Jurnal Pendidikan Sains Indonesia
(Indonesian Journal of Science Education)
https://jurnal.usk.ac.id/JPSI/index

13(4), 1032-1050 (2025)
e-ISSN: 2615-840X p-ISSN: 2338-4379
https://dx.doi.org/10.24815/jpsi.v13i4.47653

Augmented Reality Molecular Shape Cards: A Novel Approach to Strengthen Students' Understanding of Molecular Shape

M. Sindy Carolin Pratama[1], Erlina[1]*, Maria Ulfah[1], Eny Enawaty[1], Dylan Williams[2]

[1]Chemistry Education Study Program, Faculty of Teacher Training and Education, Tanjungpura University, Pontianak, Indonesia
[2]School of Chemistry, University of Birmingham, Birmingham, United Kingdom

*Corresponding autor: erlina@fkip.untan.ac.id.

Article History:
Received date: July 5 2025
Received in revised from: September 22 2025
Accepted date: October 5 2025
Available online: October 13 2025

Citation:
Pratama, M.S.C., Erlina, Ulfah, M., Enawaty, E., & Williams, D. (2025). Augmented Reality Molecular Shape Cards: A Novel Approach to Strengthen Students' Understanding of Molecular Shape. *Jurnal Pendidikan Sains Indonesia (Indonesian Journal of Science Education)*, 13(4), 1032-1050

Abstract. Students often face difficulties in visualizing molecular shapes based on the valence shell electron pair repulsion (VSEPR) theory, which is an abstract concept in chemistry. To address this issue, instructional materials need to be developed to help students visualize molecular shapes more concretely. This study uses the research and development (R&D) method with the 4D (define, design, develop, and disseminate) development model. The developed instructional materials include cards and an augmented reality (AR) application that allow students to visualize and predict molecular shapes in a tangible way. Validation was conducted by experts in media, content, and language, resulting in feasibility ratings of 98.1% for media aspects, 92.8% for content and language aspects, with an overall average rating of 95.45%. After making improvements to the media, an initial response test was conducted with students, yielding an average score of 90.5% with an excellent rating, and a main scale response test showed a percentage of 96.9%, also categorized as excellent. Based on the feasibility and response tests, the molecular shape cards (MoSCa) media is ready to be implemented in the learning process. The student responses to the initial scale test were 90.5%, and to the main scale test were 96.9%, both rated as excellent. The results indicate that the MoSCa media, based on augmented reality, is engaging and effectively supports students' understanding of molecular shape concepts.
Keywords: Molecular shape, VSEPR theory, flashcard, augmented reality

Introduction

Education is a deliberate and structured effort , to create a learning process that allows students to actively develop their potential, so that it is beneficial for society, nation and state. In addition, education is very important because it can improve the quality of human resources in living life and meeting life's needs (Enawaty, 2020). Educators must strive for development innovations so that the learning process carried out becomes more effective supported by digital technology (Zurweni & Malik, 2022).

Chemistry is often considered as one of the most difficult subjects for most students. This is due to the complex and abstract nature of many fundamental concepts, which is often one of the reasons that trigger students' difficulties in learning chemistry (Kristin et al., 2019). In chemistry, Johnstone (1993) states that chemical knowledge is represented at three levels: macroscopic (observable facts), submicroscopic (particles and their

interactions), and symbolic (formula and equations). The relationship among the three is illustrated as a triangle, underlining that learners are often required to simultaneously engage with all three components at once, rather than focusing on just one. This concept is also relevant in other sciences and shows the importance of representation in understanding chemical concepts, as evidenced by the many studies related to learning through submicroscopic representations (Kozma & Russell, 2005; Gilbert & Treagust, 2009; Zhang & Linn, 2013; Taber, 2013; Berg et al., 2019). The complexity and abstract nature of chemical concepts are often the cause of student learning difficulties. Therefore, there is a need for effective learning media that is able to visualise submicroscopic and symbolic representations to help students understand the material better (Sailendra et al., 2025; Olim et al., 2024; Kenneally, 2024). The lack of effective learning media exacerbates learners' difficulties in understanding abstract chemical concepts, so educators need media that are able to visualise submicroscopic and symbolic representations to support better understanding of the material (Ardian et al., 2021).

Molecular shape refers to the three-dimensional arrangement of atoms in a molecule. One way to predict the shape of these molecules is by using the VSEPR theory developed by Gillespie & Nylhom (Gillespie & Popelier, 2001).VSEPR theory stands for valence shell electron pair repulsion. According to this theory, the molecular shape of covalent compounds is determined by the electron domains surrounding the central atom. Electron domains are pairs of electrons, both bonding electron pairs and free electron pairs. According to VSEPR theory, molecular geometry has 5 basic shapes, namely linear, equilateral triangle, tetrahedral, octahedral, and trigonal bipyramid (Ardian et al., 2021). Teaching molecular shapes is currently generally introduced using models in the form of molecular images, three-dimensional props (such as molymod). Molymod is a teaching aid that illustrates the shape of molecules by connecting plastic spheres, which represent atoms, using rods that represent bonds (Wahid et al., 2017). It consists of atoms of different colors and can be connected with sticks or pegs to make certain shapes (Erlina et al., 2021).

Basic chemistry 1 course is one of the compulsory courses that must be taken by students of the Chemistry Education Study Program, FKIP Tanjungpura University. In accordance with the demands of the curriculum, the learning outcomes for basic chemistry 1 courses are that students are able to analyze the geometric shape of compounds based on VSEPR theory. Based on Hurrahman et al., (2022), only 45.5% of students passed the minimum completion criteria (i.e. scoring ≥ 60 out of 100), indicating that the majority scored below 60. Erlina et al., (2024) further emphasize that students encountered significant conceptual difficulties with molecular geometry, reinforcing the widespread challenges in this topic. Previous research therefore consistently shows that most students fail to achieve the minimum completion threshold—scoring below 60 out of a possible 100 points (i.e. less than 60%). which indicates an understanding problem or difficulty in learning the topic among FKIP Untan students.

