Augmented Reality-Based Flashcards to Improve Senior High School Students' Visual Intelligence in Chemistry Learning

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ARTICLE INFO	ABSTRACT
Keywords: Flashcard Augmented Reality Visual Intelligence Covalent Bond	**Purpose –** Developing augmented reality-based flashcards to improve students' visual intelligence on covalent bonds in a valid, practical, and effective manner. **Methodology –** This research employed a Research and Development (R&D) approach, utilising the ADDIE (Analyse, Design, Development, Implementation, and Evaluation) model. Data collection was conducted using validation sheets, student response questionnaires, student activity observation sheets, and visual intelligence pre-test and post-test sheets. Validity was assessed using expert judgment and analyzed descriptively using the median value. Practicality was analyzed descriptively, while effectiveness was examined using SPSS, including paired-samples t-tests and N-Gain. **Findings –** The study results indicated that the augmented reality-based flashcards for improving students' visual intelligence in the submaterial of covalent bonds are deemed feasible for application based on expert judgment, with a median validation score of 4, which falls within the valid category. The augmented reality-based flashcards were declared practical, with an average score of 90.04% in the convenient category. The media was also found to be effective, as the paired-samples t-test yielded a significance value of 0.000 (<0.05), indicating a significant difference between the students' pre-test and post-test scores, with an N-Gain of 0.79, categorised as high in both pre-test and post-test results. **Contribution –** This study contributes to chemistry education by integrating augmented reality technology into flashcards developed using visual intelligence indicators as a learning medium that can feasibly improve students' visual intelligence in the sub-material of covalent bonds.

INTRODUCTION

Chemistry is a science that deals with materials, characteristics, structures, changes, and the reactions associated with them. Subjects of scientific investigation are quite invisible and abstract, making it difficult to understand the concept (Widarti et al., 2024). Chemical bonds are a topic whose properties are challenging to understand when explained without reference to the submicroscopic level (Febriani & Aini, 2021). The submicroscopic level refers to phenomena in chemistry that are not directly visible; when these components are acknowledged as valid and existent, this acceptance is grounded in the atomic theory of matter (Ahmar et al., 2020).

Students' understanding of concepts such as covalent bonds can be influenced by how they are presented. Therefore, students need visual representations that illustrate how atoms share electrons and form bonds. The ability to visualize this is at the core of visual intelligence (Nurhidayati, 2020), which is an important aspect in understanding abstract chemical concepts that often involve submicroscopic phenomena. Based on preliminary research conducted at SMA Al Falah Ketintang Surabaya in class XI MIPA, 88.4% of students reported finding it difficult to imagine the process of covalent bond formation. In addition, 46.2% of students found it quite difficult to represent the Lewis structure in the sub-area of covalent bonds. This was also confirmed in an interview with a chemistry teacher at SMA Al Falah Ketintang Surabaya, who stated that students had difficulty understanding Lewis structures in the covalent bonds subtopic. Covalent bonds explain the process of bond formation between atoms, both between identical and different atoms, through the sharing of electron pairs. The process of covalent bond formation is challenging for students to grasp because of its abstract nature (Rizqullah & Lutfi, 2021). A comprehensive understanding of covalent bonds provides students with a foundation for understanding the following submaterials, including molecular shape in the area of chemical bonds.

Interviews with a chemistry teacher at SMA Al Falah Ketintang Surabaya reveal that instructional resources on covalent bonding are limited to blackboards, PowerPoint presentations, and educational videos. The learning media used are not yet effective enough to help students visualize the concept of covalent bonding. The limitations of the learning media used to illustrate the concept of covalent bonding make it very difficult for students to visualize the three-dimensional structure at the particle level and represent it in two dimensions (Sari & Dwiningsih, 2025).

The gap in the above description underscores the importance of improving students' visual intelligence to help them understand abstract chemical concepts. Visual intelligence is the ability of students to imagine things, conceptualize, recognize patterns, and solve problems in visual form (Rohmah et al., 2021). Based on the context of submolecular covalent bonds, visualization enables learners to form mental images of, for example, molecular structures and invisible particle interactions. The conceptual aspect helps learners understand fundamental principles, such as the octet or duplet rule, through visual representations. Searching for patterns enables learners to recognize regularities, such as in electron configuration or the tendency of atoms to bond. Visual abilities in information processing can help students solve problems, for example, when drawing Lewis structures (Danial et al., 2024).

Students can better understand abstract concepts when they use visual learning media. A visual learning medium that may be employed is flashcards (Izzati & Kamaludin, 2024). Flashcards are a practical learning tool that feature images, symbols, and text on small cards to facilitate visualization for learners (Utami et al., 2021). One limitation of flashcards is that they can only display two-dimensional visualizations (Izzati & Kamaludin, 2024). To overcome the limitations of flashcards, this visual learning medium can be integrated as a supporting medium using augmented reality (AR) technology.

The use of technology, such as augmented reality, in educational settings has been shown to improve students' comprehension of abstract concepts and their engagement in learning (Dwiningsih et al., 2025; Chiu et al., 2024; Wong et al., 2021). By combining data from various digital sources with what is visible in the

physical environment, users can experience augmented reality. This technology adds virtual objects to the world around us (Arena et al., 2022). Augmented reality is a technology that displays two- and three-dimensional virtual items in real time, seamlessly integrating them with the real world, enabling users to interact with the visuals as if they were part of the real world (Waskito et al., 2024). Three-dimensional features in augmented reality can support the visualization of covalent bonds.

