, monitor one's reasoning, check answers, and seek deeper information. Such improvement highlights students' enhanced ability to control their thought processes when solving problems [53]. To illustrate the overall improvement, Table 14.presents comparative pre-test and post-test response scores.

Table 14. Comparative Pre-Vs. Post-Response.

Indicator	Pre-response		Post-response		Change	
	Science Class A	Science Class B	Science Class A	Science Class B	Science Class A	Science Class B
Interpretation	1.42	1.60	3.45	3.43	+2.03	+1.83
Analysis	1.81	1.83	3.35	3.50	+1.54	+1.67
Evaluate	1.45	1.63	3.42	3.37	+1.97	+1.74
Inference	1.71	1.38	3.35	3.62	+1.64	+2.24
Explanation	1.94	1.63	3.58	3.60	+1.64	+1.97
Self-regulation	1.71	1.60	3.48	3.33	+1.77	+1.73

This study makes a meaningful contribution compared to previous studies by applying a contextual Socio-Scientific Issues (SSI) approach in learning hydrocarbon materials. The integration of SSI deepens students' mastery of chemical concepts and trains them to examine relevant social and environmental issues, such as the negative impact of fossil fuel use on the environment. This approach has been proven to improve critical thinking skills, especially regarding explanation and inference.

As a comparison, previous research has developed SSI-based test instruments for acid-base materials and has proven valid and effective in honing students' scientific explanation skills. Therefore, this study not only supports these findings but also extends the application of SSI to hydrocarbons and provides strong evidence that the integration of SSI can strengthen Facione's indicators, especially in explanation and inference. With this approach, the learning media developed are technologically superior, contextually relevant, and meaningful [54].

6. Evaluation Stage

The evaluation process in this study was carried out through two complementary approaches, namely formative evaluation and summative evaluation. Formative evaluation was conducted during the development stage of the interactive learning media, focusing on continuous product improvement based on feedback from expert validators and initial learner responses. Revisions were made to several aspects, including the accuracy and depth of material content, visual design, ease of navigation, and integration of socio-scientific issues in hydrocarbon topics, ensuring that the media became more relevant to user needs.

In contrast, summative evaluation was implemented after the development stage to assess the final version of the improved media. The purpose of this stage was to verify that the product met the required standards of validity, practicality, and effectiveness, thereby ensuring that the interactive learning media were ready for broader and sustainable application in chemistry learning.

CONCLUSION

Based on the results of this study, the development of AS-SSI–based interactive learning media for hydrocarbons was declared feasible and effective. The media achieved a validity score of 0.89 from material experts and 0.88 from media experts, placing it in the valid category. Practicality testing also showed consistently high results, with an average score of 4.59 in both Science A and Science B, based on assessments from readability questionnaires, student and teacher response questionnaires, classroom implementation observation sheets, and teacher ability observation sheets. Effectiveness testing indicated a significant improvement in students' critical thinking skills, with n-gain values of 0.77 (Science A) and 0.78 (Science B), both categorized as *high*. These findings demonstrate that the developed media is not only valid and practical but also effective in enhancing students' critical thinking and engagement with hydrocarbon material.Furthermore, the use of interactive learning media facilitated reciprocal interactions between teachers and students, creating a more student-centered and engaging classroom environment. The findings suggest that AS-SSI–based media can serve as a valuable tool to improve both the quality of learning and students' enthusiasm for chemistry. For future development, the media can be further enhanced by integrating audio features, 3D visualizations, and HTML5-based conversion through premium Web2APK applications. This would ensure broader accessibility, long-term usability without expiration limits, and greater immersion in the learning process

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