Based on the results of interviews with lecturers teaching basic chemistry 1, it is known that there are several factors that cause low student learning outcomes on molecular shape material according to VSEPR theory. In general, the difficulties experienced by students are as follows: (1) difficulty in interpreting the relationship between the VSEPR notation obtained and the most likely molecular shape, (2) difficulty in visualizing the three-dimensional shape of molecules based on VSEPR theory, and (3) difficulty in understanding the effect of free electron pairs (PEB) on the structure and angle of molecules. The results of interviews with several students show that most of them tend to use the memorization method when studying at home to learn this material. As a result, many students do not understand the factors that affect molecular geometry. Interview results obtained from several students showed that: (1) students encounter difficulty writing the Lewis structure of a molecule, (2) students have difficulty in visualizing the 3D shape of the molecule based on VSEPR theory. This is in line with research (Habiddin et al., 2023) with a lack of knowledge about Lewis structures and VSEPR theory can lead to

misunderstandings regarding molecular geometry, while an unscientific understanding of molecular geometry can result in difficulties and wrong ideas of symmetry (Aprianti, 2023). A study by Thayban et al., (2021) found that students tend to describe the shape of molecules based only on Lewis structures, without considering the position of molecules as three-dimensional objects.

The use of card games is an engaging method that is increasingly being applied in education because it can enhance student engagement (da Silva et al., 2025). In chemistry education, this approach has proven to significantly improve students' conceptual understanding. This study supports previous findings indicating that card-based activities help students grasp the material more effectively (Erlina et al., 2018). Accordingly, an interactive activity was designed that integrates card games, simple molecular models, and worksheets as innovative and engaging supplementary learning resources to facilitate students' understanding and application of VSEPR theory (Erlina et al., 2017). Previous research has shown that such media contribute to improved learning outcomes, increased motivation, and the development of critical thinking skills (Habiba, 2017). Card games are considered effective and beneficial in learning because they make the process more interactive and enjoyable, boost student motivation, and help simplify complex concepts. Moreover, card games strengthen cognitive skills such as memory, problem-solving, and decision-making, making learning more dynamic and encouraging active student participation.

Augmented reality (AR) technology enables interactive 3D visualisations that simplify complex science concepts, including in chemistry learning, making them easier for learners to understand. AR combines virtual objects with the real world in a natural way and supports active, contextualised learning and increases learning motivation thereby providing an effective tool for innovative science education (Koumpouros, 2024; Zhang et al., 2023; Zhang, M. M., et al., 2025). Despite its potential and proven effectiveness in helping to understand abstract chemistry concepts, its application in Indonesia is still limited (Aliyanti et al., 2025). AR is a field of technology that consists of the continuous superposition of real-world computer generated virtual images, thus expanding access to information, and creating new opportunities for interaction (Mazzuco et al., 2022). According to Ardian et al., (2021). AR is the incorporation of virtual objects (text, images, and animations) into the real world. In simple terms, AR is defined as the combination of virtual objects and real objects naturally through a computerized process, as if it looks real as if it is in front of the user (Kamelia, 2015; Levy et al., 2024). In addition, the results of previous research show that the application of AR in chemistry learning is very likely to solve learning problems caused by the difficulty of transferring understanding of abstract chemical concepts (Hurrahman et al., 2022) . This is in line with research conducted by (Oktavia, 2022; Rahmawati & Kamaludin, 2024) stating that AR media can provide visual experiences to students in order to encourage learning motivation, clarify, and simplify abstract concepts to be simpler, concrete, and easy to understand. This media can be developed according to the needs of students, so that the benefits can be felt immediately, especially with the increasingly intensive use of smartphones among students (Nazar et al., 2020).The potential of this technology can attract, inspire and motivate learners to explore and control from different perspectives that were not previously considered in education. With the widespread use of smartphones, AR becomes an adaptive and relevant medium for modern learning needs.

This study aims to measure the feasibility and student response to the use of augmented reality-based molecular shape cards (MoSCa) in learning molecular shapes based on VSEPR theory. It is expected that the development of MoSCa can help students in understanding the concept of molecular shape in accordance with VSEPR theory.

Methods

This study uses the research and development research method which refers to the 4D development model (Four D models) by Thiagarajan et al. (1974) consisting of four stages, namely, define, design, develop and disseminate. The use of the 4D development model was chosen because the stages of development are simple, systematic and detailed. However, this research method is limited to the define, design and develop stages. This research method was chosen because it aims to develop and validate the product to be used (Mazzuco et al., 2022). The population in this study were students of the Chemistry Education Study Program, FKIP Tanjungpura University class of 2023 who had taken basic chemistry 1. The results of this study were not disseminated to an agency or institution other than the research site, therefore the stages used in this development research only used three stages consisting of define, design, and develop which can be seen in Table 1.

Table 1. Stages of media development

No.	Stages	Steps to take
1.	Define	- Front-End Analysis - Student Analysis - Concept Analysis - Task Analysis - Specifying Instructional Objectives
2.	Design	- Constructing Criterion-Referenced Test - Media Selection - Format Selection - Initial Design
3.	Develop	- Instrument Validation - Validation of Practical Guide - Revision of pratical guide based on expert input - Initial trial to students accompanied by revision - Main trial to students

The subject in this study was the augmented reality-based molecular shape cards (MoSCa) media on molecular shape material, which was tested on students of class 2023 of the Tanjungpura University chemical education study program who had taken basic chemistry 1. In this study the developed product was validated by two material experts, two media and language experts using the Gregory method (Gregory, 2015). Student response was assessed using a questionnaire. Researchers used a questionnaire consisting of various questions to determine student responses to the media that had been designed. Analysis of student response questionnaire data on AR-based MoSCa media developed using a Likert scale adapted from (Sugiyono, 2015), which consists of scores 4 (strongly agree), 3 (agree), 2 (disagree) and 1 (strongly disagree). The validation test results were calculated using the Gregory matrix in Table 2 and analyzed using equation (1).

Table 2. Gregory Matrix

		Validator 1	
		Not relevant (Score 1-2)	relevant (Score 3-4)
Validator 2	Not relevant (Score1-2)	(A)	(B)
	Relevant (Score 3-4)	(C)	(D)

(Source: Gregory, 2015)

Then the coefficient of feasibility of the instrument content is calculated using the following Gregory formula:

$$\text{Content validity coefficient} = \frac{\text{D}}{(\text{A} + \text{B} + \text{C} + \text{D})}\ x\ 100\% \qquad (1)$$

Description:
A : total items with irrelevant ratings by both validators
B : total items with irrelevant ratings by validator 1
C : total items with irrelevant ratings by validator 2
D : total items with relevant assessments by both validators
Furthermore, the calculation results are interpreted according to the eligibility criteria obtained based on Table 3.