As many as 92.3% of grade XI MIPA students at SMA Al Falah Ketintang Surabaya have never been exposed to or used augmented reality-based learning media in classroom learning. Therefore, to overcome this problem, augmented reality-based flashcards were developed to improve students' visual intelligence in the sub-topic of covalent bonds. Previous studies have shown that augmented reality-based interactive learning media are demonstrably effective in improving students' visual intelligence in the field of molecular chemistry (Sari & Dwiningsih, 2025). Based on previous research, augmented reality flashcards might significantly improve the learning experience by illustrating abstractions of chemical bonds (R. Setiawan & Harahap, 2024) and chemical compound nomenclature (Mutma'inna et al., 2024), making them more tangible and easier to understand.

This research highlights a limited number of studies focused on developing augmented reality-based learning media to improve students' visual intelligence, particularly through the integration of augmented reality into flashcard media. In addition, previous studies focused on advancing augmented reality-based media to enhance visual intelligence in covalent bond materials are still relatively rare, even though these materials also exhibit high levels of abstraction and require visualization skills. This study fills a gap in previous studies by developing a visual learning medium in the form of augmented reality-based flashcards that focus on students' visual intelligence in the sub-topic of covalent bonds, which remains relatively rare. Based on these research gaps, this study aims to develop appropriate augmented reality-based flashcard media on covalent bond material intended to improve students' visual intelligence.

The novelty of this research lies in the design of flashcards integrated with augmented reality technology, which are designed based on visual intelligence indicators, namely imagination, conceptualization, pattern recognition, and problem solving, and their application to covalent bond material, which has a high level of abstraction. The research question posted in this study is to assess the feasibility of augmented reality-based flashcards as a medium for improving students' visual intelligence in the sub-topic of covalent bonds. The research hypothesis is that augmented reality-based flashcards meet the feasibility criteria, namely validity, practicality, and effectiveness as a learning medium capable of improving students' visual intelligence. This study contributes to the scientific literature by expanding the study of technology-based chemistry learning by developing augmented reality-based flashcards specifically designed to improve students' visual intelligence in covalent bonding material, thereby fostering a pedagogical approach that strengthens visual abilities in chemistry learning.
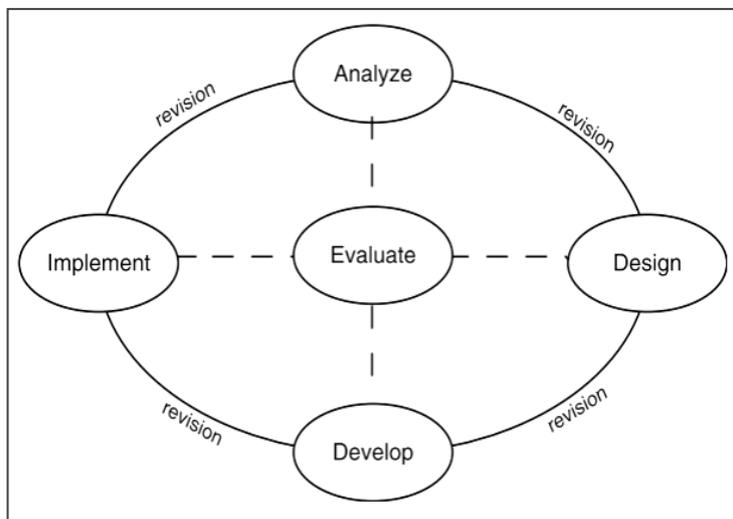
METHODOLOGY

Research Design

The Research and Development (R&D) approach used in this study is a process or series aimed at developing new products or improving existing ones (Judijanto et al., 2024). The research design is based on the ADDIE model (Analyze, Design, Develop, Implement, and Evaluate). Based on Figure 1, the ADDIE design model was chosen because it provides a structured, systematic framework that guides the development process through sequential stages and allows evaluation and refinement of each stage before moving on to the next, ensuring continuous improvement (Spatioti et al., 2022).

The first phase began with an analysis of problems and needs in chemistry teaching in schools, conducted through questionnaires and interviews. The design phase involved creating learning media using Canva and Assemble Edu, as well as designing research tools. The development phase took place in several steps, including improving augmented reality-based flashcards and creating a first draft. The next step is validation

by subject matter experts, media experts, and chemistry teachers. If the initial draft is deemed invalid, it must be revised and revalidated. If the initial draft is deemed valid, the implementation phase can proceed immediately. Data on the practicality and effectiveness of the developed media were collected during the implementation phase, including tests using augmented reality-based flashcards, pre- and post-tests, response questionnaires, and observation sheets of student activities. The next step was data analysis. The evaluation phase in ADDIE was carried out in each phase from start to finish.

Figure 1. The ADDIE Concept (Suprapto et al., 2021)

Using a one-group pretest-posttest methodology, this study employed a quasi-experimental design with a single-subject group. This design was used throughout the ADDIE development model's implementation phase. The One Group Pretest-Posttest was used to measure changes in students' abilities before and after the treatment (Sukarelawan et al., 2024) using augmented reality-based flashcard learning media. This design was selected due to its suitability for preliminary product feasibility testing in R&D studies, rather than for casual generalization.

