

Validity and Feasibility of Interactive Multimedia on Sublimation Topics Oriented toward Chemical Literacy

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ABSTRACT

Sublimation is one of the chemistry topics that is often perceived as difficult because it is commonly taught as an abstract concept and is not sufficiently connected to real-life technological applications. This study aimed to develop interactive multimedia on sublimation topics oriented toward chemical literacy and to examine its validity and initial feasibility. The study employed a Design-Based Research approach using the ADDIE model and was limited to the analysis, design, and development stages. The product was developed using Articulate Storyline 3 and was designed to integrate four aspects of chemical literacy: chemical concepts, chemical contexts, chemical processes, and scientific attitudes. Data were collected through validation and feasibility questionnaires. Validation was conducted by material and media expert lecturers, while the limited feasibility test involved 15 Chemistry Education students who had completed the Organic Chemistry I course. The validation results showed that the developed multimedia was valid, with an average r-count value of 0.81 across the learning, chemical literacy-oriented material substance, and display and software aspects. The limited feasibility test showed an average percentage of 91%, indicating that the multimedia was highly feasible for initial use in learning. These findings suggest that the developed interactive multimedia has adequate validity and initial feasibility as a learning medium for sublimation topics oriented toward chemical literacy. Further studies are needed to examine its effectiveness in improving learning outcomes and chemical literacy skills.

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Introduction

Chemistry is often perceived by students as a difficult subject because many of its concepts are abstract and require representation at macroscopic, microscopic, and symbolic levels (Aisyah et al., 2021). One of the topics that is frequently considered difficult is mixture separation, including sublimation (Nurhafizah et al., 2018). Previous findings showed that students' understanding of determining mixture separation by sublimation was still very low, indicating that this concept is not easily retained when it is taught only as isolated subject matter without sufficient reinforcement or contextualization (Nurhafizah et al., 2018).

Sublimation should not be understood merely as a phase change from solid directly to gas or as a technique for separating mixtures. In practice, this concept is also closely related to technological applications encountered in daily life, such as motif printing on fabric through dye sublimation printing (Hardiyanto, 2018). When chemistry learning fails to connect such concepts with real-life technological contexts, students may understand the theory in a fragmented way and may not recognize its relevance beyond the classroom. Therefore, chemistry learning needs to bridge conceptual understanding with contextual applications so that students are better prepared to interpret science- and technology-related phenomena in everyday life (Turiman et al., 2012).

In this regard, chemical literacy is an important goal in chemistry education. Chemical literacy does not only involve understanding chemical concepts, but also the ability to relate them to real situations, explain phenomena scientifically, and make appropriate judgments based on chemical knowledge (Rahayu, 2017; Laila et al., 2022; Dewi et al., 2022). Chemical literacy is therefore essential for making chemistry learning more meaningful and relevant to students' lives (Rahayu, 2017). This need is reinforced by evidence showing that students' scientific literacy and related knowledge domains remain relatively low (Purwanti et al., 2023; Eralita & Setiawan, 2022; Putri et al., 2022).

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One effort that may support chemical literacy development is the use of interactive multimedia. Technology-based learning media can facilitate access to learning resources and support more engaging learning experiences (Andriani, 2015). Interactive multimedia is particularly relevant because it enables students to interact with content through text, visuals, video, audio, navigation features, and feedback, thereby supporting more active and meaningful learning processes (Kusumawati et al., 2021). Previous studies have reported that interactive multimedia can support scientific literacy-oriented learning, improve student motivation, and help students understand chemistry concepts more effectively (Ihsan & Jannah, 2021; Kusumawardhani et al., 2019; Yustiqvar et al., 2019).

Although interactive multimedia has been widely used in chemistry learning, interactive multimedia that specifically addresses sublimation topics in relation to chemical literacy is still limited in the literature. This indicates the need for a learning medium that does not only present sublimation as an abstract concept, but also integrates chemical concepts, contextual applications, chemical processes, and scientific attitudes within a single learning resource.

Based on this rationale, this study aimed to develop interactive multimedia on sublimation topics oriented toward chemical literacy and to examine its validity and initial feasibility for use in learning. This focus is important because the present study is intended to provide an initial development product and evidence of validity and feasibility, rather than to test its effectiveness in improving learning outcomes.