Table 3. Criteria for gregory matrix tabulation results

No.	Score interval (%)	Criteria
1.	90 – 100	Very high
2.	60 – 89	High
3.	40 – 59	Medium
4.	20 – 39	Low
5.	0 – 19	Very low

(Source: Gregory, 2015)

The learner response test was conducted after the feasibility test by experts. The sampling techniques applied in this study include one-to-one trial with 8 students, and small group trial with 20 students. This approach ensures that the data includes various perspectives, both individuals and groups, in order to improve the quality of the research results. The instrument used was also a feasibility questionnaire using a Likert scale. The response test was conducted twice, namely the initial trial of 8 students and 20 students as the main trial. The response test results were calculated using the equation:

$$\text{P} = \frac{\Sigma\text{X}}{\Sigma\text{Xi}}\ x\ 100\% \qquad (2)$$

Description:
P = Percentage of score acquisition
ΣX = Total score (total score) of each item
Σxi = Total ideal score (highest score)
Calculate the percentage of total responses with the formula:

$$\text{Ptotal} = \frac{\Sigma P}{n} \qquad (3)$$

Description:
Ptotal = average percentage of feasibility
ΣP = average number of percentage scores per aspect
N = number of aspects assessed

Determining the criteria for student response to AR-based MoSCa and learning media on molecular shape material as follows. The percentage criteria for evaluating student responses are presented in Table 4.

Table 4. Criteria for media validity assesment

Score interval (%)	Criteria
0-20	Very poor
21-40	Not good enough
41-60	Good enough
61-80	Good
81-100	Very good

(Source: Riduwan, 2016)

Results and Discussion

This study focuses on measuring the feasibility and evaluating the responses of lecturers and students to the use of AR-based MoSCa in teaching molecular shapes based on VSEPR theory. MoSCa was developed with the aim of improving the understanding of molecular shape concepts more effectively. This study employs the 4D development model proposed by Thiagarajan (1974) which consists of the define, design, and develop stages. The results and discussion are organised based on these three stages.

Define Stage

The first stage is the define stage, which is conducting a preliminary study to find out and reveal the problems faced in the Department of Chemistry Education FKIP Untan, especially in determining the shape of molecules based on VSEPR theory. This stage consists of 5 main steps, namely: (1) Front-end analysis, the problems faced in learning basic chemistry 1 in the Department of Chemical Education FKIP Untan include students having difficulty writing the lewis structure of a molecule and having difficulty in visualizing the 3D shape of a molecule based on VSEPR theory, this is based on the results of interviews with 10 chemistry education students class 2023 FKIP Untan who have taken basic chemistry 1. (2) Learner analysis, the results of this analysis are students who have taken basic chemistry 1 and are on average 19-21 years old. At that age stage, children bbare able to develop formal thinking, and can utilize logic and abstraction from the information obtained by Wafiq et al. (2022). In studying molecular shape material based on VSEPR theory, students can develop their logic and abstraction by analyzing molecular structures based on the number of electron pairs around the central atom, creating molecular models either physically or digitally, and discussing in groups to deepen their understanding of molecular shape material based on VSEPR theory. (3) Concept analysis, determining the concepts to be taught. The concept of determining the shape of molecules based on the VSEPR theory obtained is about making electron configurations used to determine the valence electrons of an element, then describing the Lewis structure, determining bonding pair and lone pair electrons on the central atom and finally estimating

the bond angle formed through the principle of electron pair repulsion. (4) Task analysis, the results of the task analysis in the form of tasks to determine the number of bonding pair and lone pair electrons of a molecule, determine the name of the molecular form based on VSEPR theory, describe the lewis structure, can determine valence electrons using configuration, and can visualize the three-dimensional shape of the molecular form based on VSEPR theory. (5) Specifying instructional objectives sets practical objectives, at this stage the task of analysis is: formulate the purpose of using media on molecular shape material.

Design Stage

The second stage is the design stage. This stage continued with the initial development of the learning media design. MoSCa media developed consists of cards and applications, some of the main components on the cards include (1) information, (2) terms, (3) learning objectives, (4) game instructions, (5) game procedures, (6) electron pair cards, (7) molecular shape cards, (8) example cards, (9) valence electron cards, and worksheets. As for the main components of the application, namely (1) Unity default splash screen, (2) splash screen, (3) main menu, (4) instructions for use, (5) material, (6) scan, (7) settings and (8) developer profile. In addition, an expert validation questionnaire and student response questionnaire were also designed as data collection instruments. The media validation questionnaire consists of 10 statement items on media presentation aspects, 2 statement items on audio aspects, and 6 statement items on typography aspects. While the material and language validation questionnaire consists of 2 statement items on curriculum aspects, 7 statement items on content feasibility aspects, 2 items on presentation feasibility aspects and 3 statement items on language feasibility aspects. The learner response questionnaire consists of 15 statement items covering aspects of media, material, and benefits. The storyboard design that has been made is used as a reference in carrying out the process of developing prototype molecular shape topic cards based on VSEPR theory and AR applications. As for some software used to develop these two products, such as inkscape 1.3.2, microsoft windows 10, Unity 3D v.2018.4.17f1, vuforia software development kit (SDK) and Blender 3D 3.3.0., chemsketch and 3D Viewer. The tools used in the development process, such as a laptop, droidcam, android smartphone. So that a prototype is produced in the form of MoSCa media in the form of molecular shapes based on VSEPR theory in the form of cards with 13 sets of cards, 1 set of which contains 4 cards (number of bonding pair and lone pair electrons cards (red), molecular shape cards (yellow), example cards (green) and valence electron cards (blue)) with a total of 52 cards with a size of 9.5 cm x 6.5 cm and 13 QR code cards that interpret each molecular shape based on VSEPR theory. To make it easier for students to understand the use of media, several supporting cards were added, such as: (1) card information, (2) learning objectives card, (3) game instructions card, (4) game procedure card and (6) material card. The way to play this media is adapted from a 41 playing card game played by at least 4 people divided into 2 teams. In addition, this media is also equipped with an Android application called molecular shape application in .apk format with a file size of 71.5 MB shown in Figure 1.

Figure 1. MoSCa media display and molecular shape application

Develop Stage

The next part of the process was the develop stage. A total of 3 experts were involved in providing an assessment of the product consisting of experts on media, material and language aspects. Validation in research aims to minimize errors in several ways including the concept of content, language, appearance, and determine the feasibility of the product that has been designed (Wafiq et al., 2022). To determine the results of the feasibility assessment by experts, tabulation of expert assessments was carried out to calculate the validity of the practice guidelines using the Gregory test. The validation process was also continued with several revisions until finally the practice guide was suitable for use. The results of the validation assessment of each expert are presented in Figure 2.

