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Research Article

Augmented Reality–Based Flashcard Media: A Study of Foster Senior High School Students' Critical Thinking Skills on Atomic Models

Riska Anggraini[1], Leni Marlina[1,*], Sardianto Markos Siahaan[1]
[1] Master Program of Physics Education, Universitas Sriwijaya, Sumatera Selatan, Indonesia

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ABSTRACT

Purpose of the study: This study aimed to develop augmented reality–based flashcard learning media for teaching atomic models and to examine its validity, practicality, and effectiveness in fostering senior high school students' critical thinking skills.

Methodology: This study employed a research and development approach using the Rowntree model, comprising planning, development, and evaluation stages, with formative evaluation adapted from Tessmer. Data were collected through expert validation sheets, practicality questionnaires, and critical thinking skills tests. Data analysis included CVR and CVI for validity, descriptive analysis for practicality, and N-gain analysis for effectiveness.

Main Findings: The results indicated that the augmented reality–based flashcard media achieved excellent content validity, with S-CVI/Ave and S-CVI/UA values of 1.00, categorized as very valid. The media was considered practical, with mean practicality scores of 3.9 in the one-to-one evaluation and 4.1 in the small group evaluation. Additionally, the field test showed an improvement in students' critical thinking skills, with an N-gain value of 0.56, indicating moderate effectiveness.

Novelty/Originality of this study: The novelty of this study lies in integrating augmented reality technology into flashcard-based learning media to foster students' critical thinking skills in learning atomic models. Unlike previous studies that mainly emphasize visualization or conceptual understanding, this research focuses on developing higher-order thinking skills through interactive, mobile-supported learning media to address abstract physics concepts.

Corresponding Author:
Leni Marlina,
Master Program of Physics Education, Universitas Sriwijaya,
Lunjuk Jaya Road, Palembang, Sumatera Selatan, 30139, Indonesia
Email: leni_marlina@fkip.unsri.ac.id

1. INTRODUCTION

The rapid advancement of technology has encouraged teachers to implement creative and innovative learning strategies to achieve effective learning objectives [1]. The ease of accessing information without limitations of space and time has made technology inseparable from educational activities, particularly for teachers who play a central role in achieving learning goals [2]-[4]. Effective learning requires adequate facilities and teacher creativity, one of which is the use of appropriate learning media as intermediaries to minimize communication failures, focus students' attention, and create optimal and enjoyable learning environments [5]-

[7]. Several studies have reported that digital-based learning can improve students' learning outcomes compared to conventional learning approaches [8]-[10].

In recent years, technology has become an essential supporting tool in education to assist teachers in achieving targeted learning outcomes [11]. One technological innovation widely applied in education is Augmented Reality (AR), which integrates two-dimensional and three-dimensional virtual objects into real-world environments and displays them in real time [12]. AR-based learning media can present various forms of content, including text, audio, music, and video, making learning more interactive by bridging real and virtual environments [13], [14]. The use of AR through Android-based smartphones enables flexible and accessible learning [15], [16]. Flashcards assisted by AR have been shown to enhance students' memory retention, provide practical learning experiences, and support long-term information recall [17]-[19]. Furthermore, AR-based flashcard media have the potential to support the development of students' critical thinking skills through interactive learning activities [20]-[22].

Critical thinking is one of the essential skills required in the era of the Industrial Revolution 4.0 and the 21st century, as it enables students to analyze problems systematically and make reasoned decisions [23]-[25]. Critical thinking skills develop through learning processes that actively engage students in higher-order thinking activities [26]-[28]. Current educational paradigms emphasize student-centered learning, in which students actively construct their own knowledge, with greater emphasis on learning processes rather than solely on outcomes [29]. In science education, critical thinking skills are crucial to enable students to analyze and evaluate natural phenomena and develop deep conceptual understanding rather than relying on memorization [30], [31]. Therefore, learning media should be designed to explicitly support critical thinking skills in science learning contexts [32]-[34].

Physics, as part of science education, includes abstract concepts that are difficult for students to understand, particularly atomic model material taught at the senior high school level. Science learning requires students to be directly involved in observing and systematically investigating natural phenomena [35], [36]. However, atomic models involve microscopic phenomena that cannot be directly observed, making the material abstract and challenging for students [37]. Previous studies have indicated that atomic model material requires visualization and animation to facilitate students' conceptual understanding [38]. Without appropriate learning media, students often experience difficulties in understanding atomic structures, which can hinder the development of their critical thinking skills [39]-[41].

Based on a needs analysis conducted at Senior High School 3 Tanjung Raja, 66.1% of students experienced difficulties in learning atomic model material, indicating that their critical thinking skills were not yet well developed. In addition, 76.7% of teachers expressed interest in and the need for augmented reality based flashcard learning media. Therefore, this study focuses on developing augmented reality based flashcard learning media to train high school students' critical thinking skills on atomic model material.