Participant

This study involved three validators, namely an expert on the media and the topic, a lecturer in the program of chemistry education, and a chemistry teacher at SMA Al Falah Ketintang Surabaya, to determine the validity of the developed product. The study's target group consisted of 20 11th-grade MIPA students at SMA Al Falah Ketintang Surabaya, selected through purposive sampling. These students had learned about the fundamentals of elemental stability and covalent bonds in their chemistry class, making them suitable for testing the developed product. The 11th-grade students at Al Falah Ketintang High School in Surabaya were the subjects of the study, with varying initial abilities and levels of visual intelligence, as identified through a pre-test conducted before the treatment.

Data Collection

The study employed methods for collecting data, including questionnaires, interviews, observation, and tests. Data collection was carried out using several research instruments, including validation sheets, observation sheets for student activities, student response questionnaires, and pre-test and post-test sheets of students' visual intelligence. The development of the instrument's items is based on indicators that are relevant, specific, and can present the results to be measured in a targeted manner (Belcher & Claus, 2025), as shown in Table 1 below.

Table 1. Research instruments

Instrument	Purpose	Indicators	Example Item	Scale
Media validation sheets	To determine the AR-based flashcard's content and construct validity	Suitability, accuracy, clarity (Lambert & Newman, 2023)	In the AR feature, 3D animations of covalent bond formation can help students understand covalent bonding.	Likert 1-5
Student response questionnaire	To determine student response and media practicality	Convenience, interest (Uliyandari et al., 2021)	I easily understand the material on covalent bonds taught using AR-based flashcards.	Dichotomous (Yes/No)
Student activity observation sheet	To examine the contribution of student activities and practicality	Activity, involvement (A. Setiawan et al., 2020)	Students open the flashcards showing Lewis symbols and Lewis structures, and scan the CH_4 molecule marker.	Checklist (Yes/No)
Pre-test – Post-test	To examine the effectiveness of the medium used	Sub-material on covalent bonds based on visual intelligence aspects (Iswaji & Dwiningsih, 2025)	Analyze the process of covalent bond formation in H_2O compounds.	Score 0-100

Data Analysis

The collected data were subsequently analyzed to assess the validity, practicality, and effectiveness of augmented reality-based flashcards both quantitatively and descriptively. The validity data obtained were analyzed using a Likert scale, as shown in Table 2 below.

Table 2. Likert Scale (Riduwan, 2018)

Score	Category
5	Very valid
4	Valid
3	Fairly valid
2	Less valid
1	Not valid

This study employed content validity and construct validity. The validity of the augmented reality-based flashcard was assessed through content and construct validity using expert judgment. The validators' scores were analyzed descriptively, using the median to identify the central tendency of the expert evaluations. The product was considered valid if the median score was ≥ 4. The median is the central value of an ordered data set. The median is not affected by values that are very different or extreme (outliers) in a data set (Creswell & Guetterman, 2019). If one or more validators give scores far above or below the majority, the median will not be affected. The validity of AR-based flashcards is assessed using these data. Therefore, the median was used solely as a descriptive measure to summarize expert judgments, not as a statistical validity test.

The validity of the study instruments was assessed by expert judgment and analyzed using median values. The reliability of the research instruments, such as the student response questionnaire and visual intelligence test sheet, was evaluated using Cronbach's alpha coefficient, according to the criteria outlined in Table 3 below.

Table 3. Cronbach's Alpha value (Jugessur, 2022)

Cronbach's Alpha (α)	Category
$\alpha \geq 0.90$	Excellent
$0.70 \leq \alpha < 0.90$	Good
$0.60 \leq \alpha < 0.70$	Acceptable
$0.50 \leq \alpha < 0.60$	Poor
$\alpha < 0.50$	Unacceptable

The results from the student response questionnaire will be analyzed using the Guttman scale, with criteria detailed in Table 4 below.

Table 4. Guttman Scale

Response	Criteria	Score
Positive	Yes	1
	No	0
Negative	Yes	0
	No	1

To determine the percentage of student response questionnaires, the following formula is applied.

$$Practicality\ (\%) = \frac{\sum score\ for\ each\ statement}{\sum respondents} \times 100\%$$

The data obtained from the student activity observation sheets were analyzed using descriptive statistics, with the average percentage calculated using the following formula.

$$Practicality\ (\%) = \frac{\sum students'\ emerging\ activities}{\sum overall\ student\ activities} \times 100\%$$

The practicality percentages from student response questionnaires and student activity observation sheets are interpreted according to the criteria presented in Table 5 below.

Table 5. Interpretation Results of Practicality of (Riduwan, 2018)

Percentage (%)	Category
81 – 100	Highly practical
61 – 80	Practical
41 – 60	Fairly practical
21 – 40	Not practical
0 – 20	Highly Impractical

Data from pre- and post-tests on students' visual intelligence regarding covalent bonds were analyzed using paired-samples t-tests and the N-gain test. A paired-samples t-test was used to assess differences between pre- and post-test outcomes (Rizqullah & Lutfi, 2021), and the N-Gain test was used to assess the extent of the treatment effect. A hypothesis test was performed using the criteria for the paired-samples t-test. If the significance value is less than 0.05 (< 0.05), H_0 (no significant difference across the mean values of the pre-test and the post-test) is rejected, and H_a (significant difference across the mean values of the pre-test and the post-test) is accepted. The augmented reality flashcards are adequate. The pre-test and post-test data were subsequently analyzed using N-Gain, with the N-Gain values interpreted as follows.