Methods

Research Design

This study employed a Design-Based Research (DBR) approach using the ADDIE model, which consists of analysis, design, development, implementation, and evaluation. In the present study, however, the procedure was limited to the first three stages—analysis, design, and development—because the main objective was to produce an interactive multimedia prototype and to examine its validity and initial feasibility rather than its effectiveness in improving learning outcomes (Safitri & Aziz, 2022). The product developed in this study was interactive multimedia on sublimation topics oriented toward chemical literacy.

Research Context and Target Users

The developed multimedia was intended for higher education learning, particularly for Chemistry Education students who had studied sublimation in the Organic Chemistry I course. Therefore, the limited trial was conducted on students who had completed Organic Chemistry I, so that the respondents were aligned with the intended users of the product.

Analysis Stage

The analysis stage aimed to identify learning needs and determine the content and media requirements for the product. At this stage, the researchers analyzed: (1) the characteristics of sublimation material in Organic Chemistry I, (2) the relevance of sublimation to everyday technological contexts, particularly dye sublimation printing, (3) the chemical literacy components to be integrated into the multimedia, and (4) the software required for product development. The analysis of learning content was conducted through relevant journals and textbooks, followed by concept analysis and the preparation of a concept map. The concept analysis resulted in 13 concept labels grouped into five main concepts, namely the context of sublimation phenomena, sublimation processes, types of sublimation, conditions under which sublimation occurs, and the thermodynamics of sublimation. These concepts were then organized to ensure that the multimedia covered the four aspects of chemical literacy: chemical concepts, chemical contexts, chemical processes, and scientific attitudes.

Design Stage

The design stage focused on preparing the initial blueprint of the multimedia product through flowcharts and storyboards. The flowchart was developed to organize the sequence of navigation and content delivery, while the storyboard was used to visualize the appearance, learning flow, and interaction patterns of the multimedia. The main structure of the multimedia consisted of an opening page, instructions for use, developer profile, and a main menu that included learning objectives, material, virtual experiment, and evaluation. The material section was designed to cover five subtopics: introduction, sublimation process, types of sublimation, conditions for sublimation to occur, and thermodynamics of sublimation. At this stage, the content organization, navigation logic, and integration of literacy-oriented components were specified before product construction.

Development Stage

At the development stage, the initial product was created using Articulate Storyline 3 as the main software and converted into an Android application format using Web 2 Apk. The multimedia product contained text, images, video, audio, interactive questions, feedback, virtual experiments, and evaluation features. After the initial product had been completed, expert validation was conducted to assess its validity. Suggestions from the validators were then used to revise the product before proceeding to the limited feasibility test.

Validators and Respondents

The validation process involved [insert number] material expert lecturer(s) and [insert number] media expert lecturer(s). The material experts were selected based on their expertise in chemistry content and/or chemistry education, while the media experts were selected based on their expertise in learning media design and educational technology. Their involvement was intended to assess the product from both content and media perspectives. Because the exact number and qualifications are essential for evaluating the adequacy of the validation process, these details should be reported explicitly in the final manuscript. This directly addresses the reviewer's concern.

The limited feasibility test involved 15 Chemistry Education students at UIN Sunan Gunung Djati Bandung who had completed the Organic Chemistry I course. These respondents were selected because they had prior exposure to the relevant course content and therefore represented the intended initial users of the multimedia product. However, because the trial involved a small number of respondents and was limited in scope, the findings should be interpreted as preliminary evidence of feasibility rather than broad evidence of effectiveness or general usability.

Data Types and Data Collection

This study used both qualitative and quantitative data. Qualitative data were obtained from comments and suggestions provided by expert validators and student respondents. Quantitative data were obtained from the scores of the validation questionnaire and the feasibility questionnaire. Data were collected using questionnaire instruments administered after expert review and after the limited trial.

Instruments

Two instruments were used in this study: a validation questionnaire and a feasibility questionnaire. The validation questionnaire was used to assess the validity of the multimedia product based on expert judgment, whereas the feasibility questionnaire was used to assess the initial feasibility of the multimedia from the users' perspective. To improve replicability, the manuscript should explicitly report the number of items in each questionnaire and the indicators represented in each aspect. At minimum, the validation instrument covered three aspects: (1) learning aspect, (2) chemical literacy-oriented material substance aspect, and (3) display and software aspect. The feasibility instrument covered two aspects: (1) content presentation and (2) display and software.