2. RESEARCH METHOD

This study used a research and development (R&D) design based on the Rowntree model, which involves planning, development, and evaluation phases [42]. Formative evaluation was adopted from Tessmer's model, including self-evaluation, expert review, one-to-one evaluation, small group evaluation, and field testing to refine and validate the learning media [43]. The aim was to develop augmented reality–based flashcard media that are valid, practical, and effective for training critical thinking skills in atomic model learning.

The research was conducted at Senior High School 3 Tanjung Raja. Subjects included 29 Grade XII students in the 2025/2026 academic year. In the formative evaluation, three students participated in the one-to-one evaluation, nine in the small group evaluation, and all 29 students participated in the field test. Validation of the media and instruments was conducted by five experts: one material expert, two media experts, and two experts in critical thinking assessment.

Table 1. Distribution of Research Subjects Across Developmental Evaluation Stages

Evaluation Stage	Participants
One-to-one Evaluation	3 students
Small Group Evaluation	9 students
Field Test	29 students
Validators	5 experts (1 material, 2 media, 2 critical thinking)

Three main instruments were used to collect data: Validation sheets, used to assess the feasibility of the learning content, media design, and conformity with critical thinking indicators [44]. Practicality questionnaires, Likert-scale questionnaires administered to students to measure media usability. Critical thinking tests, pretest and posttest instruments developed based on Ennis's critical thinking indicators [45].

Table 2. Research Instruments and Their Functions

Instrument	Purpose
Validation sheets	Measure content, media, and indicator validity
Practicality questionnaires	Assess usability and practicality
Critical thinking tests	Measure pretest–posttest learning improvement

Content validity was analyzed using the Content Validity Ratio (CVR) and Content Validity Index (CVI) based on expert judgments. A CVR greater than zero indicates item validity, and a CVI of 1.00 indicates overall content validity. Practicality data from one-to-one and small group questionnaires were analyzed descriptively by calculating mean scores. A higher mean score indicates greater practicality in terms of ease of use and student satisfaction. Effectiveness in improving critical thinking skills was measured using normalized gain (N-gain), calculated from pretest and posttest scores. Interpretation followed Hake's criteria for categorizing gain levels.

3. RESULTS AND DISCUSSION

3.1 Content Validity of the Augmented Reality–Based Flashcard Media

The validity of the augmented reality–based flashcard media was evaluated through expert review involving five validators, consisting of one material expert, two media experts, and two experts in critical thinking assessment. Content validity was analyzed using the Content Validity Ratio (CVR) and Content Validity Index (CVI) as proposed by Polit and Beck (2006).

Table 3. Content Validity Analysis of Each Aspect

No	Aspect	CVI	Category
1	Media Design Feasibility	1.00	Very Valid
2	Learning Media Feasibility	1.00	Very Valid
3	Critical Thinking Skills Feasibility	1.00	Very Valid
	Overall Average	1.00	Very Valid

The analysis results showed that all assessment items obtained positive CVR values, indicating that more than half of the validators agreed on the relevance of each item. Furthermore, the overall content validity index reached an S-CVI/Ave value of 1.00 and an S-CVI/UA value of 1.00, which categorizes the developed media as very valid. These results indicate that the content, media design, and critical thinking indicators embedded in the flashcard media are appropriate and aligned with learning objectives.

The high validity confirms that the integration of augmented reality into flashcard media provides accurate scientific representation and supports conceptual understanding of atomic models, which are abstract and difficult to visualize [37] [38].

3.2 Practicality of the Augmented Reality-Based Flashcard Media

The practicality of the developed media was evaluated through one-to-one and small group evaluations involving students. Practicality data were collected using a Likert-scale questionnaire focusing on ease of use, clarity of instructions, attractiveness, and usefulness of the media.

Table 4. Practicality Evaluation Result

Evaluation Stage	Number of Students	Mean Score	Category
One-to-One Evaluation	3	3.9	Practical
Small Group Evaluation	9	4.1	Practical

In the one-to-one evaluation involving three students with different ability levels, the average practicality score was 3.9, categorized as practical. Meanwhile, the small group evaluation involving nine students resulted in a higher average score of 4.1, also categorized as practical. These findings indicate that students were able to use the augmented reality–based flashcards independently without significant difficulty. The portability of the flashcards combined with smartphone-based AR technology enabled flexible learning anytime and anywhere, supporting student-centered learning environments [6], [19], [46].

The positive responses suggest that AR-based flashcards are not only technologically appealing but also functionally practical in classroom learning, consistent with previous studies emphasizing the usability of AR-assisted learning media [5], [7].