Table 6. Interpretation of N-Gain Value (Hake, 1998)

Value	Criteria
g ≥ 0.7	High
0.3 ≤ g < 0.7	Medium
g < 0.3	Low

The interview data includes qualitative data obtained in this study. The analysis of this data employed the interactive approach proposed by Miles et al. (2014), namely data reduction, data presentation, and conclusion drawing or data verification. The data obtained from the interviews with chemistry teachers will be reduced to focus on information that is important and relevant to the study (Mezmir, 2020). Furthermore, the reduced data will then be presented in the form of descriptions, flows, or so on. The final stage of Miles and Huberman's interactive model analysis is to conclude or verify the data, which is checked against field facts (Asipi et al., 2022).

FINDINGS

Augmented reality-based flashcard media is considered feasible if it meets three criteria: validity, practicality, and effectiveness (Lukman et al., 2023). This study method follows the ADDIE model, encompassing the steps of analysis, design, development, implementation, and evaluation, as described below.

Analyze

The objective of the analysis phase is to identify the educational requirements inside the classroom. During the pre-research activity, a questionnaire and interviews were conducted at SMA Al Falah Ketintang Surabaya. Data collection was conducted using a questionnaire distributed to 11th-grade science students and interviews with chemistry teachers at SMA Al Falah Ketintang Surabaya.

Table 7. Results of Pre-research

Learning Aspect	Responses	
	Difficult (%)	Easy (%)
Visualizing the process of covalent bonding	88.4	11.6
Visual understanding of Lewis structures	46.2	53.8

Based on Table 7, this preliminary study found that 88.4% of students reported it was not easy to visualize the process of covalent bond formation. A total of 46.2% had difficulty understanding the formation of Lewis structures in covalent bonds. The findings align with the interview results with chemistry teachers, indicating that students have difficulty describing Lewis structures in covalent bonds.

The classroom learning media used to teach covalent bonds are still limited and ineffective at visualizing the concept. On the other hand, covalent bonds are abstract concepts that require visualization to be fully understood by students. The analysis conducted shows that the absence of visual learning media in the teaching process hinders students' ability to comprehend and clearly visualize the concept of covalent bonds. Therefore, visual media in the form of flashcards were developed to provide realistic visualizations through augmented reality technology, helping students visualize concepts and improve their visual intelligence.

Design

The design stage is all about developing a product, such as an augmented reality-based flashcard learning medium, and creating a rough draft of the design. The design was created by assembling various media materials for media development, namely compiling learning objectives and teaching modules, and compiling research instruments, including validation sheets, student activity observation sheets, student response questionnaires, and pretest-posttest sheets. The software used to design the augmented reality-based flashcard

learning medium is determined at this stage. Flashcards are created using Canva, which supports 2D media. Augmented reality technology is developed using Assemblr Edu software, which supports three-dimensional visualization of covalent bond sub-material. Storyboard creation is carried out at this stage, with a preliminary design for the media.

Figure 2. Double-sided Display on Flashcard Cover

On the first card, the front is the flashcard cover, and the back contains the learning objectives for the sub-topic of covalent bonds. The cover page includes the sub-material title and columns for the students' names and classes.

Figure 3. Core Material Display on Flashcard

Flashcards designed in Canva will be integrated with augmented reality technology by adding markers to the back of flashcards created in Assemblr Edu. This section presents sub-material on covalent bonds, including definitions, Lewis symbols and structures, free and bonded electron pairs, and types of covalent bonds.

The material presented on the flashcards supports the visualization of covalent bonds in two dimensions. Two-dimensional visualization is insufficient to depict the abstract concept of covalent bonds at the submicroscopic level, so a three-dimensional visualization is presented via augmented reality, allowing students to scan and interact with it in real time on the back of flashcards.

Figure 4. Display on Augmented Reality Feature

Development

The augmented reality-based flashcard media that has been designed will proceed to the validation stage. To determine whether the developed product is valid, a validation stage is used. The validity test was conducted by three validators: two lecturers from the chemistry education study program at the State University of Surabaya, serving as subject-matter and media experts, and a chemistry teacher practitioner at SMA Al Falah Ketintang Surabaya.