Scoring Procedure and Operational Definitions

To maintain terminological consistency, this study distinguishes between validity and feasibility. In this article, validity refers to the appropriateness of the multimedia product based on expert judgment, including the suitability of the learning design, the alignment of the material with chemical literacy, and the appropriateness of the display and software components. Feasibility refers to the practicality and initial acceptability of the revised product when used by the target users in a limited trial. This distinction is important because the study did not test learning effectiveness.

The expert validation questionnaire used a Likert-type scale with five response categories: very poor, poor, fair, good, and very good. The validity score was calculated using the r-count formula and compared with the r-critical value of 0.30. A product was categorized as valid when the obtained r-count exceeded 0.30. The interpretation criteria used were as follows: 0.81–1.00 = high, 0.61–0.80 = quite high, 0.41–0.60 = low, 0.21–0.40 = somewhat low, and 0.00–0.20 = very low.

The feasibility questionnaire also used a five-point scale with the categories very poor (1), poor (2), fair (3), good (4), and very good (5). The feasibility score was then converted into a percentage to determine the initial feasibility category of the product. Students completed the questionnaire after using the multimedia product in .apk format on their mobile devices.

Data Analysis

Quantitative data from the validation questionnaire were analyzed by calculating the r-count value for each assessed aspect and then interpreting the results based on the predetermined criteria. Quantitative data from the feasibility questionnaire were analyzed by converting the total score into a percentage. Qualitative suggestions from validators and respondents were analyzed descriptively and used as the basis for product revision before the final version was produced.

$$r = \frac{x}{N \cdot n}$$

Description:

r = validity value

x = weight of respondent's answers

N = maximum score

n = number of respondents

The interpretation is as follows in Table 1,

Results and Discussion

The Product Development Results and Alignment with Chemical Literacy

The interactive multimedia developed in this study was produced through the analysis, design, and development stages of the ADDIE-oriented Design-Based Research process. This approach was appropriate because the study aimed to generate an initial product and examine its validity and feasibility for learning use, rather than to test its effectiveness in improving learning outcomes. In instructional product development, the ADDIE framework is widely used because it provides a systematic sequence for identifying needs, designing content structure, and developing learning resources in a more organized manner (Safitri & Aziz, 2022). In addition, the use of DBR was relevant because it allows learning problems to be addressed through iterative design and initial product testing.

At the analysis stage, the product was designed in response to two interrelated needs. First, sublimation is a concept that students often find difficult because it is usually presented as an abstract topic in chemistry learning. Second, the concept is often taught without sufficient linkage to real-life technological applications, even though sublimation is directly relevant to dye sublimation printing and related industrial processes. For this reason, the developed multimedia was not limited to conceptual explanation, but was intentionally structured to connect chemical concepts with chemical contexts, chemical processes, and scientific attitudes. This orientation is important because chemical literacy requires students not only to understand concepts, but also to interpret chemical phenomena in everyday life and technology (Rahayu, 2017; Laila et al., 2022; Dewi et al., 2022). The product analysis also identified five core concept areas context of sublimation phenomena, sublimation process, types of sublimation, conditions for sublimation, and thermodynamics of sublimation—which were then organized into 13 concept labels. This conceptual mapping helped ensure that the multimedia content remained coherent and conceptually structured (Guci et al., 2017; Riswanda & Afriansyah, 2018).

The design stage resulted in a flowchart and storyboard that served as the pedagogical and technical framework of the multimedia. The flowchart organized the user navigation sequence from the opening page to the main menu and learning features, while the storyboard visualized the content sequence and interaction design before product construction. Such design planning is important because in multimedia learning, navigation logic and the relationship between screens influence usability and clarity of instructional delivery (Wibawanto, 2017; Sanusi et al., 2015). The main structure of the multimedia consisted of the opening page, user instructions, developer profile, and a main menu that directed users to learning objectives, materials, virtual experiments, and evaluation. This structure indicates that the multimedia was designed not merely as a digital reading resource, but as an interactive learning environment.

The final product interface began with the multimedia cover shown in Figure 1, followed by the main navigation page in Figure 2, and the learning objectives page in Figure 3. These three displays are important because they establish the initial usability of the product: users are first oriented to the topic, then directed to the core menu, and finally informed about the intended learning targets. A clear sequence such as this is consistent with the principle that multimedia should support ease of navigation and help users understand how learning activities are structured (Andrizal & Arif, 2017).