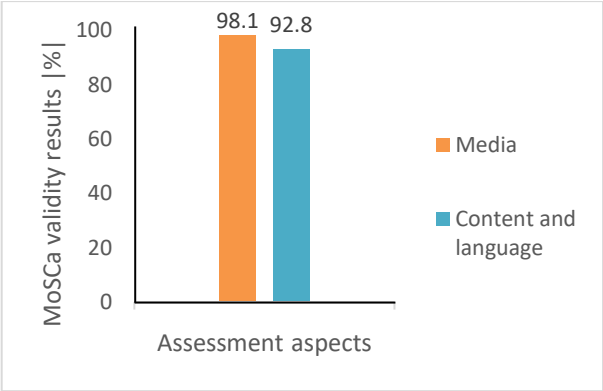


Figure 2. Percentage of average feasibility assessment on material, media and language aspects

The material, media and language validation of the product that has been developed in Figure 4 shows the average percentage of eligibility for each validation stage of 98.1 and 92.8%, so that the overall average is 95.45%. In the range of 81 - 100% indicates that the validation stage is categorized as very high (valid), so it can be used without improvement (Riduwan, 2016). Thus, based on the validation results above, it can be concluded that the resulting prototype has met the theoretical feasibility criteria in the aspects of material, media, and language. The feasibility level of this instrument or product can be determined based on the assessment of experts in their fields (Ramadhan et al., 2019).

Media validation consists of aspects of media presentation, audio and typography. The material presentation aspect contains ten assessment items, the audio aspect contains

two assessment items and the presentation feasibility aspect contains five assessment items which can be seen in Table 5.

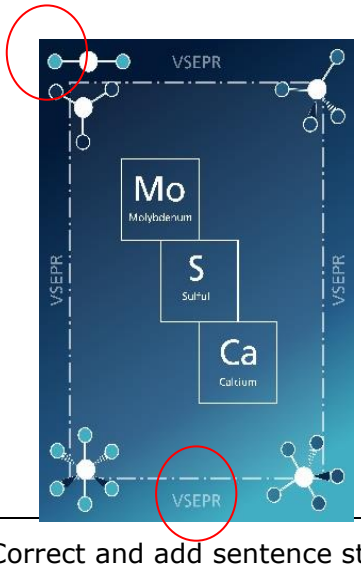
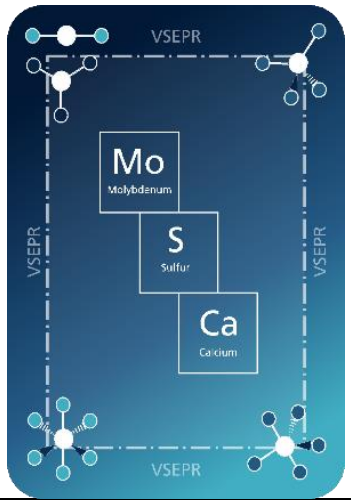
Table 5. Media validation questionnaire assessment items (N=2)

Aspect	No.	Statement item	Average validator assessment (%)
Media presentation	1.	Accuracy of color selection	100
	2.	The appearance of the image layout on the front and back covers is harmonious and has unity	87.5
	3.	The layout of logos, illustrations and icons is appropriate	100
	4.	The appearance of the image layout on the contents of the MoSCa media gives the impression of harmony and unity	100
	5.	The layout of text, illustrations, image captions is clear	87.5
	6.	The layout of the images in the application is appropriate	87.5
	7.	Graphic components in the application look harmonious and attractive	87.5
	8.	The application can operate smoothly	100
	9.	Application navigation buttons can run smoothly	100
	10.	3D visualization of the molecular shape of compounds is well presented	100
Audio	11.	Has clear sound quality	
	12.	Appropriate use of music	100
Typography	13.	The typography of MoSCa Media is simple	100
	14.	Accuracy of letter selection	100
	15.	Clarity of readability of the letters used	100
	16.	Displays a good center of view (center point)	100
	17.	Appropriate use of font size	100
	18.	The typography on the app is easy to read	100

Based on Table 5, the results of the validation of the media presentation aspect, on the 2nd assessment item, the validator suggested that the edges of the card be blunted and the position of the image on the cover be adjusted so that it would not be cut off when the card games was printed. item 5 suggested making the distance between the text so that the text does not look too tight. Next, item 6 was suggested to improve the size of the logo on the application display so that it looks proportional. Then in item 7 it is recommended to provide information on each graphic component used so that readers can follow the flow of text more easily. The suggestions for improvement from the validator are intended so that the presentation of the media can attract attention and increase the interest of readers or users, and make it easier to understand what is presented. The use of media in learning is very important, because the media can make the material presented clearer and easier to understand, and motivate students to be more enthusiastic in learning. Learning that uses media will take place more effectively, so that learning

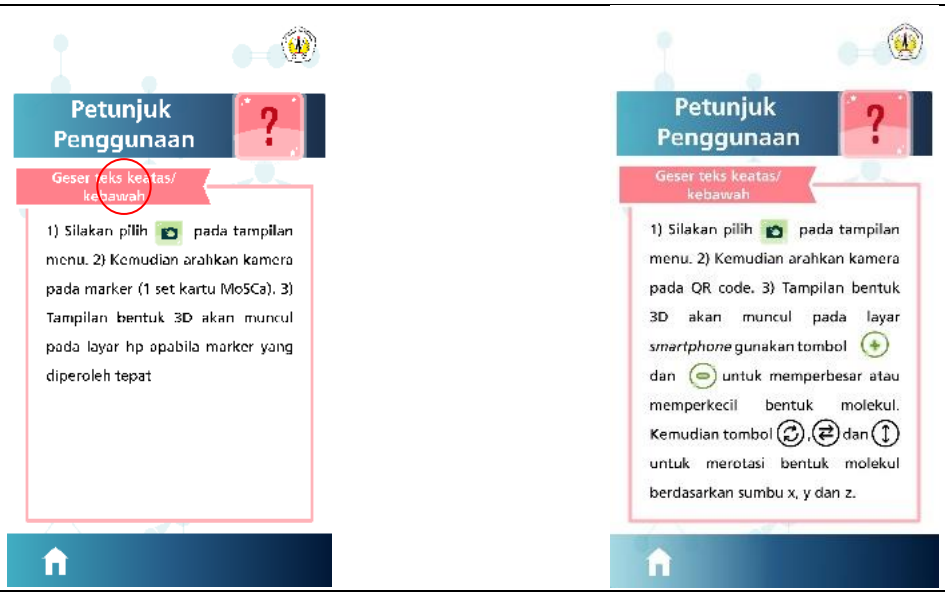
objectives can be achieved (Pradilasari et al., 2020). With a more attractive media display, it is expected to provide a learning experience that motivates students to actively participate in the learning process (Hurrahman et al., 2022). The results of improvements according to media expert suggestions can be seen in Table 6.