Data validity was collected using a validation sheet, a research instrument designed to assess validity, including content and construct validity. Content validity refers to the suitability of the content to the curriculum, the correctness of the concepts, the suitability of the media to the material, and alignment with visual intelligence indicators. In construct validity, the aspects assessed include the ease of use of the media, text readability, visual features and appearance, language use, and the benefits of augmented reality-based flashcard media for visual intelligence. The results of content and construct validation, based on expert assessment by three validators, are presented in Figures 5 and 6.
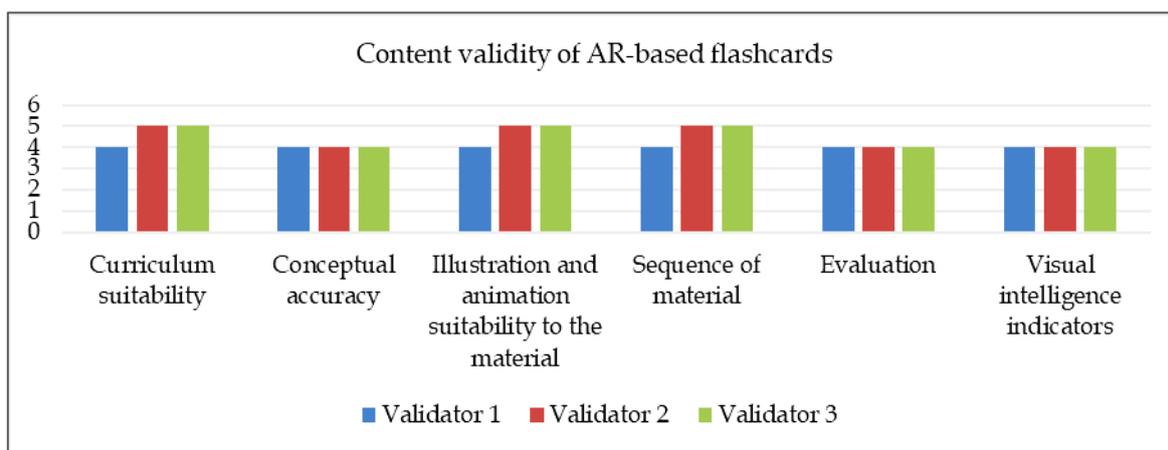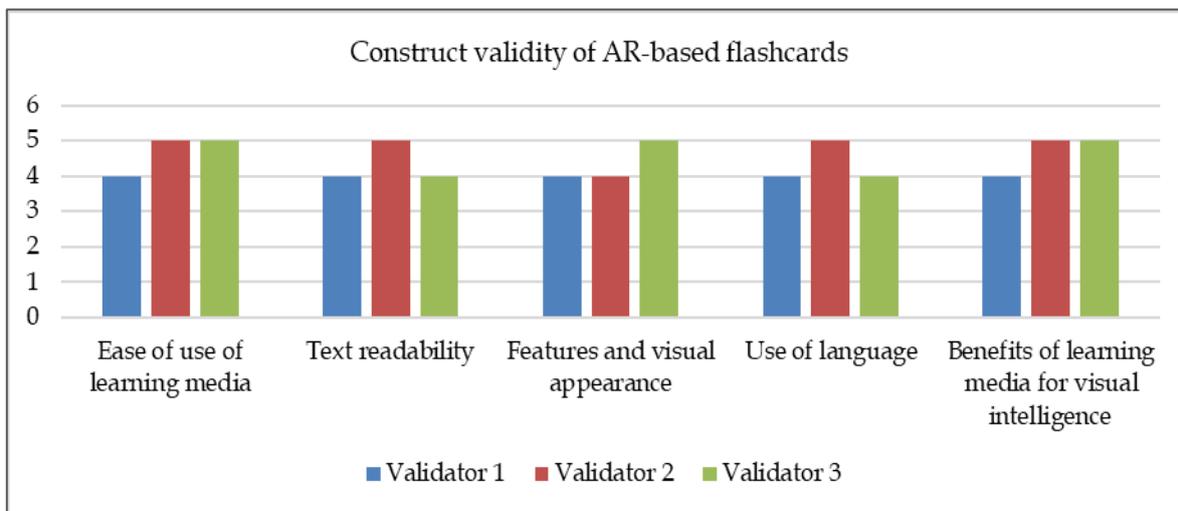

Figure 5. Content Validity of AR-Based Flashcard Diagram

Figure 5 shows that content validity was determined through expert assessment by three validators across the following aspects: curriculum suitability, conceptual accuracy, suitability of illustrations and animations, material sequence, evaluation, and visual intelligence indicators. Overall, the diagram shows that the three validators gave high scores (scores ≥ 4) for each aspect. These results indicate that augmented reality-based

flashcards are conceptually accurate, aligned with the curriculum, and suitable for improving visual intelligence in learning about covalent bonds.

Figure 6. Construct Validity of AR-Based Flashcard Diagram

Figure 6 shows that all aspects of the validity of augmented reality-based flashcards received high scores (≥ 4) from the three validators. These aspects include the ease of use of augmented reality-based flashcards, text readability, visual features and appearance, language, and benefits for visual intelligence. This signifies that the flashcard media developed align with the intended construction and are suitable as learning media that help improve visual intelligence. The validation results from the three validators were then analyzed descriptively using median values and displayed in Table 8 below.