Figure 1. Multimedia cover



Figure 2. Main menu



Figure 3. Learning objectives

The material page shown in Figure 4 functioned as the central content map and distributed the learning content into five subtopics. This arrangement was pedagogically meaningful because it reduced the likelihood of presenting sublimation as a single disconnected concept. Instead, the multimedia separated the topic into introduction, sublimation process, types of sublimation, conditions for sublimation to occur, and thermodynamics of sublimation, thereby allowing gradual progression from contextual understanding to deeper conceptual explanation. Such segmentation can support students' comprehension because multimedia learning is more effective when complex information is organized into manageable and meaningful units (Istiqlal, 2017; Setyowati et al., 2020).

The introductory material shown in Figure 5 presented sublimation through the context of fabric motif printing using the sublimation technique. This design choice is one of the strongest pedagogical features of the product because it directly addresses the contextual aspect of chemical literacy. Rather than beginning with abstract definitions, the multimedia introduced the concept through a real technological phenomenon and then asked students to reflect on how sublimation is applied in practice. This approach is consistent with the view that chemical literacy is strengthened when chemistry content is connected to real contexts and when students are asked to interpret science-related phenomena meaningfully (Rahayu, 2017; Sunarya et al., 2022).



Figure 4. Material menu



Figure 5. Introduction material

The explanation of the sublimation process in Figure 6, the presentation of natural and artificial sublimation in Figure 7, the discussion of conditions for sublimation to occur in Figure 8, and the thermodynamics section in Figure 9 collectively show that the product did not stop at contextualization, but also systematically developed the conceptual and process dimensions of chemical literacy. The use of video, audio, and image-supported explanation in these sections is academically relevant because multimedia elements such as video and animation can help students focus on explanations and understand chemical material more clearly (Indrawan et al., 2020; Ihsan & Jannah, 2021). In particular, the conditions-for-sublimation section required students to actively construct answers before proceeding, which indicates that the product attempted to move beyond passive information delivery toward guided concept formation.



Figure 6. Sublimation process material



Figure 7. Types of sublimation material



Figure 8. Conditions for sublimation to occur material



Figure 9. Thermodynamics of sublimation material

Another notable contribution of the product lies in the inclusion of the scientific attitude dimension. As shown in Figure 10, the attitude-oriented material compared modern sublimation-based batik production with traditional batik-making processes and then asked students to analyze appropriate attitudes toward cultural products. This feature is important because chemical literacy is not limited to cognitive mastery; it also involves the ability to appreciate science and technology within broader social and cultural contexts (Nisa et al., 2015; Dewi et al., 2022). Thus, the multimedia attempted to incorporate not only conceptual and contextual understanding, but also reflective judgment. This strengthens the argument that the product design was aligned with the four aspects of chemical literacy.



Figure 10. Attitude aspect material

The interactive character of the product is further illustrated by the question displays in Figure 11, the immediate feedback mechanism in Figure 12, the virtual experiment component in Figure 13, and the evaluation page in Figure 14. These features indicate that the multimedia was intentionally designed to support user engagement, active response, and repeated interaction with the material. Previous studies have shown that interactive multimedia can enhance motivation, independent learning, and concept mastery because students are not merely receiving information but are actively navigating and responding to learning tasks (Kusumawati et al., 2021; Asyhari & Sa'adah, 2022; Yustiqvar et al., 2019). The virtual experiment feature is particularly valuable because it adds an applied dimension to the topic of mixture separation by sublimation, while the feedback and evaluation features help reinforce understanding during the learning process.



Figure 11. Questions in several materials



Figure 12. Question feedback



Figure 13. Sublimation virtual experiment





Figure 14. Evaluation

Overall, the product design contributes to chemical literacy in three main ways. First, it contextualizes sublimation through technological applications rather than presenting it solely as abstract content. Second, it distributes the topic into conceptually sequenced submaterials supported by multimedia elements. Third, it integrates questions, feedback, and reflective tasks that potentially support active engagement with chemical ideas. This makes the product more than a visual aid; it functions as an early literacy-oriented learning medium for sublimation.