Table 6. Revised results of media presentation aspects

Before revision	After revision
1. Changing the edges of the card games cover and adjusting the position of the image	
	
2. Correct and add sentence structure to complete the information on the card	
	

3. Correct the size of the logo on the application display to be proportional

4. Adjust the use of graphic components to follow the flow of the text



The last stage in validation is material and language validation. The purpose of this validation is to ensure that the content presented is accurate, in line with the learning objectives, and uses clear and understandable language. This process is important to determine the feasibility of the learning media, so that it can be effective in conveying information and supporting student understanding in an appropriate and efficient way. The assessment items of each aspect can be seen in Table 7.

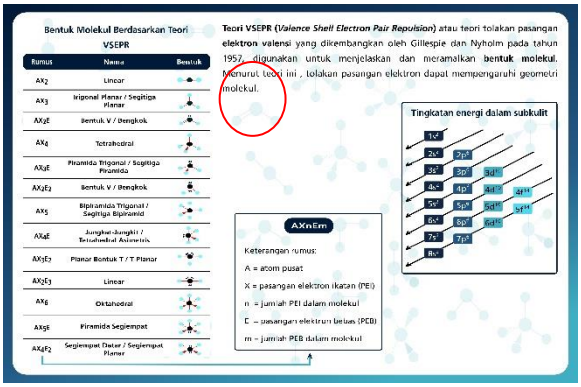
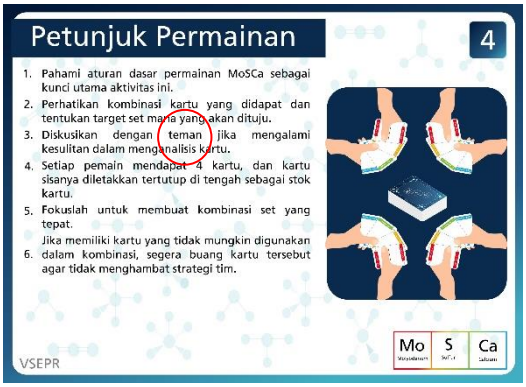
Table 7. Revision result presentation of material and language (N=2)

Aspect	No.	Statement item	Average validator assessment (%)
Curriculum	1.	The material presented is in accordance with the course learning outcomes (CLO)	87.5
	2.	Depth of material	87.5
Content feasibility	3.	The material presented in the MoSCa media is in accordance with the VSEPR theory molecular shape material.	100
	4.	The material in MoSCa media is presented accurately	100
	5.	The example image of lewis structure in MoSCa media is presented accurately	100
	6.	Visualization of 3D animation of molecular shapes in the application is presented accurately	100
	7.	Suitability and correctness of the answer key with the task	100
Presentation feasibility	8.	The material presented is systematic	87.5
	9.	The material presented adds insight to the user's knowledge	87.5
Language feasibility	10.	Accuracy of sentence structure	100
	11.	Sentence effectiveness	100
	12.	Standardization of terms	100
	13.	Ease of learners understanding the message conveyed in MoSCa media	100
	14.	Ease of learners understanding the message conveyed in the application	100
	15.	Accuracy of grammar	100
	16.	Accuracy of spelling used	87.5
	17.	Suitability to the intellectual development of learners	87.5
	18.	Appropriateness to the learners' emotional development level	87.5
	19.	The use of terms, symbols, and icons in the application is consistent	100

Based on Table 7, about the results of the validation of the presentation of material and language aspects, in the curriculum aspect, the validator provides suggestions to adjust the material presented on the MoSCa media so that students can more easily understand the material about molecular shapes. Furthermore, in the presentation feasibility aspect, the validator suggested adding material about the principle of electron pair repulsion to the card games. This suggestion aims to make the material presented systematically, enrich users' insights, and make learning more structured, easy to follow,

and deepen users' understanding of the topics discussed. Then, on items 16, 17, and 18 related to language aspects, the validator suggested improvements in the use of words to be in accordance with Indonesian grammar rules and easily understood by students, so that learning materials are presented correctly, relevant, and in accordance with the needs and abilities of students, support effective understanding, and provide a positive learning experience. The results of improvements according to the content expert's suggestions are presented in Table 8.

Table 8. Revision result presentation of material and language.

Before revision	After revision
1. Adjusting the material presented in the MoSCa media and adding material about the principle of electron pair repulsion.	
	
2. Customize the use of words to fit the rules of Indonesian grammar	
	

Based on Table 8, material and language adjustments to the MoSCa media need to be made by adding material about the principle of electron pair repulsion and ensuring the use of language in accordance with Indonesian grammar rules. After that, a student response test to the MoSCa media was conducted, involving 2023 students cohort from the Chemistry Education Study Program at FKIP Tanjungpura University who had completed the chemical kinetics course. The instrument used was a response questionnaire with a 4-point Likert scale, which had been previously validated. This instrument was distributed to 8 chemistry education students in the one-to-one trial stage, to obtain in-depth feedback. The second stage, the small group trial, involved 20 students to test the validity and effectiveness more broadly. This approach aims to make the data obtained

reflect various points of view, both individuals and small groups, in order to improve the quality of research results. The response questionnaire covered three aspects: media, materials, and benefits. The initial trial process was followed by revisions until the MoSCa media was ready for the main trial. The initial response results are shown in Figure 3