Table 8. Results of Media Validity

Validity Aspect	Indicator	Median	Category
Content	Curriculum suitability	5	Very valid
	Conceptual accuracy	4	Valid
	Illustration and animation suitability for the material	5	Very valid
	Sequence of material	5	Very valid
	Evaluation	4	Valid
	Visual intelligence indicators	4	Valid
Construct	Ease of use of learning media	5	Very valid
	Text readability	4	Valid
	Features and visual appearance	4	Valid
	Use of language	4	Valid
	Benefits of learning media for visual intelligence	5	Very valid

The study's findings reveal that the generated augmented reality flashcard media has a median validity score of 4 in the "Valid" category, as shown in Table 5. This means that the content of the augmented reality-based flashcard media is appropriate for learning about covalent bonds and indicators of visual intelligence, and that the media's simplicity of use, appearance, presentation, and language are appropriate. The augmented reality-based flashcards were deemed acceptable for usage as a learning medium to improve students' visual intelligence in the subject matter of covalent bonds.

In addition, the research instruments used in this study were tested for validity through expert assessment and analyzed using median scores before implementation, as presented in Table 9.

Table 9. Results of Instrument Research Validity

Research Instrument	Median	Category
Questionnaires of student response	4	Valid
Test Sheets	5	Very Valid

Based on Table 9, the student response questionnaire instrument obtained a median validity score of 4 in the "Valid" category, and the pretest-posttest test sheet obtained a median validity score of 5 in the "Very Valid" category. This indicates that the instrument is valid for research purposes. The instrument's reliability was assessed using Cronbach's Alpha, as shown in Table 10 below.

Table 10. Reliability Results of the Research Instrument

Research Instrument	Cronbach's Alpha	N of Items	Category
Questionnaires of student response	0,744	13	Good
Test Sheets	0,648	7	Acceptable

Based on the reliability test results, a Cronbach's Alpha value of 0.744 was obtained with a "Good" category for the student response questionnaire, indicating that the items in the instrument were consistent and produced stable measurements (Jugessur, 2022). On the visual intelligence test sheet, a Cronbach's Alpha value of 0.676 was obtained, which falls within the "Acceptable" range, indicating that the reliability of the student response questionnaire is acceptable, given the limited number of test items and the varying knowledge of the covalent bond sub-material being tested (Taber, 2018). Thus, both instruments can be declared reliable and suitable for data collection.

Implementation

During the implementation stage, a limited trial was conducted in class XI of SMA Al Falah Ketintang Surabaya with 20 students. The limited trial was conducted after the developed media and research instruments were declared valid. Data collection during the limited trial stage was conducted through student response questionnaires and pretest-posttest visual intelligence test sheets. This step is intended to ascertain the practicality and effectiveness of the developed product. Practicality was assessed through student response questionnaires and observation sheets of student activities during the media trial. The practicality data is shown in Figure 7 below.
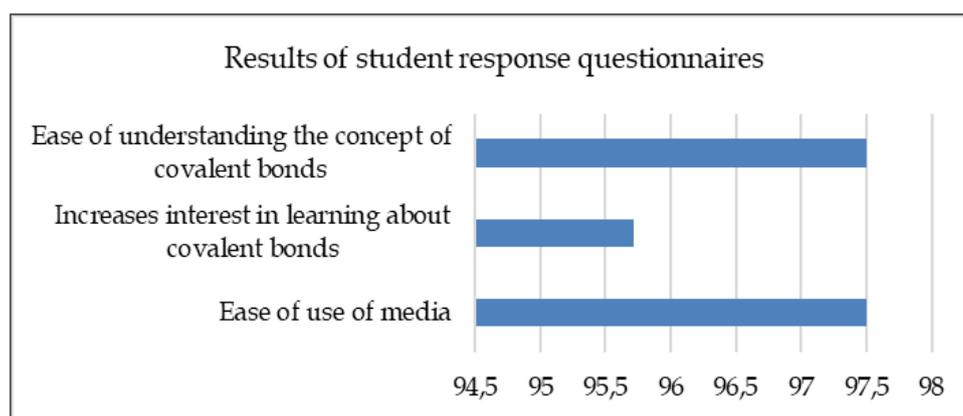
Figure 7. Results of Student Response Questionnaire Diagram

Augmented reality-based flashcards are deemed practical if they achieve a criterion of ≥ 61% in the practical category. Based on Figure 7, the findings show that the augmented reality-based flashcard media achieved an overall average percentage of 96.90% in the "Highly Practical" category. Observing student activity revealed an overall average activity percentage of 83.17%, which meets the practicality criteria of ≥ 61% in the "Highly Practical" category. The overall average practicality percentage was 90.04%, categorized

as "Highly Practical." Therefore, augmented reality-based flashcards can be considered a practical learning medium for improving students' visual intelligence in the sub-topic of covalent bonds.
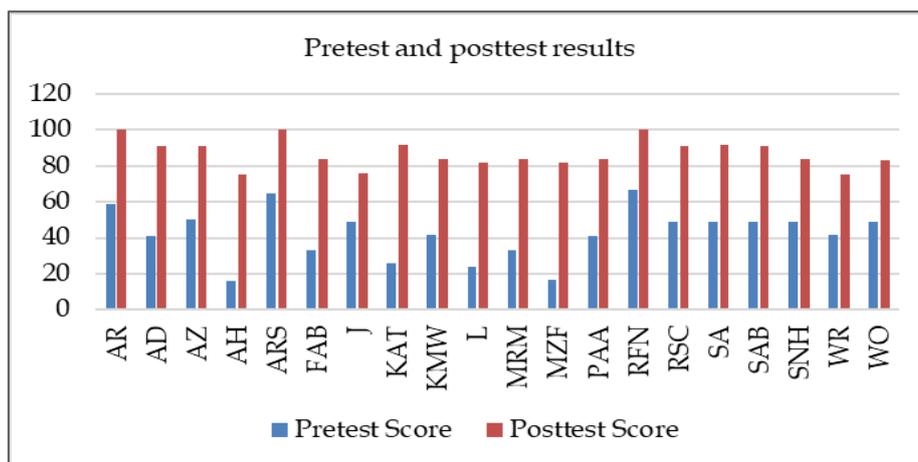
Figure 8. Pre-test and Post-test Result Chart