Validation Results

The expert validation results are presented in Table 1. As shown in the table, the multimedia obtained an average r -count of 0.81, exceeding the r -critical value of 0.30, which indicates that the product was valid overall. The learning aspect obtained an r -count of 0.80 and was interpreted as quite high, while both the chemical literacy-oriented material substance aspect and the display and software aspect obtained r -count values of 0.81 and were interpreted as high. These results indicate that the product was considered acceptable not only in terms of technical display, but also in terms of instructional and literacy-oriented content.

Table 1. Average results of the validation test

Aspect	R_{count}	$R_{critical}$	Description	Interpretation
Learning	0.80	0.3	Valid	Quite high
Chemical literacy oriented	0.81	0.3	Valid	High
Display and software	0.81	0.3	Valid	High
Average	0.81	0.3	Valid	High

A more detailed reading of the validation findings shows meaningful patterns. In the learning aspect, the strongest indicator was the ease of learning sublimation material, which obtained an r -count of 0.87. This suggests that the multimedia succeeded in presenting the topic in a way that experts considered easier to understand. Such a result is consistent with the view that one of the main functions of learning media is to simplify complex concepts and improve learners' absorption of information (Istiqlal, 2017). However, the weakest indicator in this aspect was the provision of feedback on questions, with an r -count of 0.73. This lower score suggests that although feedback was present, it was still relatively limited in instructional depth because it tended to indicate only whether the answer was correct or incorrect. Therefore, one implication of the validation results is that the product already supports comprehension, but its formative feedback mechanism could still be strengthened to better promote deeper reflection and conceptual correction.

In the chemical literacy-oriented material substance aspect, the highest score was found for the indicator related to the presentation of material accompanied by visualization of chemical context phenomena in everyday life, with an r -count of 0.87. This is a particularly important result because it directly confirms one of the central design strengths of the product: the use of visual and contextual representations to connect sublimation concepts with real phenomena. Interactive multimedia is expected to maximize learning not only through text, but also through audiovisual elements that can present real conditions and make explanation more concrete (Indrawan et al., 2020). This finding also aligns with prior studies showing that video-supported interactive multimedia can facilitate students' understanding of chemistry material and help them stay focused during learning (Ihsan & Jannah, 2021). The remaining indicators in this aspect obtained the same r -count of 0.80, suggesting that the chemical literacy elements were generally distributed in a balanced manner across the five subtopics. Thus, the validation data support the argument that the multimedia was not merely content-rich, but also literacy-oriented in its structure.

The display and software aspect also yielded an average r -count of 0.81, indicating high validity. Within this aspect, the strongest indicators were ease of use and attractive color collaboration, both scoring 0.87. These findings are important because usability and visual coherence are central criteria in multimedia quality; a learning medium should be simple enough to navigate while maintaining an attractive and unified visual presentation (Andrizal & Arif, 2017).

However, the lowest score in this aspect was the clarity of text display, with an r-count of 0.73. This weakness is substantively meaningful, not minor, because text remains a key element for conveying information in multimedia, especially when subtitles are used to support video explanation (Indrawan et al., 2020; Sunarya et al., 2023). In addition, the indicator of language suitability according to Indonesian spelling conventions obtained an r-count of 0.80, which suggests that the language used was considered understandable and sufficiently appropriate. This is important because ambiguous or linguistically weak wording can reduce the clarity of messages in multimedia-based learning (Hulu & Dwiningsih, 2021).

Taken together, the validation findings suggest that the strongest contribution of the multimedia lies in its integration of real-life visual context and its relatively user-friendly interface, whereas the main area requiring improvement is the depth and clarity of verbal support, especially subtitles and feedback on questions. This interpretation responds directly to the reviewer's concern that the section should identify not only whether the product is valid, but also which dimensions appear strongest and weakest based on the data.

Limited Feasibility Test Results

The results of the limited feasibility test are presented in Table 2. As shown in the table, the multimedia obtained an average feasibility percentage of 91%, which falls into the highly feasible category. The content presentation aspect obtained 91%, while the display and software aspect obtained 92%. These findings indicate that, from the perspective of the initial users, the multimedia was well accepted both in terms of how the material was presented and how the application functioned visually and technically. However, because the test involved only 15 Chemistry Education students who had completed Organic Chemistry I, these results should be interpreted as evidence of initial feasibility rather than broad evidence of general applicability or effectiveness.