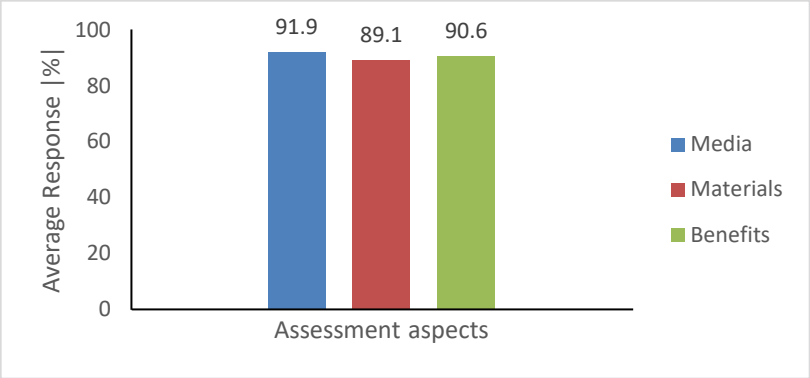


Figure 3. Percentage of the results of the initial learner response test aspects of media, material and benefits

The purpose of this response test is to find out the students' responses to aspects of media, material and benefits in using MoSCa media and applications. Based on the results of the student response test that has been carried out, the percentage obtained in the media, material and language aspects is 91.9%, 89.1% and 90.6%. The overall percentage obtained was 90.5%. The number 81-100% is a very high response interpretation criterion (Riduwan, 2016). The input submitted by students in the initial trial was to improve some writing formats and some sentences to match the rules of Indonesian grammar and add images to the application instructions so that they can clarify the information referred to in the section on how to operate it. After the revision, it was continued with a small group trial on 20 students of the chemistry education study program at FKIP Untan. The results of student responses to MoSCa media can be seen in Figure 4.

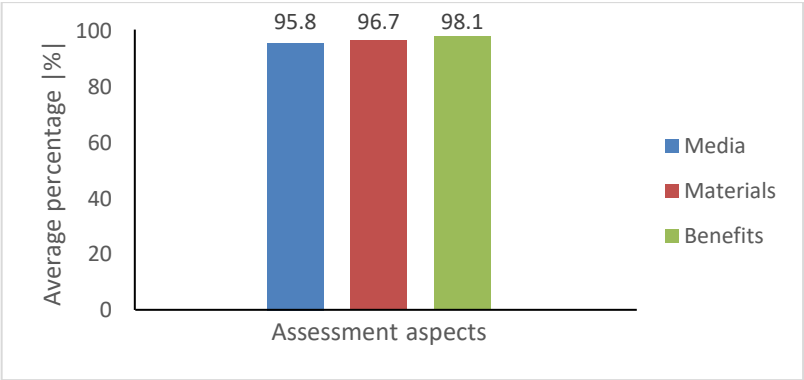


Figure 4. Percentage of results of the main response test of learners in the aspects of media material and benefits

Based on the results of student response data in the main trial of MoSCa media in the aspects of media, material, and benefits, the response was very good with a percentage of 95.8%, 96.7% and 98.1% respectively with an overall percentage of 96.9%. This indicates that the MoSCa media that has been designed has an attractive appearance and is easy to use. Then, the use of fonts and 3D visualization of molecular shapes is very clear and easy to understand. The material presented in MoSCa media is in line with the curriculum taught by educators in the classroom, so it is very relevant and supports the

learning process. The language used in the media and applications is also easy for learners to understand, and the illustrations, graphics and images included can help understand the material better. The learning topics are clearly presented, which can make learners more interested in learning about molecular shapes. Overall, MoSCa media is considered an effective tool in learning molecular shapes, increasing interest in learning, and helping learners understand the material better. Concept understanding, which allows students to solve problems related to the concepts they learn systematically, must be instilled by educators in the learning process (Lestari, 2021). The results of the learner response test showed a positive response from Chemistry Education students of FKIP Untan so that the developed product can help and facilitate students in understanding the concept of molecular shape material based on VSEPR theory. This finding is in line with some previous research results, card games is effective in increasing user engagement and motivation, including in education. By using game elements such as challenges, rewards, and competition, card games makes learning more interactive and interesting. In the context of using card games for learning, it can foster learners' intrinsic motivation and improve information retention. It makes the learning process more enjoyable and encourages learners' active participation (Erlina et al., 2024; Levy et al., 2024). According to Hurrahman et al. (2022) AR has the potential to be a solution in learning chemistry, especially to overcome difficulties in understanding abstract concepts. The AR system helps students visualise the submicroscopic level of chemical reactions (such as molecular structures and bond changes) interactively through AR cards, thereby bridging the gap between macroscopic and submicroscopic concepts (Tarng et al., 2022). AR can help teachers explain complex material such as molecular structures by visualising molecules in three dimensions via an android smartphone, thereby significantly facilitating students' understanding during the process of learning abstract chemical concepts that are difficult to explain using two-dimensional images.

Conclusion

The research and development results indicate that the MoSCa media, based on AR and VSEPR theory in molecular shape learning, obtained a feasibility score of 98.1% in the media aspect and 92.8% in the material and language aspect, with an overall average of 95.45%. The results of the study show that the MoSCa media, which is based on augmented reality, is attractive and effective in supporting students' understanding of molecular shape concepts. After improvements were made, the initial student response test achieved 90.5% with a very good criterion, while the main scale response test achieved 96.9% in the very good category. This shows that MoSCa is effective in improving students' understanding, engagement, and motivation to learn, and is ready to be applied in chemistry learning.

References

Aliyanti, C., Pratiwi, N., & Hasan, M. (2025). Development of Contextual Based Augmented Reality Science Learning Media to Improve Critical Thinking Skills of Junior High School Students. *Jurnal Pendidikan Sains Indonesia*, 13(2), 426–443. https://doi.org/10.24815/jpsi.v13i2.44052

Aprianti, D.S. (2023). Penerapan Pendekatan Konstruktivisme melalui Mind Mapping untuk Meningkatkan Hasil Belajar IPS [Implementation of the Constructivist Approach through Mind Mapping to Improve Social Studies Learning Outcomes]. *Jurnal Riset Pendidikan Indonesia*, 3(2), 278–289. https://ojs.unsiq.ac.id/index.php/jrpi/article/view/6196/2790

Ardian, Z., Pratiwi, E.A. & Raudhatun, N.Z. (2021). Pembuatan Aplikasi AR Geokul sebagai Media Pembelajaran Bentuk Molekul pada Mata Pelajaran Kimia di SMA Menggunakan Teknologi Augmented Reality Berbasis Android [Development of the Geokul AR Application as a Learning Medium for Molecular Structures in High School Chemistry Using Android-Based Augmented Reality Technology]. *Journal of Informatics and Computer Science*, 7(2), 68–71. https://jurnal.uui.ac.id/index.php/jics/article/view/1641/858