Effectiveness was measured through visual intelligence test sheets administered before and after the use of augmented reality-based flashcards. The pre-test and post-test data presented in Figure 8 were analyzed using a paired-samples t-test. The normality of the data was assessed using the Shapiro-Wilk test before a paired-samples t-test was performed. The test results are displayed in Table 11.

Table 11. Shapiro-Wilk Normality Test

|	Statistic	df	Sig.
Pre-test	0,942	20	0,259
Post-test	0,918	20	0,089

According to Table 6, the normality test results indicate that the pre-test and post-test data yielded p-values of 0.259 and 0.089, respectively. Given that the significance value exceeds 0.05 (>0.05), it can be concluded that the pre-test and post-test data for the students have a normal distribution and can be used for hypothesis testing with a paired-samples t-test. The outcomes of the paired-samples t-test are displayed in Table 12 below.

Table 12. Result of Paired Sample t-Test

	t	df	Sig. (2-tailed)
Pair 1 Pre-test - Post-test	-18,112	19	0,000

Table 8 shows that the paired-samples t-test yielded a significance value of 0.000 (<0.05). Since the significance value is less than 0.05 (<0.05), this means that H_0 (he average score on the pre-test and post-test is not significantly different) is rejected and H_a (the average score on the pre-test and post-test is significantly different) is accepted. It can be deduced that a significant difference exists between the pre-test and post-test score averages before and after learning with augmented reality-based flashcards. N-Gain was used to assess the size of the change after employing augmented reality-based flashcards. The findings of the N-Gain analysis are displayed in Figure 9.

Based on Figure 9, 85% of students achieved an N-Gain score of ≥ 0.7 in the high category, whereas 15% achieved an N-Gain score within the medium category (0.3 ≤ g < 0.7). According to the analysis, the N-Gain average score is 0.79, corresponding to 79%. This indicated a significant gain of 0.79 in students' visual intelligence on the covalent bonds sub-material. Following an analysis of data derived from a paired-samples t-test and N-Gain, the augmented reality-based flashcard media developed was determined to be effective in improving students' visual intelligence regarding the submaterial of covalent bonds.
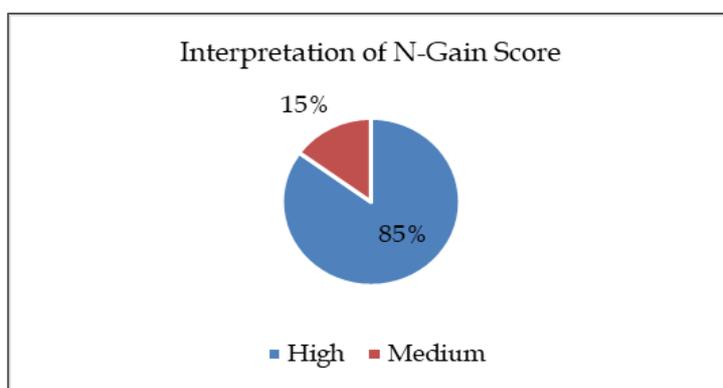
Figure 9. Diagram of N-Gain Score Interpretation

Evaluation

Throughout the entire research stage, from start to finish, the evaluation stage is carried out, covering the analysis, design, development, and implementation stages. This stage focuses on the overall effectiveness of the design (Boateng et al., 2024). At this stage, formative evaluation is conducted to assess quality at each stage and improve the final product (Rossie et al., 2025).

DISCUSSION

The development of augmented reality-based flashcards aligns with Jean Piaget's constructivist theory, which perceives learning as an active process of knowledge construction through interaction with the learning environment (Mir et al., 2025). The visualization of covalent bonds in augmented reality allows students to develop conceptual understanding independently by linking visual representations to their prior knowledge. The improvement in students' visual intelligence results from the process of knowledge construction through visual learning experiences delivered via augmented-reality-based flashcards. Cognitively, high school students, such as those in grade 11, are in the formal operational stage, which enables individuals to think abstractly (Mir et al., 2025). Visualization in augmented reality-based flashcard media acts as a bridge between abstract thinking and visual representations in the formal operational stage, where visual intelligence is an important component in optimizing students' abstract reasoning (Iswaji & Dwiningsih, 2025).

Research into the development of AR-based flashcards has a good chance of succeeding, which bodes well for the future of interactive, innovative learning media, supports the visualization of abstract chemical concepts, and enhances students' visual intelligence by keeping pace with technological developments. It has a high level of feasibility. The feasibility of a developed medium can be assessed using several criteria, including validity, practicality, and effectiveness, which are evaluated consecutively (Lukman et al., 2023). The developed augmented reality flashcard learning medium is suitable for improving students' visual intelligence because it meets all three criteria.