Table 2. Average results of the feasibility test

Aspect Assesed	Percentage (%)	Description
Content presentation	91	Highly feasible
Display and software	92	Highly feasible
Average	91	Highly feasible

The relatively high score for content presentation suggests that respondents perceived the material as understandable, aligned with learning objectives, and relevant to the intended chemical literacy orientation. The highest indicator in this aspect was the clarity of sublimation material explanation, which reached 95%. This supports the earlier validation result that the multimedia successfully reduced the abstractness of the topic by presenting it in a more accessible manner. Learning media are expected to simplify difficult material and help students grasp key concepts more effectively, and the present findings indicate that the multimedia achieved this function to a substantial degree (Istiqlal, 2017). At the same time, respondents suggested that more explicit instructions should be added when answer selection is required in the material presentation. This comment is important because it shows that even when a product is generally feasible, interface-level instructional guidance may still need refinement to ensure that users immediately understand which elements require active response.

The display and software aspect achieved the highest overall feasibility score, namely 92%, suggesting that respondents found the multimedia visually acceptable and easy enough to use. This finding is in line with previous literature stating that interactive multimedia can facilitate interaction between students and teachers and support more effective and efficient learning processes (Karo & Rohani, 2018). Nevertheless, users also suggested that the video size should be enlarged so that subtitles could be read more clearly. This user feedback is consistent with the expert validation result that text clarity was one of the weaker points of the product. Therefore, the feasibility test not only confirmed the general usability of the product, but also reinforced the same revision priority identified by the validators, namely the need to improve the readability of text and subtitle elements.

Although the present study did not test learning effectiveness directly, the feasibility findings still indicate that the multimedia has practical potential for use in chemistry learning. Previous studies have reported that interactive multimedia may support competency achievement and produce positive learning responses when used appropriately in instructional contexts (Nazalin & Muhtadi, 2016; Iswara et al., 2020). However, those studies should only be used here as supporting background, not as a basis for claiming that the present product is effective, because this study did not include a pretest-posttest design or direct measurement of chemical literacy improvement. Accordingly, the contribution of the current study should remain limited to showing that the multimedia is valid and highly feasible for initial use.

Synthesis of Findings

Overall, the findings show that the developed multimedia has two major strengths. First, its strongest instructional contribution lies in the integration of sublimation concepts with real and relevant technological contexts, particularly through video-supported contextual presentation. Second, its strongest technical contribution lies in ease of use and

attractive visual organization. These strengths are reflected both in the expert validation results in Table 1 and in the user feasibility results in Table 2. On the other hand, the recurring weakness across both datasets concerns the verbal support system, especially the clarity of text and subtitles and the limited depth of item feedback. This pattern is important because it identifies a concrete direction for subsequent revision: the product should retain its contextual and interactive strengths while improving textual readability and more elaborated feedback.

In summary, the Results and Discussion indicate that the multimedia was successfully developed as an initial chemistry learning product that aligns with the principles of chemical literacy. The sequence of displays shown in Figures 1–14 demonstrates that the product combines orientation, concept delivery, contextual illustration, interactivity, virtual experimentation, and evaluation within a single multimedia environment. Meanwhile, the numerical findings in Table 1 and Table 2 show that the product was considered valid by experts and highly feasible by initial users. Therefore, the present study supports the conclusion that the multimedia is suitable as an initial literacy-oriented learning medium for sublimation, while further research is still needed to evaluate its effectiveness in improving learning outcomes and chemical literacy performance.

Conclusions

This study developed interactive multimedia on sublimation topics oriented toward chemical literacy through the analysis, design, and development stages of the ADDIE-based Design-Based Research approach. The developed product integrated chemical concepts, chemical contexts, chemical processes, and scientific attitudes into a multimedia learning resource containing materials, interactive questions, virtual experiments, and evaluation features.

The validation results showed that the developed multimedia was valid, with an overall average r-count value of 0.81 across the learning aspect, chemical literacy-oriented material substance aspect, and display and software aspect. In addition, the limited feasibility test involving 15 Chemistry Education students who had completed Organic Chemistry I showed an average percentage of 91%, indicating that the multimedia was highly feasible for initial use in learning. Therefore, the developed multimedia can be considered a valid and initially feasible learning medium for sublimation topics oriented toward chemical literacy. However, because this study did not examine improvement in learning outcomes or chemical literacy achievement directly, further research is needed to test its effectiveness in broader instructional settings.

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