Berg, A., Orraryd, D., Pettersson, A.J., & Hultén, M. (2019). Representational Challenges in Animated Chemistry: Self-generated Animations as a Means to Encourage Students' Reflections on Sub-micro Processes in Laboratory Exercises. *Chemistry Education Research and Practice*, 20(4), 710–737. https://doi.org/10.1039/c8rp00288f

da Silva, J.N., et al. (2025). 1925–2024: One Century of Educational Games in Chemistry. *Journal of Chemical Education*, 102(1), 1–8. https://doi.org/10.1021/acs.jchemed.4c01238

Enawaty, E. (2020). Deskripsi Kemampuan Psikomotorik Mahasiswa Pendidikan Kimia pada Titrasi Asam Basa [Description of the Psychomotor Ability of Chemistry Education Students on Acid-Base Titration]. *Ar-Razi Jurnal Ilmiah*, 8(2), 91–101. https://doi.org/10.29406/ar-r.v8i2.2133

Erlina, E., Eny, E., & Rahmat, R. (2021). Using Simple Molecular Model to Enhance Students' Understanding on Molecular Geometry Based on VSEPR Theory. *Jurnal Pendidikan dan Pembelajaran Kimia*, 10(1), 24–33. https://doi.org/10.23960/jppk.v10.i1.April2021.04

Erlina, Cane, C., & Williams, D.P. (2018). Prediction! The VSEPR Game: Using Cards and Molecular Model Building to Actively Enhance Students' Understanding of Molecular Geometry. *Journal of Chemical Education*, 95(6), 991–995. https://doi.org/10.1021/acs.jchemed.7b00687

Erlina, N., Williams, D.P., Cane, C., Hairida, Ulfah, M., & Wafiq, A.F. (2024). Reconstructing Perspectives: Investigating How Molecular Geometry Cards (MGCards) and Molecular Model Building (MMB) Disrupt Students' Alternative Notions of Molecular Structure – A Qualitative Study. *Chemistry Education Research and Practice*, 25(4), 973–975. https://doi.org/10.1039/d3rp00038a

Erlina, Williams, D.P., & Cane, C. (2017). Developing New Learning Resources to Address Students' Misconceptions of Molecular Geometry Based on VSEPRT in the UK and Indonesia. Paper Presented at the Variety in Chemistry Education and Physics Higher Education Conference (ViCEPHEC), UK and Indonesia. https://doi.org/10.13140/RG.2.2.34338.85444

Gilbert, J. & Treagust, D. (2009). Multiple Representations in Chemical Education. In: Gilbert J, Treagust D, editors. *Multiple Representations in Chemical Education*. Dordrecht: Springer Netherlands. https://doi.org/10.1007/978-1-4020-8872-8_1

Gillespie, R.J. & Popelier, P.L.A. (2001). Chemical Bonding and Molecular Geometry: From Lewis to Electron Densities, Chemical Bonding and Molecular Geometry. New York: Oxford University Press Inc. https://doi.org/10.1016/s0022-2860(02)00050-9

Gregory, R.J. (2015). Psychological Testing: History, Principles and Applications Seventh Edition. England: Pearson Education Limited.

Habiba, R.I. (2017). Peningkatan Hasil Belajar dengan Media Kartu Kwartet dalam Keterampilan Menyusun Portofolio [Improving Learning Outcomes Using Quartet Card Media in Portfolio Compiling Skills]. *Ilmu Pendidikan: Jurnal Kajian Teori dan Praktik Kependidikan*, 2(1), 85–91. https://doi.org/10.17977/um027v2i12017p085

Habiddin, H., Farizka, L., & Shuid, A.N. bin. (2023). Chemistry Students' Understanding of Lewis Structure, VSEPR Theory, Molecular Geometry, and Symmetry: A Cross-Sectional Study. *Jurnal Tadris Kimiya (JTK)*, 8(1), 1–9. https://doi.org/10.15575/jtk.v8i1.24410

Hurrahman, M., Erlina, E., Melati, H.A., Enawaty, E., & Sartika, R.P. (2022). Pengembangan E-Modul Berbasis Multipel Representasi dengan Bantuan Teknologi Augmented Reality untuk Pembelajaran Materi Bentuk Molekul [Development of E-Module Based on Multiple Representations Assisted by Augmented Reality Technology for Learning Molecular Shape Material]. *Jurnal Pendidikan Sains Indonesia (Indonesian Journal of Science Education)*, 10(1), 89–114. https://doi.org/10.24815/jpsi.v10i1.22579

Kamelia, L. (2015). Perkembangan Teknologi Augmented Reality sebagai Media Pembelajaran Interaktif pada Mata Kuliah Kimia Dasar [The Development of Augmented Reality Technology as an Interactive Learning Medium in Basic Chemistry Courses]. *Jurnal Kajian Islam, Sains dan Teknologi*, 9(1), 238–253. https://journal.uinsgd.ac.id/index.php/istek/article/view/184

Kenneally, C.D. (2024). *A Cognitive Load Approach to Molecular Geometries.* Education Sciences, 14(9), 1036. https://doi.org/10.3390/educsci14091036

Koumpouros, Y. (2024). Revealing the True Potential and Prospects of Augmented Reality in Education. *Smart Learning Environments*, 11(1), 1–63. https://doi.org/10.1186/s40561-023-00288-0

Kozma R, & Russell J. (2005). Students Becoming Chemists: Developing Representation Competence. In: Gilbert JK, editor. *Visualization in Science Education*. London: Kluwer Academic Publishers, pp. 121–146. https://doi.org/10.1007/1-4020-3613-2_8

Kristin, N., Astuti, A.P., & Wulandari, V.A. (2019). Analisis Kesulitan Belajar Kimia Materi Hidrokarbon (Studi Kasus SMA Negeri di Semarang) [Analysis of Chemistry Learning Difficulties on Hydrocarbon Material (Case Study at Public High School in Semarang)]. In: *Seminar Nasional Edusainstek FMIPA UNIMUS*, pp. 348–356.