3.3 Effectiveness in Training Students' Critical Thinking Skills

The effectiveness of the developed media was measured through pretest and posttest results assessing students' critical thinking skills based on Ennis's indicators, including providing simple explanations, building basic skills, drawing conclusions, giving further explanations, and setting strategies and tactics [47].

Table 5. Pretest and Posttest Results of Critical Thinking Skills

Test	Mean Score
Pretest	35.0
Posttest	71.8
N-Gain	0.56
Category	Moderate

The results showed an improvement in students' critical thinking performance after using the augmented reality–based flashcard media. The normalized gain (N-gain) analysis yielded an average score of 0.56, which falls within the moderate category. This indicates that the media is effective in enhancing students' critical thinking skills. The improvement can be attributed to the interactive visualization provided by augmented reality, which allows students to actively explore atomic models rather than passively memorizing concepts. This aligns with constructivist learning principles that emphasize active engagement and cognitive processing in developing higher-order thinking skills [29], [30], [48]. The findings of this study demonstrate that augmented reality–based flashcard media can function as a valid, practical, and effective learning tool for training students' critical thinking skills in atomic model learning. The results suggest that the integration of interactive visualization with concise learning prompts supports students in analyzing abstract atomic structures, which are traditionally difficult to conceptualize. This finding is consistent with recent studies reporting that AR-based instruction significantly enhances critical thinking performance in physics education by promoting active engagement and deeper cognitive processing [49].

The novelty of this research lies in the pedagogical integration of augmented reality technology with flashcard media explicitly designed to foster higher-order thinking skills, rather than merely supporting conceptual understanding or student motivation. While previous AR studies in physics education primarily emphasize visualization and engagement, this study highlights the role of structured AR-flashcard interactions in stimulating analysis, evaluation, and reasoning processes. Recent systematic reviews also emphasize that AR learning environments are most effective when aligned with clear cognitive objectives, particularly for abstract physics concepts [50]. From an educational perspective, the findings imply that AR-enhanced flashcards can be strategically implemented in physics classrooms not only as visualization tools but also as instructional media to support the development of critical thinking skills. The portability and ease of use of flashcards combined with AR features allow flexible integration into classroom activities, independent learning, or enrichment tasks. This is supported by recent research indicating that AR-based learning environments, when combined with inquiry-oriented approaches, facilitate student interaction and critical exploration of scientific phenomena [51].

Despite these promising results, this study has several limitations. The absence of a control group limits the strength of causal conclusions regarding the effectiveness of the developed media. Additionally, the study was conducted in a single school context, which may restrict the generalizability of the findings. Practical implementation of AR-based learning media also depends on technological infrastructure and teacher readiness, challenges that have been identified in recent AR implementation studies [50]. Future research is therefore recommended to employ experimental or quasi-experimental designs with control groups to provide stronger evidence of effectiveness. Further studies could also explore the application of AR-based flashcards across different physics topics and educational levels to assess broader applicability. Additionally, investigating the integration of AR-flashcard media with other pedagogical models, such as guided inquiry or problem-based learning, may offer deeper insights into its potential to enhance critical thinking and other higher-order cognitive skills in science education. The novelty of this research lies in the systematic embedding of critical thinking skills into portable flashcard-based augmented reality media, enabling students to engage in higher-order thinking processes while learning abstract physics concepts. This approach provides an innovative solution to the challenges of teaching atomic models, which are inherently microscopic and abstract. Overall, the findings support the use of augmented reality–based flashcards as an effective learning medium to foster critical thinking skills and enhance meaningful learning in physics education at the senior high school level.

4. CONCLUSION

This study successfully developed an augmented reality–based flashcard learning media for atomic model material that is valid, practical, and effective in training senior high school students' critical thinking skills. The content validity results showed excellent validity based on CVR and CVI analysis. Practicality evaluation indicated positive student responses, demonstrating that the media is easy to use and beneficial in

learning activities. Furthermore, the effectiveness test revealed a moderate N-gain score, indicating an improvement in students' critical thinking skills after using the developed media. Therefore, augmented reality–based flashcards can be used as an alternative learning media to support student-centered and higher-order thinking–oriented physics instruction.

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AUTHOR CONTRIBUTIONS

Conceptualization, Methodology, Validation, Investigation, Resources, Data Curation, Writing-Original Draft Preparation, Supervision, Writing-Review & Editing: Riska Anggraini. Formal Analysis, Visualization, Project Administration: Leni Marlina and Sardianto Markos Siahaan.

CONFLICTS OF INTEREST

The author(s) declare no conflict of interest.

USE OF ARTIFICIAL INTELLIGENCE (AI)-ASSISTED TECHNOLOGY

The authors declare that no artificial intelligence (AI) tools were used in the generation, analysis, or writing of this manuscript. All aspects of the research, including data collection, interpretation, and manuscript preparation, were carried out entirely by the authors without the assistance of AI-based technologies.

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