The validity of this media includes relevance (content validity) and consistency (construct validity). Content validity refers to the augmented reality-based flashcards developed in accordance with existing chemistry knowledge, namely the sub-topic of covalent bonds. Construct validity refers to the design produced in this medium being logically interconnected and easily used to improve students' visual intelligence regarding covalent bonds. The augmented reality-based flashcard media developed obtained validity results from three validators with a median value of 4 in the valid category. Thus, a flashcard-based augmented reality application can be deemed valid and used to assess the practicality of the developed media.

The practicality of AR-based flashcards was assessed through student response questionnaires, with an average score of 96.90% in the convenient category. Based on student activity observation sheets, the average percentage in the convenient category was 83.17%. In the convenient category, the total average percentage result was 90.04%. It would be possible to assess the effectiveness of the developed flashcard media when it was deemed practical.

The effectiveness of this augmented reality-based flashcard media was assessed by comparing students' visual intelligence pre-test and post-test scores. The results of the paired-samples t-test showed a significance value of 0.000 (<0.05), indicating that the average scores on the pre-test and post-test visual intelligence measures are significantly different. N-Gain was also used to measure the extent of the difference or improvement in students' pre-test and post-test visual intelligence scores. 85% of students achieved a high N-Gain, 15% a medium N-Gain, and the average N-Gain was 0.79. Thus, the flashcard developed using augmented reality media can be deemed effective in improving students' visual intelligence in the sub-material on covalent bonds, particularly in imagination, conceptualization, pattern recognition, and problem-solving. This learning medium is valid, practical, and effective. It can help chemistry teachers in schools teach chemistry and support visualization, thereby facilitating students' comprehension of the abstract concept of covalent bonding.

This study is also consistent with previous studies on the application of augmented reality technology to improving students' visual intelligence in chemistry classes, as shown in research conducted by Sari & Dwiningsih (2025), interactive multimedia that has been developed is valid, practical, and effective in improving students' visual intelligence through three-dimensional representations of material that was initially only text-based or two-dimensional images. Students need to observe three-dimensional representations of molecules to facilitate learning from multiple perspectives (Alzahrani, 2020).

Augmented reality can help to illustrate abstract chemical concepts more clearly (Hurrahman et al., 2022). Augmented reality can facilitate students' interactions by enabling zooming, rotation, and other spatial interactions, allowing them to view learning materials from various perspectives in real time in the real world (Li et al., 2025). This allows students who struggle with visualization to conceptualize phenomena, even within intricate materials, therefore aiding their comprehension and problem-solving abilities, as reflected in the indicators of visual intelligence (Alzahrani, 2020).

In addition, there is previous research by Izzati & Kamaludin (2024), which integrates augmented reality into flashcards on voltaic cell materials, demonstrating strong validity and practicality and improving conceptual understanding. However, unlike that study, which focused on improving conceptual understanding in general, this study specifically positioned visual intelligence as the primary variable, thereby contributing to the theory that the effectiveness of augmented reality-based flashcards is reflected not only in cognitive learning outcomes but also in improvements in students' visual intelligence.

This study's innovation lies in its integration of augmented reality into flashcards on the sub-topic of covalent bonds, where augmented reality-based flashcards were developed using visual intelligence indicators, including visualization, conceptualization, pattern recognition, and problem-solving (Rohmah et al., 2021). The visualization indicator is prominent in augmented reality, where it displays the process of covalent bond formation at the submicroscopic level. The conceptualization indicator is loaded onto flashcards, where students can connect basic concepts to build more complex ones from the visualizations displayed on this media. Meanwhile, the pattern recognition indicator appears on both flashcards and augmented reality features, particularly in the sub-material on electron configuration and types of covalent bonds. The augmented reality feature includes mini quizzes that support problem-solving indicators in visual intelligence. Deep visual understanding at the submicroscopic level is the key to solving more complex chemistry problems (Papageorgiou et al., 2019).

However, this study has limitations, including that the content is limited to the subfield of covalent bonding. This limitation presents an opportunity for further research to evaluate the feasibility of augmented reality-based flashcards for other chemistry topics, such as ionic bonds, molecular geometry, and other abstract concepts that require visual representation. In addition, the sample size in the test phase was relatively small, with only 20 students. The study also did not measure the lasting effects of using an AR-based flashcard on students' visual intelligence, as the study period was too short. Therefore, the long-term impact of augmented reality flashcards on improving visual intelligence cannot be fully identified. Therefore, further research using a larger sample and a longitudinal study design is recommended to observe the sustainability

of improvements in students' visual intelligence after using the media for a specific period of time (Moufdi & Mansouri, 2021).

CONCLUSION

The purpose of this study is to develop augmented reality-based flashcards that are feasible in improving students' visual intelligence in the sub-topic of covalent bonds. The results of the study show that this objective has been achieved by meeting the three criteria: validity, practicality, and effectiveness. The augmented reality-based flashcard media developed has been declared valid based on expert assessment, including content and construct validity, and has been found practical and effective as a learning medium for improving visual intelligence in the sub-subject of covalent bonds. The findings of this study can be applied to other chemistry teaching content that requires a high level of visualization, thereby improving students' visual intelligence.

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