Lestari, I. & Erlina E. (2021). Identifikasi Pemahaman Mahasiswa Pendidikan Kimia pada Materi Stereokimia Hidrokarbon [Identification of Chemistry Education Students' Understanding on Hydrocarbon Stereochemistry]. *Edukatif: Jurnal Ilmu Pendidikan*, 3(6), 4810–4817. https://doi.org/10.31004/edukatif.v3i6.1555

Levy, J., Baillie, L., & Angell, C. (2024). An augmented reality application for understanding 3D molecular structure and intermolecular interactions (MoleculAR). *Journal of Chemical Education,* 101(9), 2890–2902. https://doi.org/10.1021/acs.jchemed.3c01045

Mazzuco, A., Krassmann, A.L., Reategui, E., & Gomes, R.S. (2022). A Systematic Review of Augmented Reality in Chemistry Education. *Review of Education*, 10(1), 1–26. https://doi.org/10.1002/rev3.3325

Nazar, M., Zulfadli, Z., Oktarina, A., & Puspita, K. (2020). Pengembangan Aplikasi Pembelajaran Interaktif Berbasis Android untuk Membantu Mahasiswa dalam Mempelajari Materi Larutan Elektrolit dan Nonelektrolit [Development of an Android-Based Interactive Learning Application to Help Students Learn Electrolyte and Nonelectrolyte Solutions]. *Jurnal Pendidikan Sains Indonesia*, 8(1), 39–54. https://doi.org/10.24815/jpsi.v8i1.16047

Oktavia, R. (2022). Kebutuhan Pengembangan Media Pembelajaran Berbasis Augmented Reality pada Pembelajaran Biologi di SMA 1 Pante Ceureumen Aceh Barat [The Need for Developing Augmented Reality-Based Learning Media in Biology Learning at SMA 1 Pante Ceureumen Aceh Barat]. *Jurnal Bionatural*, 9(2), 26–32. https://doi.org/10.61290/bio.v9i2.135

Olim, S.C., et al. (2024). *Augmented reality interactive experiences for multi-level chemistry education.* Heliyon / ScienceDirect (article ID S2212-8689(24)00050-3). https://www.sciencedirect.com/science/article/pii/S2212868924000503

Pradilasari, L., Gani, A., & Khaldun, I. (2020). Pengembangan Media Pembelajaran Berbasis Audio Visual pada Materi Koloid untuk Meningkatkan Motivasi dan Hasil Belajar Siswa SMA [Development of Audio-Visual Based Learning Media on Colloid Material to Improve Motivation and Learning Outcomes of High School Students]. *Jurnal Pendidikan Sains Indonesia*, 7(1), 9–15. https://doi.org/10.24815/jpsi.v7i1.13293

Ramadhan, S., Mardapi, D., Prasetyo, Z.K., & Utomo, H.B. (2019). Development of an Instrument to Measure the Higher Order Thinking Skill in Physics. *European Journal of Educational Research*, 8(3), 743–751. https://doi.org/10.12973/eu-jer.8.3.743

Ramadhan, S., Mardapi, D., Prasetyo, Z.K., & Utomo, H.B. (2019). Development Augmented Reality Based Flashcards On Molecular Geometry Material For Increasing Interest In Learning High School Students. *Jurnal Penelitian Pendidikan IPA,* 10(4), 1539–1550. https://doi.org/10.29303/jppipa.v10i4.7329

Riduwan. (2016). *Dasar-Dasar Statistika*. Bandung: CV Alfabeta.

Sailendra, P.R., Erlina, Ulfah, M., Enawaty, E., & Nizam, D.N.M. (2025). Interactive Video-Based Learning with Edpuzzle: A Tool for Understanding Intermolecular Forces. *Jurnal Pendidikan Sains Indonesia (Indonesian Journal of Science Education)*, 13(1), 80–99. https://doi.org/10.24815/jpsi.v13i1.41443

Sugiyono. (2015). *Metode Penelitian Kuantitatif, Kualitatif dan R & D*. Bandung: CV Alfabeta.

Taber, K.S. (2013). Revisiting the Chemistry Triplet: Drawing upon the Nature of Chemical Knowledge and the Psychology of Learning to Inform Chemistry Education. *Chemistry Education Research and Practice*, 14(2), 156–168. https://doi.org/10.1039/c3rp00012e

Tarng, W., & kolega. (2022). Application of Augmented Reality for Learning Material Structures and Chemical Equilibrium. *Systems*, 10(5), 141. https://doi.org/10.3390/systems10050141

Thayban, T., Habiddin, H., Utomo, Y., & Muarifin, M. (2021). Understanding of Symmetry: Measuring the Contribution of Virtual and Concrete Models for Students with Different Spatial Abilities. *Acta Chimica Slovenica*, 68(3), 736–743. https://doi.org/10.17344/acsi.2021.6836

Thiagarajan, S., Semmel, D. S., & Semmel, M.I. (1974). *Instructional Development for Training Teachers of Exceptional Children: A Sourcebook*. Bloomington, Indiana: Indiana University. https://doi.org/10.1016/0022-4405(76)90066-2

Wafiq, A.F., Melati, H.A., Erlina, E., Hairida, H., Masriani, M., & Sasri, R. (2022). Practical Guide for Determining the Reaction Rate and Reaction Order Based on the Colorimeter® Application. *Jurnal Pendidikan Kimia Indonesia*, 6(2), 142–153. https://doi.org/10.23887/jpki.v6i2.50365

Wahid, A., Anra, H., & Tursina. (2017). Cross Platform Aplikasi Augmented Reality untuk Mata Pelajaran Kimia Struktur Molekul [Cross-Platform Augmented Reality Application for Molecular Structure Chemistry Subject]. *Jurnal Sistem dan Teknologi Informasi*, 5(3), 201–205. https://jurnal.untan.ac.id/index.php/justin/article/view/20908

Zhang, M.M., et al. (2025). *Analyzing and comparing augmented reality and virtual vocabulary learning: A systematic/experimental study.* Frontiers in Virtual Reality, 6, Article 1522380. https://doi.org/10.3389/frvir.2025.1522380

Zhang, S., Zhou, C., & Zhao, J. (2023). Chinese Pre-Service Chemistry Teachers' Perception of Augmented Reality-Assisted Secondary Chemistry Learning. *Disciplinary and Interdisciplinary Science Education Research*, 5(1), 1–16. https://doi.org/10.1186/s43031-023-00090-5

Zhang, Z.H. & Linn, M.C. (2013). Learning from Chemical Visualizations: Comparing Generation and Selection. *International Journal of Science Education*, 35(13), 2174–2197. https://doi.org/10.1080/09500693.2013.792971

Zurweni, Z. & Malik, A. (2022). Development of Performance Technology Competency Training Model for Students of Chemical Education. *Formatif: Jurnal Ilmiah Pendidikan MIPA*, 12(1), 135–146. https://doi.org/10.30998/formatif.v12i1.12143